HUMIDITY CHANGER FOR AIR CONDITIONING

Fig. 7.

Fig. 8.

NEAL A. PENNINGTON,
INVENTOR,

By

ATTORNEY.
HUMIDITY CHANGER FOR AIR-CONDITIONING

Neal A. Pennington, Tucson, Ariz., assignor of one-fifth to Robert H. Henley, Tiptonville, Tenn., and one-fourth to Roger Sherman Hoar, South Milwaukee, Wis.

Application June 29, 1951, Serial No. 234,501

21 Claims. (Cl. 261—83)

My invention relates to new and useful improvements in a humidity-changer for air-conditioning, and more particularly to a combined humidifier-dehumidifier, primarily for use in a "universal" (i.e., both summer and winter) air-conditioning apparatus.

This present application is a continuation, as to all common subject-matter, of my copending application for improvements in universal air-conditioner, Serial No. 765,554, filed August 1, 1947, now abandoned without prejudice to this present application and one other continuation-in-part, Serial No. 234,800, filed July 2, 1951, and embraces the elected subject-matter of that parent case, plus certain subsequent improvements. This elected subject-matter is that part of my complete apparatus which effects moisture transfer.

Outdoor air, when heated in winter for use indoors, thereby almost always acquires too low a relative humidity, and hence requires to be humidified. Outdoor air, when cooled in summer for use indoors, thereby almost always acquires too high a relative humidity, and hence requires to be dehumidified.

Accordingly it is the principal object of my present invention to devise a simple mechanism, adapted to perform selectively, at will under automatic control, these two functions of humidifying and dehumidifying the incoming air.

It is a further object to devise this mechanism so that it performs these functions by moisture-exchange, between two streams of air (one incoming and one outgoing), transferring the moisture in either direction, at will or under automatic control, without any rectorying of the two main air-streams.

In addition to the objects above stated, I have worked out a number of novel and useful details, which will be readily evident as the description proceeds.

My invention consists in the novel parts and in the combination and arrangement thereof, which are defined in the accompanying drawings, which are hereinafter particularly described and explained.

Throughout the description the same reference number is applied to the same member or to similar members.

Figure 1 is a longitudinal vertical central section of my apparatus.

Figure 2 is a transverse vertical section of my apparatus taken along the line 2—2 of Figure 1.

Figure 3 is a horizontal section of the rotary moisture-exchanger, and adjacent parts, of my apparatus, taken along the line 3—3 of Figure 2.

Figure 4 is an enlargement of a portion of Figure 3, to illustrate my means for preventing the leakage of air past my rotary moisture-transferrer in either air-passage, and for preventing the leakage of air from one air-passage to the other at the periphery of said transferrer.

Figure 5 is a diagrammatic detailed showing of the gear-shift for changing the rotation speed of my heat-exchanger and my moisture-transferrer, this gear-shift being merely indicated in Figure 1.

Figure 6 is a chart, which shows the psychrometric interaction of the air-streams as they pass through my rotary moisture-transferrer, and of the particles of the latter as it rotates across the air-streams, all under humid summer conditions.

Figure 7 is a psychrometric chart, which shows the same under winter conditions.

Referring now to Figure 1, we see that 11 is the main container of my invention, in which 12 is an air-inlet from outdoors. Centrifugal fan 13 impels this air into passage 14, thence through filter-pad 20, and thence through the upper portion of rotating wheel-like moisture-transferrer 15.

This moisture-transferrer 15 is built very similar to the "aluminum wool pad" of my Patent No. 2,464,766, but employs novel means to prevent the leakage of air from one air-passage to the other, and to prevent the leakage of air past the periphery of the moisture-transferrer. These novel means will be described and explained later herein.

The rim 16, ribs 17, and hub 18 of my moisture-transferrer are of substantially the same width in an axial direction. Each of the sectors between successivelylocated ribs is fully and rigidly but loosely stuffed with some air-pervious liquid-absorbing non-heat-conducting packing 19, which may be excelsior or other similar filamentous material, or corrugated asbestos paper or the like with the corrugations extending axially.

The packing should be impregnated with some appropriate solution of an hydraulic liquid or oils.

For an impregnating liquid, I prefer glycerine, or one of the polyethylene glycols (such as triethylene, or polyethylene 200 or 300). Glycerine I consider the best; the drawback of high viscosity, which has prevented the use of this absorbent in liquid circuits, is no drawback to it as an impregnant of such a rotary moisture-transferrer as hereinafter described.

For an impregnating hygroscopic salt solution, I prefer some such combination as that described and claimed in my copending application for improvements in hygroscopic composition of matter, Serial No. 814,445, filed June 13, 1951, to which application reference may be made for further details.

Whether in the claims I refer to a salt, I intend thereby to include a combination of salts.

The use of a rotary moisture-transferrer packed with an inert air-pervious carrier having a rigid space-structure, and impregnated with a liquid absorbent combines the simplicity of reactivation heretofore possessed only by solid absorbents, with the lack of resistance to airflow heretofore possessed only by liquid absorbents.

It also possesses the advantages of complete counterflow and one-to-one correspondence, applied to moisture Patent No. 2,464,766 applies to the transfer of sensible heat. Thus, in my rotary moisture-transferrer, the sensible heat and/or moisture of the air encountered by each round of the impregnated packing penetrates clear into the Saybacked, will pass before the minute portion in question passes into the other air-stream and begins to reverse the process. This causes the packing to act as though it were composed of many discrete minute specks. In the discussion of Figures 6, 7, and 8, which follows, I shall refer to an almost infinitesimally small-angled almost infinitely thin (in the direction of air-flow) sector of such specks, as a "particle," and shall refer to the plane in which it rotates as a "level" of my wheel.
2,700,537 3 24 be closed, all the incoming air will by-pass the by-pass.
In any event, the main stream of incoming air continues on in passage 26, until it encounters heat-transferrer 27, rotating at a speed of about 30 R. P. M.
This heat-transferrer 27 is preferably of the "wood pad" of my Patent No. 2,464,766, already alluded to.
Instead of packing the heat-transferrer with metal wool, it would be permissible to fit it with a foraminiferous carrier impregnated with some non-hygrosopic liquid, such as mineral-oil of the sort employed in my copending application, Serial No. 505,924, filed October 12th, 1954, now Patent No. 2,618,217, issued January 15, 1954.
Let us now compare moisture-transferrer 15 and heat-transferrer 27. Except for the nature of the packing, these two transferrers could be identical. However, I have shown them slightly different, so as to illustrate two alternative means for preventing the leakage of air past them in each air-stream, or from stream to stream.
My heat-transferrer 27 rotates in a casing 28, spanned by briquettes 29, with sectoral openings between each face of the casing and the corresponding bridge, all as shown and described in my Patent No. 2,464,766.
But my moisture-transferrer 15, although having very similar briquettes 30, has a single shroud 31, which projects inwardly from the main container 11, nearly touching the center line of the periphery of rim 16 of the moisture-transferrer. The rim consists of two annular pieces of felt 32, one being on each side of, and touching or nearly touching the sides of, the inwardly projecting edge of the shroud.
From Figure 4, we see that, in addition to partition 33, which separates the two air-passage, I have between the two bridges 30, in extension of the partition, two small plates 34 attached to the two bridges 30, the shroud 31, and the wall 11 of the container, and almost touching the rim 16 of the rotating moisture-transferrer and the two felts 32.
These expedients could equally well be substituted in connection with the heat-transferrer. They serve to prevent appreciable leakage of air past the moisture-transferrer, or from passage to passage.
In the case of my heat-transferrer, it is desirable to hold the packing in place in some convenient manner, as for example by metal screening secured to each face of the transferrer in any convenient manner, as for example (see Figure 2) by being put into sectors 35 inserted between successive ribs 17, and in turn held in place by wires 36, strung in spider-web formation through transverse holes 37 therein, and to the edges thereof.
The incoming air, after having been cooled by heat-transferrer 27, is further cooled by passing through evaporative pads, and called my "secondary" pad. Water from tank 39 is sucked through pipe 40 by electric pump 41, by which this water is impelled through feed pipe 42 to the top of pad 38, whence it trickles downward through this pad, so much of the water as is not evaporated therein, being returned to the tank through pipe 43.
The tank is supplied with water from any convenient source through supply pipe 46 and small-cock 47.
The air then enters the room or other enclosure through louvres 44.
Exhaust air leaves the room or other enclosure through louvres 44, and is cooled by passing through evaporative pad 48, which I call my "primary pad," and which is supplied with water from tank 39 by pump 49 in exactly the same manner as secondary pad 38, already described.
Water from tank 51 is sucked through pipe 52 by electric pump 53, and this water passes through radiating plate 54, and then to the bottom of chamber 55, where it is joined by the by-passed portion of incoming air entering the chamber by-pass 23.
In this chamber there is an air-heater, which might be an electrically-heated grid of German-silver, or any equivalent air-heating means; but, as shown, is a furnace (preferably gas) 52, which heats the air by means of this flame 53 on its flue 54. This furnace, and its flue and flaps, are represented here merely conventionally.

The furnace or alternative form of air-heater, could be located in an adjoining chamber, with heat-exchange means (such as heat-transferrer 27) transferring heat from that chamber to chamber 51.
The outgoing air, greatly heated by the furnace, then passes through radiation-shield 55.
Chamber 51 should be lined with some highly heat-reflective material, backed by heat-insulating material, in a convenient construction which will shield heat-transferrer 27 from the direct rays emanating from air-heater 52, while permitting the free passage of air. In other words, it should be substantially impervious to heat-radiations, and yet pervious to air. I prefer a stationary pad of much the same sort of aluminum-wool as employed as a filler for heat-transferrer 27. Radiation-shield 55 is similar, and similarly protects moisture-transferrer 15 from the rays of air-heater 52.

The outgoing air, having been raised in temperature by passing through heat-transferrer 27 and through radiation-screens 50 and 55, and by the addition of by-passed incoming air, and by air-heater 52, then passes through moisture-transferrer 15, where it dries and heats the hygroscopic packing thereof.
Thence it is sucked through centrifugal fan 56 into passage 57, whence it passes outdoors through exit opening 58. In this opening is butterfly-valve 59.
From passage 57, in the opposite direction there extends a draft-passage 60, which connects with furnace 52 in such manner as to furnish draft-air therefor. The amount of this draft can be regulated by butterfly-valve 59.
By thus utilizing the exhausting air as draft-air for the furnace, I not only avoid the expense of an additional draft fan, and obtain preheated draft-air, but also utilize the principle that somewhat damp air is better than dry air for draft purposes. I have found that this simple expedient of utilizing my heat-exchanger results in a fuel-saving of about 15%.

Motor 61 drives shaft 62 through pulley 63, belt 64, and pulley 65. Fans 13 and 56 are keyed to, and driven by, this shaft 62.

This shaft 62, through gear-reduction 66, drives shaft 67 at a very slow speed (about 3 R. P. M., or less), and drives shaft 68 at a relatively-faster speed (about 25 to 30 R. P. M.). On these speeds, see later herein. Shafts 67 and 68 enter speed-changer 69, the details of which are shown enlarged and somewhat symbolically in Figure 5.

In that figure, slow shaft 67 terminates in male clutch member 70. Aligned with shaft 67, there is a driven shaft 71, on which and keyed thereto, shaft 72 and female clutch member 73 integral with this gear.
Fast shaft 68 terminates in female clutch-member 74 and gear 75 integral therewith. Aligned with shaft 68, there is a driven shaft 76, on which gear 77 is keyed, and on which male clutch-member 78 integral with this gear. A fixed dog 79 engages and locks this gear when in its upper position.
Driven shaft 71 drives sleeve 80 which is keyed to rotary moisture-transferrer 15. Driven shaft 76 drives shaft 81 which is keyed to rotary heat-transferrer 27.

The operation and object of this whole speed-change system, just described, is as follows:

Gear 72 and its female clutch member 73, and gear 77 and its male clutch member 78, are raised or lowered simultaneously, when they are both in their lower position, gears 72 and 75 are disengaged, and both clutches are disengaged. The slow speed of shaft 67 is transmitted, through shaft 71 and sleeve 80 to moisture-transferrer 15; and the fast speed of shaft 68 is transmitted, through shaft 76 and shaft 81, to heat-transferrer 27.
When they are both in their raised position, the situation shown in Figure 5, both clutches are released, gear 72 engages gear 75, and gear 77 engages dog 79. The fast speed of shaft 68 is transmitted through shaft 76, through sleeve 80, to moisture-transferrer 15; and the engagement of gear 77 with dog 79 locks shaft 76 and thence shaft 81 and heat-transferrer 27 against rotation. In place of gear 77 and dog 79, any convenient form of brake could be used.
The optimum rotation speeds differ somewhat for various materials, but can easily be experimentally determined for each. The optimum fast speed for both ex-
changes is of the order of 25 to 30 R. P. M., but somewhat more would be permissible.

The optimum slow speed for a fully-impregnated moisture-transfer film is of the order of 3 R. P. M. or less. For example, for excelsior fully impregnated, with triethylene glycol, it is 2 to 3 R. P. M. For excelsior fully impregnated with the best hygroscopic salts, it is ½ to ½ R. P. M. For excelsior fully impregnated with the best hygroscopic salts, it is of the order of ½ R. P. M. On the effects of underimpregnation, see later herein.

The object of the two speeds for the moisture-transfer film is to perform only the slow speed herein when I discuss the psychrometric properties of my apparatus; 

TÌ and TA are two thermostats (but might as well be regarded as two double-stage thermostats), and H is a humidistat. These could be plotted at any strategic location in the room or other enclosure which is being air-conditioned, or equivalently in the outgoing air-passage just inside the louvres at 45. These state control the turning on and off of pumps at 40 and 39, and valve V which supplies fuel to furnace 52, all in a manner described in the second continuation-in-part of parent application Serial No. 765,254, which second continuation-in-part  is filed in accordance with 35 U.S.C. 132, filed July 2, 1951. Said parent case has now been abandoned without prejudice to the two continuations in part.

Figure 5, which shows the psychrometric circuits of the air in the humidifier and use of the machine, and also a temperature-moisture plot of two typical "paths" of my moisture-transfer, one on the outdoorward facing side, and the other on the indoorward face of the moisture-transfer.

From the point of view of the sensible-heat and heat-capturing capacities, as defined earlier herein, I deal with the total of the carrier, the sorbent, and the absorbed water. From the point of view of the vapor-pressure of the moisture at the point of contact with air, I deal with the carrier, the sorbent, and the absorbed moisture.

Psychrometric charts are well-known devices for plotting the thermodynamic characteristics of the atmosphere. But the use to which I put these charts in connection with my present invention is also a discovery of my own. Inasmuch as there is, to my knowledge, no available literature to which I shall now explain it.

The chart which I use has several vertical and horizontal lines representing dry-bulb temperature, temperature of dew-point and dew-point pressure, moisture content, and humidity, representing wet-bulb and constant humidity, and curving southwest northeast lines representing relative humidity. Representing the thermodynamic characteristics of particles of my exchange, I plot the dry-bulb lines to represent sensible temperature, and the dew-point lines to represent vapor-pressure. Thus at any point on the chart, a plot of my moisture-exchanger plotted thereon, and atmosphere past it, will be in both temperature equilibrium and vapor-pressure equilibrium with each other, i.e., in complete equilibrium.

But we must note and always bear in mind one very important difference between plotting the characteristics of the atmosphere and plotting the characteristics of my particles: namely that although the dew-point lines are lines of constant moisture-content as respects the atmosphere, they do not perform this function with respect to my particles. For, in this latter connection the lines of constant moisture-content are practically coincident with the relative-humidity lines near the bottom of the chart, veering more and more to the left of those lines (although still very slightly) as we approach the top of the chart. These characteristic lines have no apparent significance, as applied to my particles.

A plotted line-of-change of characteristics of one of my particles, indicates: gain of moisture if it veers to the left of one of the humidity lines, and loss of moisture if it veers to the right thereof; mass of sensible heat if it veers to the left of one of the dry-bulb lines, gain of sensible heat if it veers to the right thereof. This ends the explanation of how the psychrometric characteristics of one of my particles can be plotted on a chart which was designed merely to plot the characteristics of the atmosphere.

And now to discuss the psychrometric interaction between my particles and air.

Between two plotted points, which respectively represent

2,700,587

sent a particle and air in contact with it, moisture flow from the point higher up on the chart to the point lower; and sensible-heat flows from the rightmost point to the leftmost.

But, as to heat-flow, this does not tell the whole story, for change in sensible heat takes place in three interrelated ways, namely: (1) The moisture change, if condensation, tends to warm up the particle, but if evaporation, it tends to cool the particle, by conversion of sensible heat into latent heat. (2) The sensible-heat of the transferred moisture is averaged into the sensible-heat of the transfer, but has no direct effect on the temperature of the transfer. (3) Between the air and the particle, each with its temperature modified by the two foregoing steps, there is a flow of sensible-heat by direct contact.

Finally there is an important empirical fact as to my moisture-exchanger, namely that (due to the heavy temperature-difference) the sensible-heat exchange effected thereby between the atmosphere and a particle is very much rapid than the moisture-exchange, and hence predominates during the early part of the passing of the particle across either air-stream.

It is particularly to be noted that inasmuch as each moisture-exchange particle moves transversely across each air-stream, no single point on the plot either corresponds to any single point of the plot of the other.

Each point on the plot of either air-stream represents the average of the conditions of that stream at a given level of the moisture-exchanger, and hence corresponds to a whole half of a point of a given particle, which half plot represents the changes in characteristics of the particle as it crosses the airstream at that particular level.

With these preliminaries out of the way, let us now consider circuit abeda, which constitutes the plot of the change in characteristics of each particle of the outermost level of the moisture-exchanger as that particle crosses the two air-streams at that level, and interchanges sensible heat and moisture therewith.

The incoming outdoor air enters this level with characteristics A.

As one of the particles on the outdoorward face of the moisture-exchanger leaves the outgoing air-stream and enters the incoming air-stream, it has thermodynamic characteristics represented by B.

The reason for this will appear later. The atmosphere which it encounters has characteristics represented by A, and it will continue to encounter air of characteristics A all the way across the incoming stream.

The particle, being much hotter than the atmosphere, will tend to cool off rapidly. If there were no moisture-exchange, the plot of the other side of the particles of the moisture-exchanger would lie downward along one of the almost vertical lines.

But as the particle has a higher vapor-pressure than the air, it will give up moisture to the air. This moisture-exchange will cause the plot of the particle to veer to the right. But the cooling due to evaporation will speed up the descent of the plot toward cooler vertical lines. Thus the plot will reach b, a point of vapor-pressure equal to that at A, very quickly, after having traversed only a small sector of the incoming air-stream.

The lesser temperature of the air from that of the particle still continues to draw the plot of the particle diagonally downward. But now the plot will veer to the left, as the particle absorbs moisture from the air, due to the vapor-pressure of the particle being now increasingly less than that of the air. The sensible-heat exchange becomes less, as the plot of the particle approaches the vertical lines through A, and this slow-up is enhanced by the release of heat of condensation. This phase too of the plot consumes relatively little time.

But, as soon as the plot reaches very nearly the vertical lines through A, i.e. at the bottom of the plot, the rest of the time the particle spends in the transferable phase, is spent in practically pure moisture-exchange, extracting moisture from the air, until the particle leaves the incoming air-stream at c.

So much for the plot of the characteristics of the particle in the outdoorwardmost face of the pad, as they cross the incoming air-stream.

Now as to the plot of the characteristics of that stream. The narrow sector of air first encountered by the particles, in this part of its circuit, will have its characteristics tend from A toward a. Each successive narrow
sector of the air will have its characteristics tend from A toward lower and lower points on the abc plot, until those of the final sectors of the air will tend toward A.

The plot of the characteristics of the particles in the next level of the pad will be similar to abc, but will lie a little to the right thereof on the chart, until finally the characteristics of the particles in the indooreward face of the pad, will be represented by ab’c’.

The average characteristics of the sectors of the indooreward air-stream, which first encounter these successive particles at separate levels, will be represented by AB’ by discarding, through by-pass 25, the incoming air of the first air-sectors, the retained air will average in its passing through the pad, a change in characteristics from A to B.

Let us pause a moment to summarize the reasons for this discarding. From the foregoing psychrometric description, we have seen that, as each particle (i.e., narrow sector) of each level of the moisture-transferer enters the incoming air-stream, the particle is so hot as to continue to give up moisture and sensible heat to the incoming air, whereas we want to do is to extract moisture from that air and not to heat that air any more can be avoided. But by the time the particle has crossed out a fourth of the stream, it has cooled sufficiently so that it has given up all or practically all of its sensible heat, and has begun to extract moisture from the air. Hence, by discarding through the by-pass, the one-fourth effect of the remaining one-fifth of the stream is what we want, namely dehumidification with only such heating as is due to the heat of condensation.

The one-fifth by-product is that we conserve the sensible heat of the by-passed air, for use over again in the outgoing stream.

Turning now to the outgoing air, let us assume that it enters the moisture exchanger with characteristics H. Then by the same reasoning as detailed hereinbefore, the plot of the characteristics of particles will be c’d’a’ in the indooreward level of the moisture-exchanger, and c’d’a in the outdooreward level; the plot of the average characteristics of the first sectors of air of the outgoing stream will be H’; and the plot of the average of most of the air-streams will be H. Only, as all the outgoing air gets discarded anyway, we don’t need to by-pass the air of the early sectors.

I have thus described the psychrometry of merely that part of the apparatus comprised in my moisture exchanger. The complete psychrometry of my apparatus will be given in the second continuation-in-part already mentioned.

Let us now turn to Figure 7, which shows the psychrometric circuits of the air in the dry summer use of my machine with the furnace shut off; and also a temperature-humidity plot of two typical cycles of my moisture-transferer, one being on the indooreward face of the moisture-transferer and the other on the outdooreward face of the moisture-transferer.

Comparing the relative characteristics of the incoming air (A) and the outgoing air (H) in Figure 6, with the corresponding relative characteristics in Figure 7, we see that in Figure 6 the moisture-differential and the temperature-differential opposed each other, whereas in Figure 7 both differentials tend to transfer moisture in the same direction, namely from the outgoing stream to the incoming stream. Thus in the humid air case (Figure 7) we had to use slow rotation, in order to give the temperature-differential the preponderance and thus transfer moisture from the incoming air. Whereas in the dry air case (Figure 6) we could speed up both sensible heat and moisture transfer in the direction which we desire, namely to the incoming air.

Referring back to Figure 6, we see that the characteristics of a particle in the outdooreward face of my moisture-transferer pass through three phases as the particle crosses the incoming air of characteristics A. From a to b, inasmuch as it is hotter than and has a higher vapor-pressure than the air, it gives up both sensible heat and moisture. Some of its original sensible heat is, of course, absorbed by evaporation. From b to c, inasmuch as the particle is still hotter than the air but now has a lower vapor-pressure than the air, it still gives up initial sensible heat (and in addition the heat created by condensation) to the air, but now extracts moisture from the air.

In Figure 7, the plot of the characteristics of a corresponding particle is represented by the loop ab’c’a’, which in this counter-clockwise. Each particle of the outdooreward level of my moisture-transferer, in the dry summer case now under consideration, enters the moisture-transferer, its characteristics or, and evaporators (the air) have a higher vapor-pressure than the air, although only slightly greater than the air, there will be an initial burst of moisture discharge from the particle to the air, with resulting evaporative cooling of the particle and hence of the air. Hence the loss of moisture and sensible heat by the particle happens at the initial stage, from m to p. From then on the moisture-loss is less rapid, and the particle gains sensible heat from p to n, when it leaves the incoming stream.

The complete psychrometry of my apparatus shows in Figure 7, as in Figure 6, the position change in characteristics of the corresponding initial sectors of the incoming air. H1 represents the change in characteristics of the corresponding initial sectors of the outgoing air, which (for the same reason as in Figure 6) is not by-passed. H1 represents the change in characteristics of the average of the main portion of the incoming air. H1 represents ditto for the outgoing air.

A comparison of lines AB and AB’ shows that those sectors of the incoming air which the particles first traverse, emerges from the moisture-transferer not so much cooler than the air, but more humidified, than the finest line of the incoming air. In fact, in practice, due to slight differences in air speed, this temperature difference may be slightly more, and this moisture difference slightly less, than as shown. So no harm results from leaving the by-pass open. And it would be extremely inconvenient to have to keep opening and closing the by-pass, as the furnace goes on and off, due to frequent changes, during summer operation of my machine. Accordingly the psychrometry of Figure 7 is based on the assumption that the by-pass is open.

And although fast rotation would probably produce more efficient humidification of the incoming air, the same considerations of simplicity of control lead me to keep the moisture-transferer set for slow rotation throughout the summer.

Before turning to Figure 8, the following preliminary discussion is in order. If the speed of rotation of my moisture-transferer be increased, the amount of temperature fluctuation and vapor-pressure fluctuation of each particle thereof becomes less and less. Thus the loops abed, ab’ecd’a’, mmn, and m’n’s’in 25 of Figures 6 and 7, shrink practically to points at about 25 to 30 R. P. M.

The ability of my moisture-transferer to transfer moisture from an air-stream of lesser vapor-pressure to an air-stream of greater vapor-pressure is due to fluctuating the vapor-pressure of each particle (this being in turn accomplished by fluctuating its temperature), so that that vapor-pressure will alternately be higher than that of the air in the dry-stream, and lower than that of the low-vapor-pressure air-stream. It follows that, if these fluctuations be reduced by speeding up the rotation, this effect will finally cease, and there will be no temperature differential between the two streams. Thus there lies somewhere between my optimum low-speed rotation and my optimum high-speed rotation a critical speed below which a proper temperature-differential can cause moisture to pass from air-stream to air-stream against the vapor-pressure differential, and above which critical R. P. M. must perforce pass from air-stream to air-stream with the vapor-pressure differential.

Above this critical R. P. M., as rotation is further sped-up, the transfer of both sensible heat (in the direc-
tion of the temperature differential) and moisture (in the direction of the vapor-pressure differential) becomes more and more efficient, inasmuch as the increase in the number of rotations per minute more than offsets the decrease in the direction of the vapor-pressure differential) becomes almost as though there were an intimate direct contact between the two streams, without the intervention of the moisture-transferrer, and yet with either strong mingling with or interfering with the flow of the other.

Faster rotation than this would cause appreciable entrainment of air from one stream to the other, and would also interfere with the air-flow of the other.

Figure 8 is a psychrometric plotting of how, in winter, with the moisture-transferrer rotating at fast speed, in one alternating switching of my machine, the incoming air increases its temperature and moisture content from A to B, by counter-flow exchange with the outgoing air from H to I. L and L' represent the practically constant temperatures and moisture-pressures of the two parts of the outdoor and indoor air, respectively, with the heat-exchanger, at about 25 to 30 R. P. M.

When the by-pass is closed, the furnace is of course on, and only one of the evaporative pads are operating, depending on the amount of humidification necessary.

b) To briefly summarize the operations of my rotary moisture-transferrer.

It always transfers sensible heat from the air-stream of higher temperature to the air-stream of lower temperature.

As for its transfer of moisture. At optimum low rotation-speed for any given combination of carrier and impregnant, the loops (which plot the characteristics of the particles) are long, and moisture-transfer occurs from the air-stream of lower temperature to the air-stream of higher temperature, regardless of the relative vapor-pressures of the two streams. But at high rotation-speeds the loops contract to mere points, and moisture-transfer occurs from the air-stream of greater vapor-pressure to the air-stream of lesser vapor-pressure, regardless of the relative temperatures of the two streams.

Condensation of moisture on the particle from either air-stream, adds sensible-humidity to that stream, by increasing the temperature of the particle, and thence increasing the temperature of the air. Evaporation of moisture into the other air-stream, subtracts sensible heat from that stream.

The net effect of the above principles results in the three operations discussed in connection with Figures 6, 7, and 8, whereby:

(1) On a warm humid day, with the moisture-exchanger rotating slowly, the by-pass open, and the furnace on, the incoming air will be dehumidified and somewhat warmed. Other means, described but not claimed herein, are employed to then cool the incoming air.

(2) On a warm dry day, with the moisture-exchanger rotating slowly, the by-pass open, and the furnace off, the incoming air will be humidified and somewhat cooled. The other means, above mentioned, are then employed to further cool the incoming air.

(3) On a cold day, with the moisture-exchanger rotating rapidly, the by-pass closed, and the furnace on, the incoming air will be humidified and considerably warmed.

And now finally to describe a further improvement in rotary moisture-exchanger.

The amount of moisture transferred impregnant, or of any other hygroscopic salt or combination of salts, or of one of the glycols, or of any other impregnant, to be used to impregnate excelsior, corrugated asbestos paper, or other air-exchanger materials, is extremely important.

It would naturally be supposed that the more impregnant the better, up to the maximum which the carrier will hold. It is true that the more impregnant the carrier, the more will both moisture and impregnant extract it from and give up to the air. But it turns out not to be true that we ought to employ the maximum non-water components of the impregnant which the carrier will hold; for I have found that this introduces an undesirable phenomenon, which I shall call "peeling," namely, that when my rotary moisture-transferrer stands still in humid atmosphere, a considerable portion of the moisture absorbed by the impregnant will drip away, carrying some of the impregnant with it, and reduces the efficiency of moisture-transferrer thereafter, unless and until the lost impregnant is replaced (whereupon the cycle is repeated). This has necessitated a compensating change (to be discussed hereafter) in the apparatus. Weeping is also messy, and subjects the apparatus to corrosion.

However, I have found that weeping can be effectively eliminated, in all atmospheres normally encountered, by reducing the weight of the non-water components of the impregnant by a given weight of carrier, to a fraction of the possible maximum which the carrier could carry. This fraction can be determined in either of two ways, and the resulting underimpregnation can be fully compensated for, in either of two ways, all of which will now be described.

Starting with a given carrier and an impregnant of chemical composition definite except as to amount of water-dilution, it is a simple matter to determine by cut-and-try the amount of dilution which will reduce the carrier to be "fully impregnated," which term I define as meaning that the carrier is impregnated by soaking it with the maximum quantity of the impregnant which the impregnation which the carrier is capable of holding when the non-water components of the impregnant are in an aqueous solution of such strength as to be in equilibrium with an atmosphere of 35% relative humidity.

The carrier is then underimpregnated, according to one or the other of the following two formulas:

(1) To a "degree of underimpregnation" of approximately one-third the amount of non-water components required to fully impregnate; the quoted term meaning the quotient obtained by dividing the actual quantity of the non-water components of the carrier by the quantity per pound of carrier required to fully impregnate the carrier.

(2) To a degree of underimpregnation such that the impregnant solution will be in equilibrium (at equal temperatures) with an atmosphere of 90% relative humidity, or somewhat less.

The two alternative ways of compensating for either of the above methods of underimpregnation are as follows: (1) approximately double the thickness of the wall; or (2) increase the speed of rotation, which fact renders the second method of compensation preferable to the former.

Thus far we have considered as a humidity-changer the two air-passages, the fans, and my moisture-transferrer 15, hereby per se, or in combination with an air-heater 52 to reactivitate the hygroscopic packing in the moisture-transferrer, or in further combination with my by-pass 23. But if we still further add my heat-transferrer 27, and specify slow rotation for my moisture-transferrer, the resulting subcombination of my complete universal "air-conditioner, can still be regarded as merely a humidity changer. This subcombination without the addition of further features, has many uses, such as in chemical processes or storage rooms, for which dryness rather than coolness is the predominating consideration. Or it could be employed as a dehumidifying unit for air-conditioning, the cooling being supplied in some other manner than in my own universal air-conditioner.

Let us, then, consider this subcombination by itself. See Figure 1. The air in the upper passage passes to the left through the slowly rotating moisture-transferrer 15, after which the non-dehumidified or least-dehumidified portion of the air is carried off through by-pass 23. This by-passed air carries all or practically all of the sensible-heat which has been transferred into the upper air-stream by the moisture-transferrer. The non-by-passed dehumidified air, carrying the heat of condensation resulting from its dehumidification, then has practically all of this heat extracted from it by my very efficient heat-transferrer 27, and then passes on for whatever use may have been planned for it.

Meanwhile the air in the lower passage, from what-
ever source derived, passes in countercurrent toward the right. First, it extracts from heat-transferrer 27 all the heat which that heat-transferrer extracted from the upper air. Then it is mingled with the hot air from bypass 23. Then it is further heated by air-heater 5. Then its heat, acquired in all these ways is utilized to dry the hygroscopic packing of moisture-exchanger 15, and thus reactivate the moisture exchanger.

The chief feature of all this is that nearly all the sensible-heat put into my moisture-transferrer is recaptured by means of my bypass, and nearly all the heat of condensation developed by dehumidifying the upper air-stream is recaptured by means of my heat-transferrer, and all this recaptured heat is reused (by preheating the reactivation air) to help reactivate my moisture-transferrer, thus greatly reducing the load on my air-heater.

Having now described the various features and components of my invention, I wish it to be understood that my invention is not to be limited to the specific details herein described.

1. A rotary cylindrical transferrer for use in an air-conditioning unit, to transfer, between two air-streams passing through said unit, a thermodynamic characteristic of air, said transferrer comprising: a wheel-like casing, having spokes, a hub, and a rim, all impermeable, and all of the same thickness; each spoke being divided into sectors, each of which being filled with a composition of matter, which composition consists of an air-permeable carrier impregnated with a water-solution of an hygroscopic substance the quantity of whose non-water component is not less than the quantity of such components which, in water-solution in equilibrium with an atmosphere at 90% relative humidity, would produce weeping from the carrier.

12. A rotary wheel-shaped moisture-transferrer, divided into sectors, each sector being substantially filled with a composition of matter, which composition consists of an air-permeable carrier impregnated with a water-solution of an hygroscopic substance the quantity of whose non-water component is not less than the quantity of such components which, in water-solution in equilibrium with an atmosphere at 90% relative humidity, would produce weeping from the carrier.

References Cited in the file of this patent

UNITED STATES PATENTS

1,206,977  Batten Dec. 5, 1916
1,481,221  Nuss Jan. 15, 1924
1,541,147  Ikeda et al. June 9, 1925
1,583,238  Saidler May 4, 1926
1,912,784  Miller et al. June 6, 1933
2,273,227  Robie Nov. 26, 1940
2,227,773  Warren Jan. 7, 1941
2,302,807  Shoeld Nov. 24, 1942
2,503,523  Stuart Apr. 11, 1950