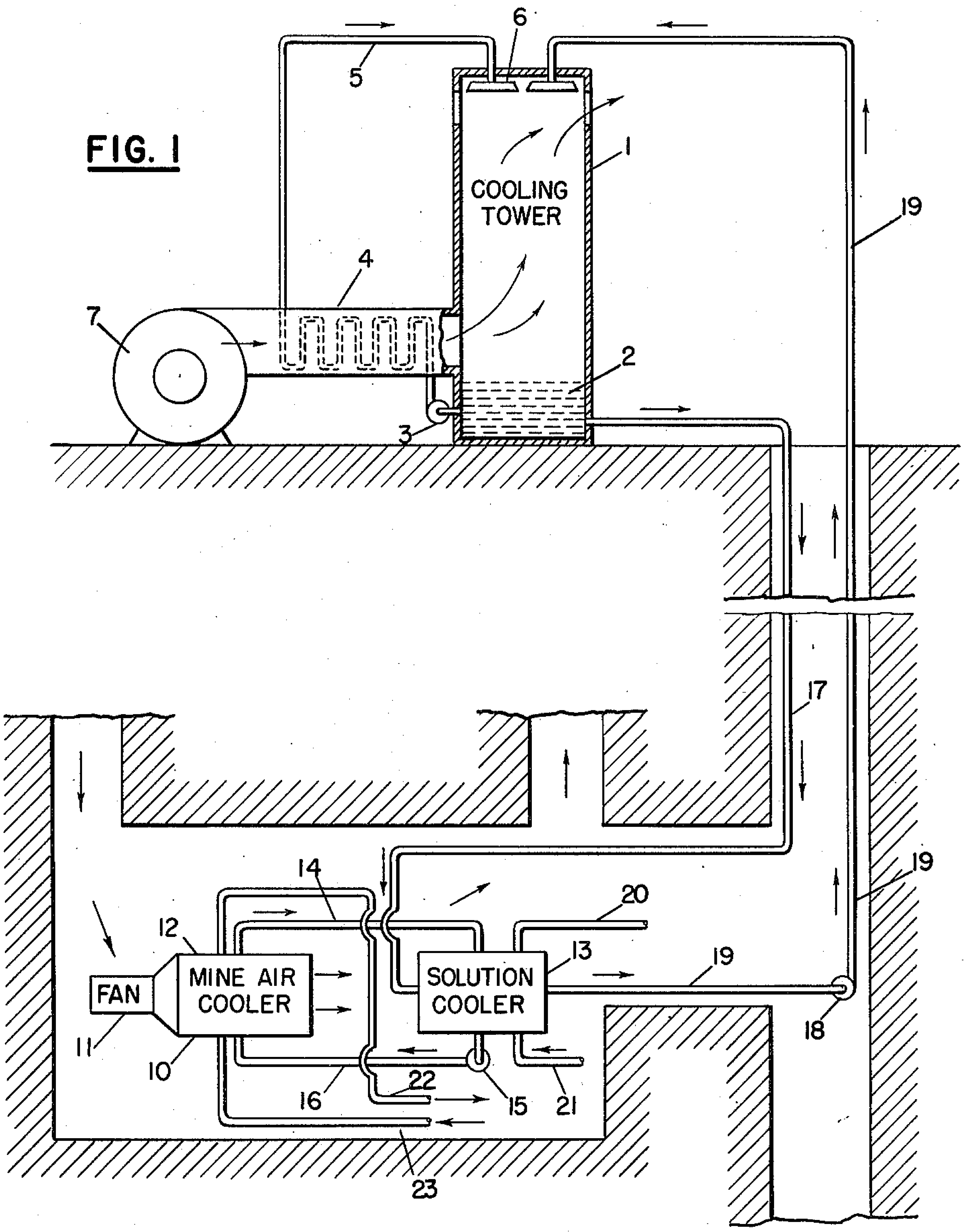
Oct. 10, 1950 A. S. RICHARDSON 2,525,045

COOLING AIR

Filed March 5, 1946 2 Sheets-Sheet 1

FIG. I



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Filed March 5, 1946 2 Sheets-Sheet 2

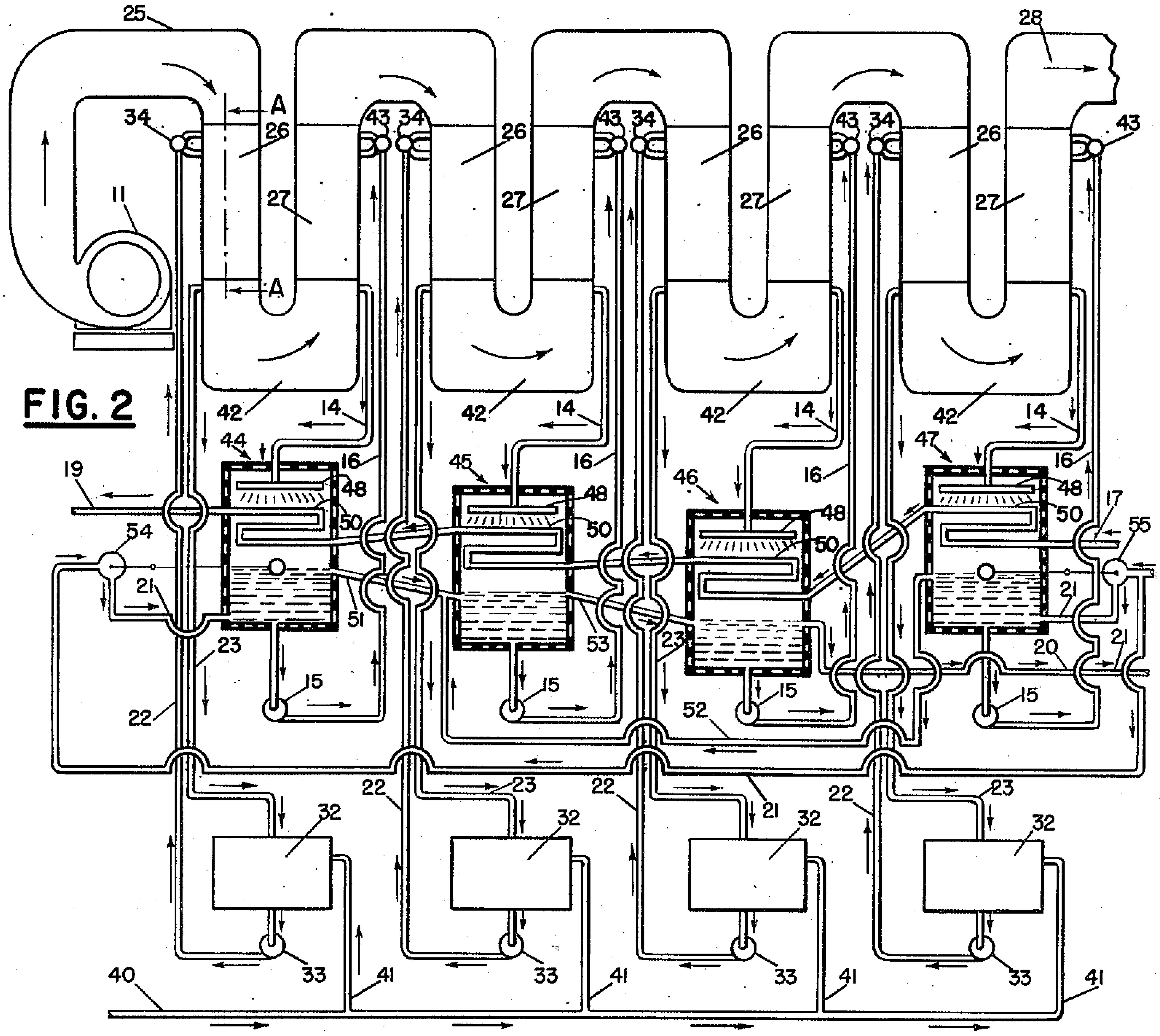

FIG. 2

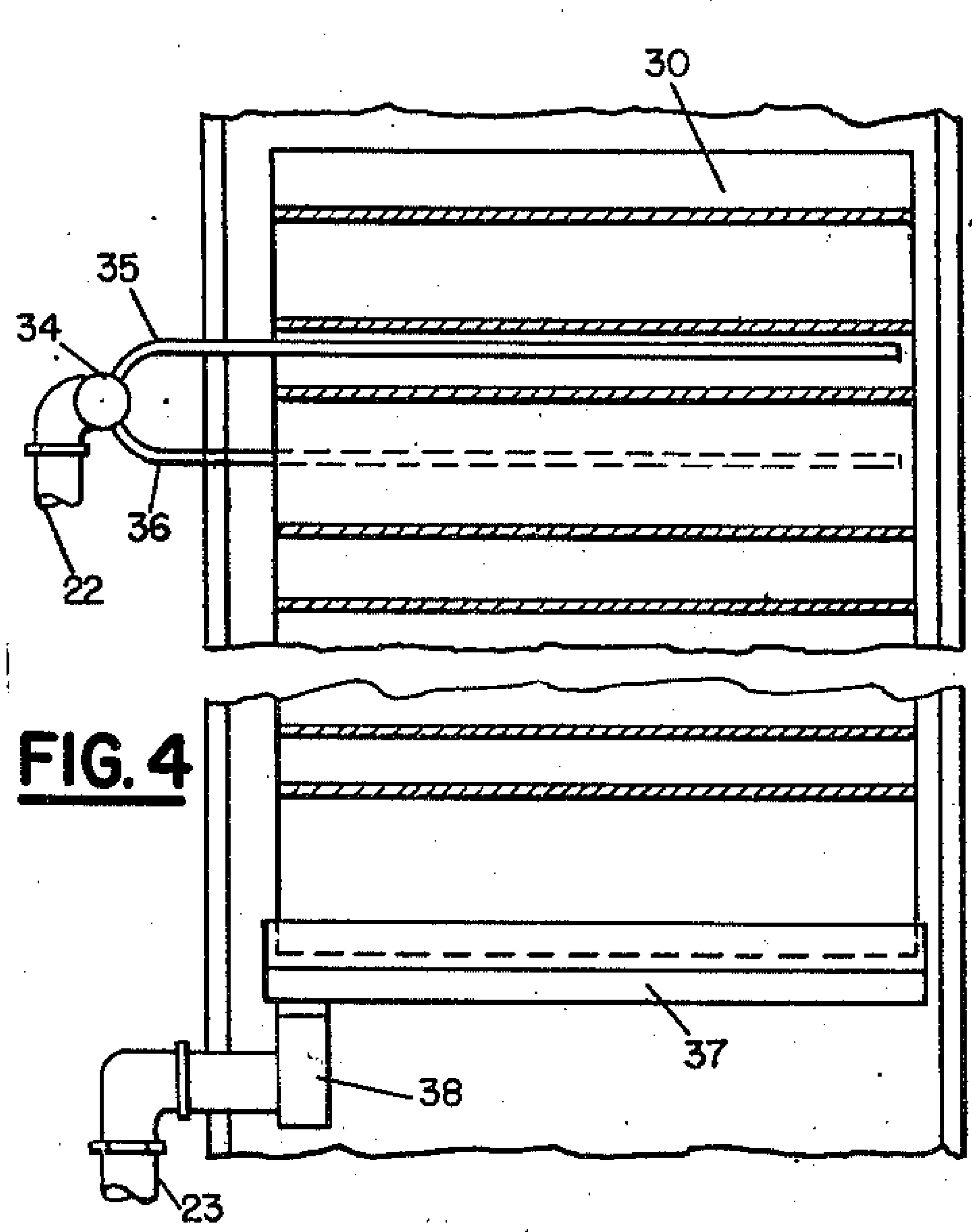

FIG. 4

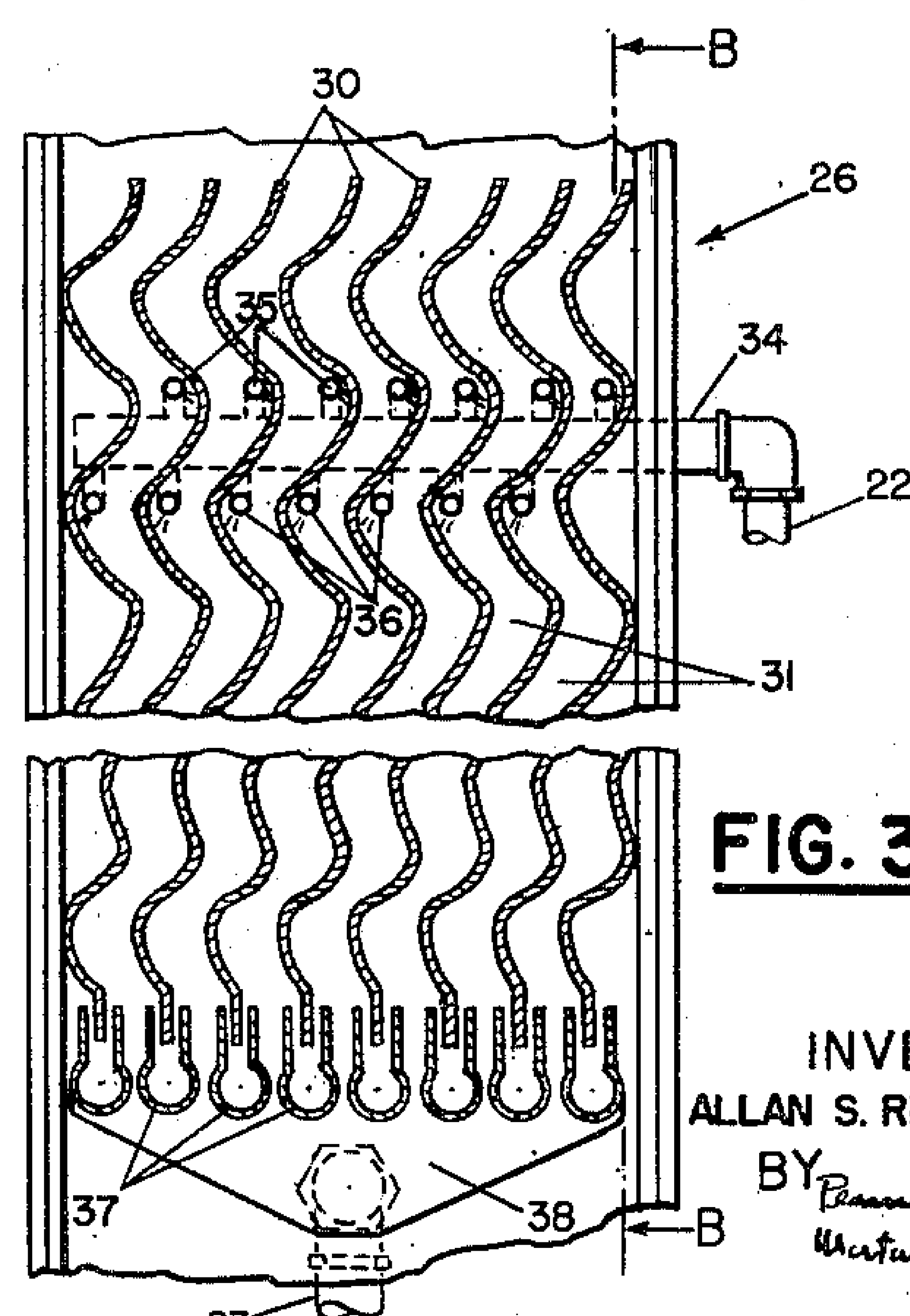

FIG. 3

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COOLING AIR

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Application March 5, 1946, Serial No. 651,991

9 Claims. (Cl. 183—120)

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This invention relates to cooling air by dehydration, and has for its principal object the provision of an improved method and apparatus for this purpose. This application is a continuation-in-part of my prior copending application Serial No. 527,125, now Patent No. 2,479,408, filed March 18, 1944.

In my above-mentioned application, I have described an improved method of cooling warm humid mine air by absorption of the water vapor it contains in a hygroscopic liquid, with accompanying transfer of heat to liquid. Heat from the liquid then is transferred to any suitable place outside the mine, and the liquid is regenerated by removal of absorbed water therefrom. The present invention provides an improved cooling method particularly applicable for use in cooling mine air in conjunction with the foregoing method (although not limited to use in conjunction therewith); and further provides apparatus applicable for use in carrying out the improved method.

It has heretofore been proposed (as, for example, in my aforementioned application) to absorb moisture from humid air by passing the air in intimate contact with a hygroscopic liquid. As an incidence to this absorption of the moisture, or water vapor, from the air, the heat of condensation of the water vapor is transferred to the liquid. This heat may then be transferred through suitable heat exchange apparatus to a point outside the mine or other space in which the air is being cooled or conditioned.

While the temperature of the air is not necessarily decreased by this dehydration treatment, it feels substantially cooler, and it has a substantially enhanced ability to cool moist surfaces, because in consequence of its reduced moisture content a given volume of such air can cause the evaporation of a larger quantity of moisture, and cause it to evaporate more rapidly, from the skin or other moist surface. The heat of vaporization required for this evaporation is absorbed from the moisture itself and its immediate surroundings, with consequent cooling thereof.

The present invention contemplates an improved method, involving absorption of moisture from humid air in a hygroscopic agent, which not only reduces the relative humidity of the air, but actually effects a substantial lowering of its temperature, thus truly conditioning the air (as distinguished from simply cooling the air without reducing its moisture content or reducing its moisture content without substantially lowering its temperature).

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In accordance with the method of the invention, air at less than 100% relative humidity is passed adiabatically in contact with liquid water at a temperature such that the relative humidity of the air is increased and its temperature is decreased. The air is then dehydrated by passing it in contact with a hygroscopic agent. The hygroscopic agent is at a temperature somewhat above the wet-bulb temperature of the humidified air, but its vapor pressure is substantially below that of said air. The temperature and vapor pressure of the hygroscopic liquid are established at such values that, while the dry-bulb temperature of the air is increased somewhat during dehydration, the moisture content of the air concurrently is reduced to a value below that prior to humidification, and low enough to more than offset, in net cooling effect, the increase in dry-bulb temperature. Thus the combination of humidification and dehydration steps results in a net cooling of the air, because during humidification the dry-bulb temperature of the air is reduced, and during dehydration the relative humidity is reduced without permitting the dry bulb temperature to rise to a value high enough to offset, in heating effect, the reduction in humidity. The heat of condensation of the moisture absorbed in the hygroscopic liquid is taken up largely in the liquid. By repeating this sequence of steps a number of times, the dry-bulb temperature of the air may be very substantially reduced, and its relative humidity may be reduced to a comfortable value.

The hygroscopic liquid employed for dehydration is used at a temperature somewhat above the wet-bulb temperature of the air (advantageously at a temperature intermediate the dry-bulb temperature of the air before and after humidification) because the liquid then will be at a temperature, after passage through the dehydration step, such that it may be cooled readily by cooling water at about the wet-bulb temperature of the air. Since the hygroscopic liquid is heated during dehydration, and since its vapor pressure increases with increase in its temperature, cooling of the liquid is necessary. Cooling of the liquid is most conveniently and economically carried out by use of cooling water cooled by evaporation into air. The temperature of cooling water thus cooled cannot be lower than the wet-bulb temperature of the air into which evaporation occurs and in practice will actually be a few degrees warmer than this temperature. By employing the hygroscopic liquid at a temperature above the wet-bulb temperature of the air after humidification (when the dry-bulb and wet-bulb temperatures of the air are almost the same), the hygroscopic liquid is heated during dehydration to a temperature high enough so that cooling water cooled by evaporation in the atmosphere may be used efficiently and economically. The fact that the dry-bulb temperature of the air is increased somewhat during dehydration as a result of this procedure is not serious, and is balanced by the economy resulting from efficient and economic cooling by water which has been cooled by evaporation into the atmosphere.

Any appropriate hygroscopic agent may be used for dehydrating the humidified air, but it is particularly advantageous to employ a hygroscopic liquid, such as an aqueous solution of calcium chloride, lithium chloride, zinc chloride, or diethylene glycol. The water-vapor pressure of the hygroscopic liquid (or other agent), with which the air is passed in contact after humidification, must, of course, have a water-vapor pressure less than that of the humidified air.

For efficiency in operation of the new method, it is advantageous to prevent any substantial entrainment of liquid water in the air passing from the humidification step to the dehydrating step, because such entrained moisture is ineffective for cooling the air, and it will accumulate in the dehydrating agent and will have to be removed therefrom during regeneration.

The apparatus provided by the invention comprises a humidification chamber, with means for passing air into this chamber, and with means for introducing water therein and into contact with air passing therethrough. Means are included for preventing entrainment of liquid water in the humidified air. A dehydrating chamber is provided, together with means for passing air from the humidification chamber into the dehydrating chamber, and means are arranged for introducing a hygroscopic liquid into a dehydrating chamber and into contact with air passing therethrough.

In a particularly advantageous embodiment of the invention, there are means for introducing air into the upper portion of the humidification chamber and means for introducing liquid water also into the upper portion of this chamber. Means are provided for directing the water thus introduced downwardly in intimate concurrent contact with air passing downwardly through this chamber. In this embodiment, a passage connecting the lower portion of the humidification chamber and the lower portion of the dehydrating chamber provides for conducting air from the humidification chamber to the dehydrating chamber, and means are provided for withdrawing air from the upper portion of the dehydrating chamber. Suitable means for introducing hygroscopic liquid into the upper portion of the dehydrating chamber also are provided, together with means for directing the hygroscopic liquid downwardly in intimate countercurrent contact with air passing upwardly through this chamber.

Advantageously the means for directing the water in the humidification chamber and the hygroscopic liquid in the dehydrating chamber into intimate contact with the air comprise closely spaced sinuous sheets providing tortuous passages for the flow of air through the chambers. The means for introducing the water and the hygroscopic liquid then preferably are arranged to deliver the water and the liquid respectively to the upper portions of such sheets in the respective chambers. The construction and arrangement of the sinuous sheets and the means for delivering water or hygroscopic liquid to the surfaces thereof may be as described in my Patent No. 2,231,088, dated February 11, 1941.

When sinuous sheets are employed within the humidification chamber, as is generally preferable, the means for preventing entrainment of liquid water in the humidified air may be in the form of troughs arranged adjacent the bottom of the sheets for collecting liquid water flowing to the bottom thereof, and thus preventing its entrainment in air flowing between the sheets.

The invention is described more in detail below with particular reference to the accompanying drawings, showing an embodiment of the invention as it may be arranged for cooling the air in mines, in which

Fig. 1 is a schematic layout of the complete apparatus used for cooling mine air;

Fig. 2 shows a preferred arrangement of the apparatus comprising the mine-air cooler and the connected solution cooler shown schematically in Fig. 1;

Fig. 3 is a section taken substantially along the line A—A of one of the air cooler units shown in Fig. 2; and

Fig. 4 is a section taken substantially along the line B—B of Fig. 3.

The arrangement of apparatus shown schematically in Fig. 1 is substantially as described in my above-mentioned application Serial No. 527,125, now Patent No. 2,479,408. It comprises a cooling tower 1 having a reservoir 2 for the accumulation of water and a pump 3 for circulating the water from the reservoir through an air pre-coooler 4 and up to the top of the tower through a pipe 5 to a distributor 6 from which the water is sprayed into the tower and permitted to fall into the reservoir. Atmospheric air is blown by a fan 7 over the pre-cooler coils and in countercurrent contact with the spray of water in the cooling tower, thereby cooling the water which enters the reservoir 2.

At a place inside the mine, preferably near the active working area, the apparatus 10 for treating the mine air is installed. This apparatus comprises a fan 11 for blowing the mine air to be treated into and through a mine-air cooler 12. The mine-air cooler includes means for first humidifying the air and then dehydrating it by bringing it into contact with a hygroscopic solution. A solution cooler 13, advantageously located near the mine-air cooler 12, is provided for maintaining the temperature of the hygroscopic solution within proper limits. The hygroscopic solution from the mine-air cooler circulates through a pipe 14 through the solution cooler, and is returned by a pump 15 through piping 16 to the mine-air cooler. In the solution cooler 13, the liquid circulates in heat exchange contact with cooled water brought from the reservoir 2 through piping 17 and returned to the top of the cooling tower 1 by means of a pump 18 and piping 19. It is apparent that liquid in the piping 17 and 19 is substantially in hydrostatic balance, and the pump 18 therefore serves mainly to overcome the frictional resistance in the piping to effect circulation.

A part of the hygroscopic solution circulating through the solution cooler 15 is continuously removed and sent through piping 20 to a suitable regenerator for concentration, such as an evaporator, or a refrigerating unit wherein the water is removed by freezing. Regenerated solution is, of course, returned to the apparatus through piping 21.

Liquid water for humidifying the air prior to dehydrating it by contact with the hygroscopic liquid is circulated through the mine-air cooler 10, through suitable piping 22 and 23.

The mine-air cooler assembly of chambers and the associated solution-cooler apparatus is shown more in detail in Figs. 2 to 4. The fan 11 takes air from the mine or other space to be cooled and blows it through a duct 25 into and through a series of air-cooler units, each comprising a humidification chamber 26 and a dehydrating chamber 27. Cooled and dehydrated air from the last dehydrating chamber in the series passes through a duct 28 back into the space in which the cooled air is desired.

Each of the humidifying chambers 26 is in the form of a tower, in which are mounted a considerable number of closely spaced, vertically arranged sinuous sheets 30 (Figs. 3 and 4). These sheets provide tortuous passages 31 for the flow of gas between them and advantageously are of the form described in my above-mentioned Patent No. 2,231,088.

In order to humidify the air as it flows through each of the humidification chambers 26, water from a supply tank 32 is pumped into each of these chambers by a pump 33 through the piping 22. The piping 22 feeds a header 34 to which a number of spray pipes 35 and 36 are connected. These spray pipes enter the humidification chamber 26 and distribute the water in the form of a film on each side of the sinuous sheets 30. The water flows down the sheets in concurrent relation with the air flowing between the sheets, and water reaching the bottom of the sheets drains into troughs 37, disposed adjacent the bottoms of the sheets. Water collected in the troughs 37 drains into a header 38 to which the piping 23 is connected for the purpose of returning the surplus water to the storage tank 32.

As the air flows downwardly through the tortuous passages 31 between the sheets 30, its direction of flow is continually being reversed, and it is brought into intimate concurrent contact with the film of water flowing downwardly from the spray pipes 35 and 36 along both sides of the sheets 30. This intimate contact favors evaporation of the water into the air flowing between the sheets. Conditions within the chambers are substantially adiabatic (that is, no heat is supplied from an external source to the air-water system within the chamber and none is abstracted therefrom to a point external of the system). Consequently, the heat of vaporization required for evaporating the water from the sheets into the air must come from within the system itself. Some of the heat may be supplied by the water flowing down the sheets, and if so it will be correspondingly cooled, but a large portion is supplied by the air into which the water evaporates, and the dry-bulb temperature of the air is, therefore, reduced as it flows down between the sheets and as its relative humidity is increased. Advantageously the air is humidified as closely as possible to saturation (100% relative humidity), for then maximum reduction in the dry-bulb temperature of the air is effected, subsequent dehydrating is facilitated, and a minimum number of successive humidification and dehydrating steps is necessary to effect a given total degree of cooling.

Water lost in the humidification chamber by evaporation into the air may be replenished by supplying fresh water through piping 40 and 41 from a source (not shown) to the storage tanks 32. Since water circulated in closed circuit through each humidification chamber assumes the wet-bulb temperature of the air passing through that chamber, best results are obtained by using a separate water storage tank in connection with each humidification chamber in the series, as shown in the drawings, but it is possible to supply the several humidification chambers from a common storage tank.

Humidified air from the humidification chamber 26 flows through a passage 42 connecting the lower portion of the humidification chamber 26 with the lower portion of the associated dehydration chamber 27, and flows upwardly through the latter chamber. The dehydrating chamber is constructed similarly to the humidification chamber, and has suspended within it a considerable number of closely spaced, substantially vertical sinuous plates, arranged in the same manner as described above in connection with the humidification chamber. As in the latter chamber, these plates define a series of tortuous passages through which the air flows upwardly in its passage through the dehydrating chamber.

Each of the dehydrating chambers is supplied with a hygroscopic solution fed to it by the pumps 15 through piping 16. The pipes 16 connect with headers 43, one of which is associated with each dehydrating chamber. A number of spray pipes are connected to each header and deliver hygroscopic liquid to both surfaces of the sinuous sheets within the respective dehydrating chambers in the same manner as water is delivered to the corresponding sheets in the humidification chamber. The hygroscopic liquid flowing along the surfaces and to the bottom of the sheets is collected in troughs and drains into a collecting header at the bottom of the dehydrating chamber, again in the same fashion as described above with reference to the humidification chamber. The collected liquid is returned through the piping 14 to the particular cooling unit 44, 45, 46 or 47 from which the solution was originally fed by the pump 15 to the dehydrating chamber.

As humid, cooled air from the humidification chamber flows upwardly through the tortuous passages in the dehydrating chambers, the air is brought into intimate countercurrent contact with the downwardly flowing film of hygroscopic solution on the sinuous plates within this chamber. The hygroscopic liquid (which may be an aqueous solution of calcium, zinc, or lithium chloride, or of diethylene glycol) is supplied to the dehydration chamber at a temperature somewhat above the wet-bulb temperature of the humidified air (say at a temperature intermediate its dry-bulb temperature prior to humidification and its wet-bulb temperature after humidification), and at a concentration such that its water-vapor pressure is less than the water-vapor pressure of the air passing in contact therewith. In consequence, moisture is absorbed from the air into the solution and the relative humidity of the air thus is decreased. Absorption of the water vapor in the hygroscopic liquid may be considered equivalent to condensation of the vapor, and in any event results in liberation of heat equivalent to the heat of vaporization of the amount of moisture thus absorbed. For the most part the liberated heat is transferred directly to the hygroscopic liquid in which the water vapor is absorbed, so that the temperature of the liquid is increased appreciably. The dry-bulb temperature of the air also is increased during this step, by heat exchange with the hygroscopic liquid, but this increased temperature of the air (at least in the second and subsequent dehydration chambers) still is lower than its dry-bulb temperature prior to humidification, and with the reduction in its relative humidity which dehydration brings about, the net result is to effect a substantial cooling of the air.

Since the hygroscopic liquid is appreciably warmed during dehydration of the air, and since the vapor pressure of the hygroscopic liquid is markedly increased by an increase in its temperature, it is necessary for most efficient and economical operations to cool the liquid withdrawn from the bottom of the dehydration chamber before returning it for reuse. This cooling is accomplished in the cooling units **44**, **45**, **46** and **47**, forming components of the solution cooler **13** diagrammatically represented in Fig. 1. As shown in Fig. 2, a separate cooling unit is associated with each dehydrating chamber in the series. The warmed hygroscopic solution flowing from each of the dehydrating chambers to the associated cooling unit is sprayed by a head **48** over and in heat exchange relation with cooling coils **50** within each unit. The cooling coils in the several cooling units are connected in series, and cooled water flows to them through the piping **17** from the cooling tower **1** (Fig. 1), and is returned from them to the cooling tower through the piping **19**. As the hygroscopic liquid is used at a temperature above the wet-bulb temperature of the humidified air, and as its temperature is still further increased during dehydration, it is warm enough when withdrawn from the dehydration chamber so that it can be adequately and economically cooled by water from the cooling tower **1**.

As shown in Fig. 2, the flow of cooling water through the several cooling units **44**, **45**, **46** and **47** is countercurrent to the flow of air through the associated dehydrating chambers. As more fully described in my above-mentioned application Serial No. 527,125, this arrangement provides that the hygroscopic solution fed to the last dehydrating chamber in the series is most effectively cooled and thus has the lowest vapor pressure, so that air discharged from the last dehydrating chamber will have its moisture content (relative humidity) reduced to the greatest practical extent.

Hygroscopic liquid flowing through the several dehydrating chambers, in addition to being warmed by the absorption of moisture from the air, is also diluted somewhat by the absorbed moisture. Since the water-vapor pressure of the hygroscopic solution is in part dependent upon its concentration (in general being increased by a decrease in concentration), provision is made for continuously withdrawing a portion of the hygroscopic liquid from the system, regenerating it by the removal of water, and returning the regenerated solution to the system. In the embodiment here particularly described, this is accomplished by providing for the flow of hygroscopic liquid from the cooling unit **44** associated with the first dehydrating unit in the series, through a pipe **51** into the next cooling unit **45** in the series, and also for the flow of hygroscopic liquid from the last cooling unit **47** in the series through piping **52** into the same cooling unit **45**. Hygroscopic liquid from the second cooling unit **45** flows through a pipe **53** into the third cooling unit **46**. Surplus hygroscopic liquid accumulating in this latter cooling unit **46** flows through the pipe **20** to the regeneration means (not shown) where the liquid is concentrated by the removal of water (as by evaporation or freezing), and the concentrated liquid is returned through piping **21** to both the first and the last cooling units **44** and **47** in the series.

Hydrometer-actuated control valves **54** and **55** in the piping system **21** may be provided to regulate the admission of regenerated liquid to each of the first and last cooling units **44** and **47** in accordance with the extent to which the liquid in these cooling units is diluted, and so requires replenishment with fresh concentrated solution.

As described in my above-mentioned application Serial No. 527,125 now Patent No. 2,479,408, this arrangement for circulating the hygroscopic liquid between the several separate cooling units, for withdrawing liquid for regeneration from an intermediate unit, and for returning regenerated liquid to the first and last units insures most efficient and economic operation of the system as a whole. This results from the following several circumstances:

(1) The air flowing through the first dehydrating chamber in the series is at a higher wet-bulb temperature than in any later dehydrating chamber, and so can best be dehydrated by bringing it in contact with fresh hygroscopic liquid. Further, the cooling unit **44** associated with the first dehydrating chamber is the last in the series from the standpoint of the flow of cooling water, and so is least effectively cooled. By supplying hygroscopic liquid at maximum concentration to this cooling unit and from it to the first dehydrating chamber in the series, the liquid can absorb more moisture from the air and hence be heated to a higher temperature than would be possible if solution at a more dilute concentration were here supplied. Consequently, such concentrated liquid can be better cooled by the cooling water which has already flowed through all other cooling units in the series and is at its highest temperature prior to return to the cooling tower.

(2) Since air from the last dehydrating chamber in the series is to be discharged into the working space in the mine, or other space where cooled and dehydrated air is desired, it is advisable, for purposes of maximum dehydration, to insure that in passing through the last dehydrating chamber the air comes in contact with hygroscopic liquid from the coolest and most concentrated body thereof. This is insured, in the arrangement shown, by the provision for introducing fresh concentrated liquid to the cooling unit **47** and by providing that this cooling unit is the first into which the cooling water flows from the cooling tower.

(3) The intermediate cooling units serve to maintain the hygroscopic liquid circulating through the intermediate dehydrating chambers in condition for effecting maximum economical dehydration of the air preparatory to the next successive humidification and cooling step. Hygroscopic liquid accumulating in the cooling unit **46** associated with the next to the last in the series of dehydrating chambers is at its most dilute concentration. By withdrawing hygroscopic liquid from this body for regeneration purposes, the liquid can be most economically concentrated, and with minimum circulation through the concentrating apparatus.

Provision according to the invention for the use of hygroscopic liquid that is at a temperature progressively higher in each successive dehydration stage proceeding in a direction countercurrently to the direction of air flow and concurrently to the direction of cooling water flow, results in total heating of the hygroscopic liquid through a wide temperature range and to a high final temperature. In consequence, cooling of the liquid is very efficiently effected by evaporation-cooled water. In fact the temperature range through which the cooling water is heated may range from a number of degrees below the atmospheric wet-bulb temperature to forty or more degrees above this temperature. It is evident that this permits efficient and economic transfer of heat from the air being cooled to the place where it is dissipated. At the same time provision for first humidifying and then dehydrating the air, and preferably repeating these steps a number of times, results in substantial cooling of the air. Hence the invention is particularly advantageous for use where it is desired not only to reduce the humidity of the air (thus increasing its ability to cool moist surfaces), but where it is also desired actually to reduce the temperature of the air. By passing the air repeatedly through the series of towers in which the air is first humidified and then dehydrated, the ultimate decrease in wet-bulb temperature will amount substantially to the sum of the several separate wet-bulb temperature reductions. At the same time, if the incoming air is particularly humid, the method and apparatus of the invention are effective for reducing the humidity to a comfortable value.

I claim:

1. The method of cooling air which comprises passing the air at less than 100% relative humidity adiabatically in contact with liquid water at a temperature such that the relative humidity of the air is increased and its dry-bulb temperature is appreciably decreased, and then dehydrating said air by passing it in contact with a hygroscopic liquid having a temperature substantially above the dry-bulb temperature of the humidified air but having a vapor pressure substantially below that of said air, the temperature and vapor pressure of said liquid being such that the dry-bulb temperature of the air after dehydrating is increased and the moisture content of said air is reduced to a value below that prior to humidification and low enough to more than offset in cooling effect the increase in dry-bulb temperature, the temperature of said hygroscopic liquid being increased during dehydration sufficiently so as to permit effective cooling thereof by water at about the wet-bulb temperature of the atmospheric air.

2. The method of cooling air which comprises repeatedly subjecting the air to the sequence of steps comprising adiabatically humidifying the air to a high relative humidity, whereby its dry-bulb temperature is substantially decreased, and then dehydrating the air by passing it in contact with a hygroscopic agent having a temperature substantially above the dry-bulb temperatures of the air after humidification and having a vapor pressure substantially below that of the air introduced in contact therewith, whereby the wet-bulb temperature of the air is decreased to a value below the corresponding values prior to humidification, and whereby the hygroscopic liquid is heated to a value sufficiently high to permit effective cooling thereof by water at a temperature near the wet-bulb temperature of the atmospheric air.

3. The method of cooling air which comprises adiabatically humidifying the air, whereby its dry-bulb temperature is decreased and its relative humidity is increased, then passing the air through a dehydrating chamber in contact with a hygroscopic liquid having a temperature which is intermediate the dry-bulb temperatures of the air before and after humidification but which is substantially above the dry-bulb temperature of the air after humidification, and having a vapor pressure substantially below that of the humidified air, whereby the air is dehydrated and its dry bulb temperature is increased but insufficiently to offset in cooling effect the effect of said dehydration, and whereby the temperature of the hygroscopic liquid is substantially increased, withdrawing the heated hygroscopic liquid from said chamber and cooling it to a temperature above the dry-bulb temperature of the humidified air by passing it in heat exchange relation with cooling water cooled by evaporation in air, and reintroducing the cooled hygroscopic solution into said chamber.

4. The method of cooling air which comprises humidifying the air by passing it downwardly through a chamber in concurrent contact with liquid water, recirculating the water through said chamber, thence passing the air upwardly through a second chamber in countercurrent contact with a hygroscopic liquid having a temperature substantially above the dry-bulb temperature of the humidified air but having a water-vapor pressure less than that of the air in contact therewith, whereby said hygroscopic liquid is heated to a still higher temperature, withdrawing said liquid from adjacent the bottom of said chamber, cooling said liquid to a temperature above the dry-bulb temperature of the humidified air, and introducing the cooled liquid at said temperature into said second chamber adjacent the top thereof.

5. The method of cooling air which comprises passing the air through tortuous air passages in contact with films of liquid water, maintaining substantially adiabatic conditions within said passages, whereby the relative humidity of the air is increased and its dry-bulb temperature is decreased, and passing the cooled and humidified air substantially free of entrained liquid water through tortuous passages in contact with films of a hygroscopic liquid having a temperature substantially above the dry-bulb temperature of the humidified air but having a water-vapor pressure less than that of the humidified air, whereby the dry-bulb temperature of the air is increased but its wet-bulb temperature is decreased sufficiently to more than offset in cooling effect said increase in dry-bulb temperature increase.

6. The method of cooling air which comprises humidifying said air under adiabatic conditions by passing it in contact with liquid water, thence passing the air in contact with several separate bodies of hygroscopic solution, flowing liquid from the first and last bodies to at least one intermediate relatively dilute body, withdrawing and regenerating solution from said intermediate body by removing water therefrom, and reintroducing the regenerated solution into said first and last bodies.

7. The method of cooling air which comprises passing the air through a series of several chambers in each of which the air first is passed through a humidification section under adiabatic conditions in contact with liquid water, whereby

the relative humidity of the air is increased, and then is passed through a dehydrating section in contact with a hygroscopic solution having a water-vapor pressure less than that of the air in contact therewith, whereby the relative humidity of the air is decreased and the temperature of the solution is increased and its concentration decreased, circulating solution from each of said dehydrating sections through a separate cooling vessel associated therewith and thence back to the dehydrating section, flowing solution from the first and last of said cooling vessels to at least one intermediate vessel, withdrawing solution from said intermediate vessel and regenerating it by removal of water therefrom, and returning the regenerated solution to the first and last of said vessels.

8. Apparatus for cooling air comprising a humidification chamber, means for introducing air into the upper portion of said chamber, means for introducing liquid water into the upper portion of said chamber, means for directing the water downwardly in intimate concurrent contact with air passing downwardly through said chamber, a dehydrating chamber, a passage connecting the lower portions of both chambers for conducting air from the humidification chamber to the dehydrating chamber, means for withdrawing air from the upper portion of said dehydrating chamber, means for introducing a hygroscopic liquid into the upper portion of said dehydrating chamber, and means for directing the hygroscopic liquid downwardly in intimate countercurrent contact with air passing upwardly through said dehydrating chamber.

9. Apparatus for cooling air comprising a humidification chamber side by side with a dehydrating chamber, said chambers being in communication at their lower ends, means for delivering air into the upper end of the humidification chamber and for withdrawing air from the upper end of the dehydrating chamber, closely spaced sinuous sheets in each of said chambers providing tortuous passages for the flow of air therethrough, means for delivering liquid water to the upper portions of the sheets in the humidification chamber, and means for delivering a hygroscopic liquid to the upper portion of the sheets in the dehydrating chamber.

ALLAN S. RICHARDSON.

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