United States Patent [19]

Dufour et al.

[11] **3,774,374**

[45] **Nov. 27, 1973**

[54] **ENVIRONMENTAL CONTROL UNIT**

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[22] Filed: **June 9, 1971**

[21] Appl. No.: **151,349**

[52] **U.S. Cl.** **55/316,** 55/34, 55/163, 55/208, 55/222, 55/233, 55/270, 55/312, 55/388, 62/94, 165/7, 237/17

[51] **Int. Cl.** **B01d 53/06**

[58] **Field of Search** 55/34, 163, 208, 55/269, 390, 77, 222, 233, 270, 312, 316, 388; 165/6, 7, 105; 62/94, 271; 237/17

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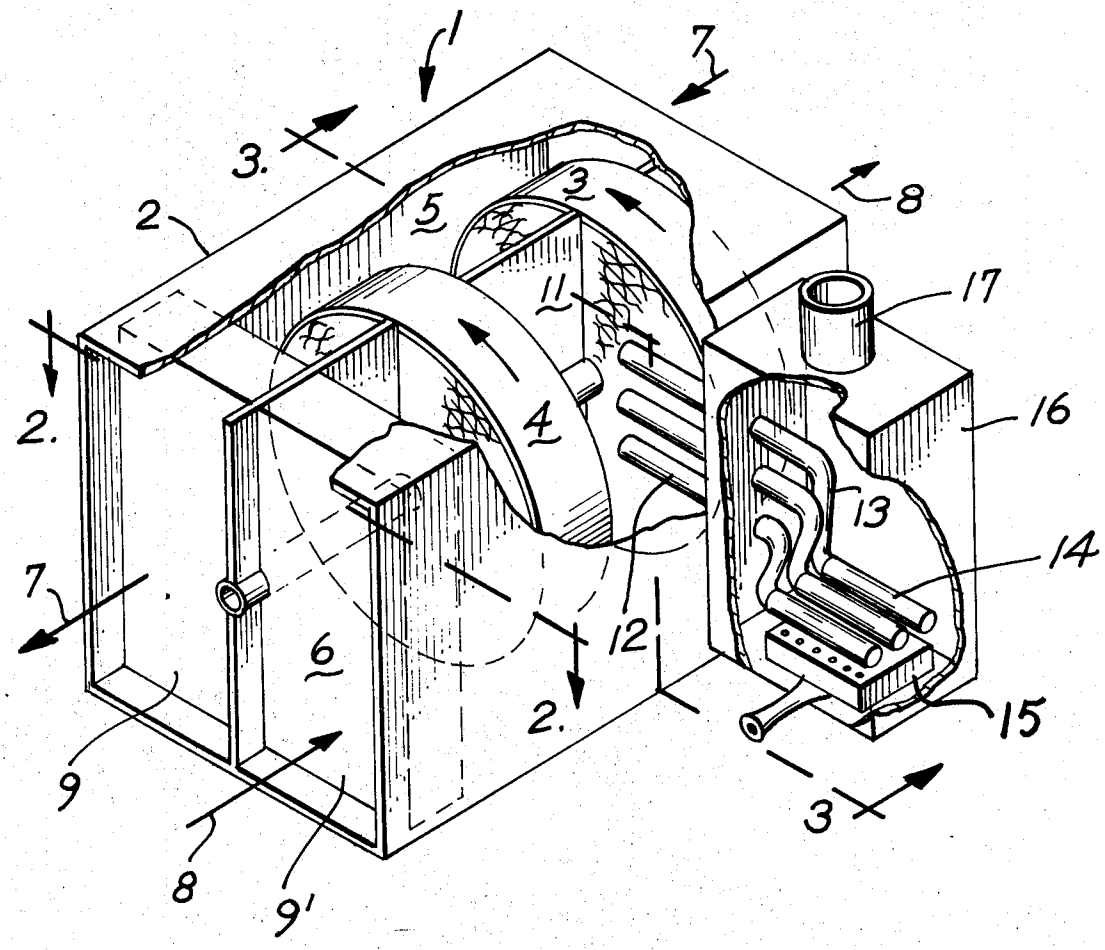
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[57] **ABSTRACT**

The application discloses an improved environmental control unit using in unitary combination a heat pipe as the heat source for the regeneration of the L-wheel. The heat pipe contains sodium metal which is vaporized by heating one end of the pipe in a firebox remote from the environmental control unit. The other end of the heat pipe extends into the heating section just upstream from the L-wheel. There, the air passing over the heat pipe surface, which optionally may be finned, causes sodium vapor in the pipe to condense, thus giving up its latent heat of condensation to the air stream, heating it to a temperature sufficient to dry the wheel. The improved heat pipe is efficient, safe, easily controllable and self-adjustable.

4 Claims, 3 Drawing Figures



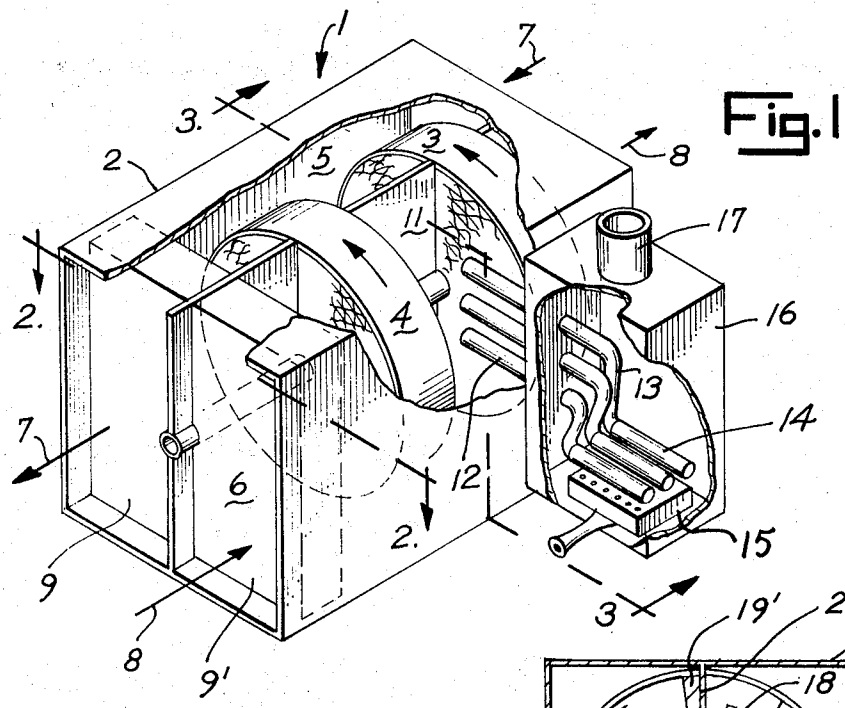


Fig. 1

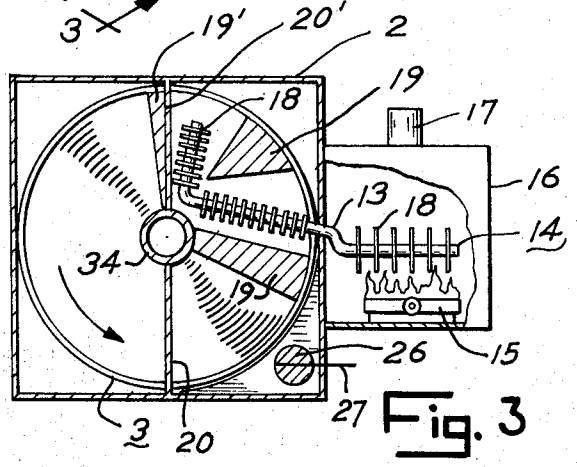


Fig. 3

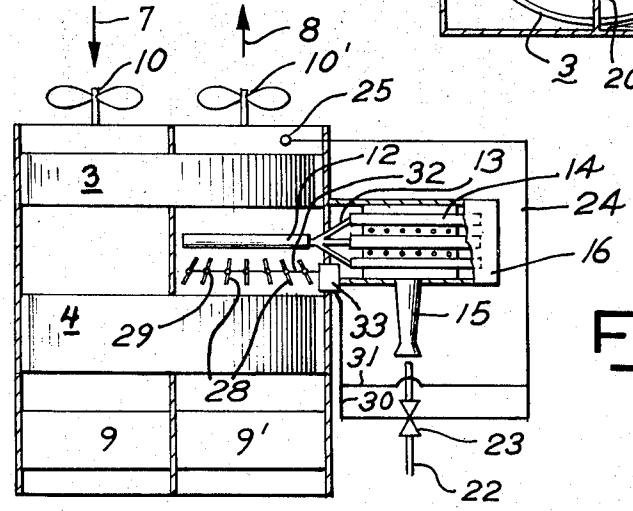


Fig. 2

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ENVIRONMENTAL CONTROL UNIT

BACKGROUND AND FIELD OF THE INVENTION

This invention relates to environmental control units which provide cooling in the summer, heating in the winter, and year round control of humidity with effective removal of dust and pollen. In particular, the unit of this invention employs an improved heating section utilizing a heat pipe for providing highly uniform heat transfer to the air stream passing thereover, and which is self-adjusting to variations in the air stream temperature and volumetric flow.

Environmental control units of the so-called Munters type (hereinafter called MEC units) operate on the principle that dry, warm air can be simultaneously cooled and humidified by contacting it with water. In geographic areas where the air is both warm and humid, it must be dried before it can be cooled by evaporation. The MEC unit incorporates both these cooling and drying functions in an assembly which utilizes a gas burner in conjunction with a rotating desiccant wheel to remove moisture from the outside air. During the heating season, an MEC unit can be used to warm and humidify cold, dry air by making minor changes in the unit's operating cycle. Typical examples of these units are shown in Munters U.S. Pat. Nos. 2,926,502 and 3,009,540 and in the patent to Pennington 3,398,510 and patents cited therein.

The essential parts of an MEC unit are two, treated rotating asbestos wheels, one operating as a desiccant support and the other as a heat exchanger. The wheels employed in the system are basically rolls of corrugated material, wound so that there are thousands of passages aligned parallel to the axis of the wheel and to permit the free flow of air therethrough. These wheels are spaced apart laterally and operate in combination with a gas burner for air drying and a water curtain for cooling and rehumidification.

During the cooling operation, outside ambient air is continuously drawn into the rotating, desiccant-treated L-wheel where moisture is removed. The wheel is so named because it removes moisture from the air and liberates latent heat of absorption and adsorption to the air passing therethrough. Thetemperature of incoming air is thus considerably increased. Heat is then removed from this air by the rotating S-Wheel, so named because it removes the sensible heat from the incoming air. The air exits from the S-wheel as tempered, dry air. This tempered, dry air then passes through a water curtain, ordinarily in the form of an E-pad structure, named such after its function as an evaporative pad. The air is further cooled by evaporation and rehumidified to the desired condition by passage through the E-pad before it is delivered to the conditioned space.

The second half of the cycle is that of regeneration, which is accomplished by exhausting air from the conditioned space through the water curtain in the E-pads where it is further cooled by evaporation. This cooled exhaust air provides the means for thermally regenerating the S-wheel which has rotated now into the regenerative half of the unit. The exhaust air picks up heat from the S-wheel which correspondingly is cooled and rotates into the incoming stream, there to pick up heat from the incoming air and thus completing its aspect of the cycle. The exhaust air which has been warmed by the S-wheel is then conventionally further heated by means of a gas burner placed in the heating section of the unit, which heating section is disposed between the S-and the L-wheels. The burner raises the temperature of the regenerating air to a high value, on the order of 500° F, and it is thus relatively dry. This relatively dry, hot air and the flue products pass through the L-wheel. Because the air is relatively dry, it removes the moisture from the desiccant material adsorbed onto the L-wheel, thus effecting moisture regeneration of the L-wheel so that it can continuously remove moisture from the outside air which is taken into the system by rotation of the L-wheel into the incoming side of the machine.

For the heating season, an MEC unit has a capability of delivering heated, filtered and humidified air to the conditioned space. Conversion of an MEC unit from cooling to heating is accomplished very simply by stopping rotation of the S-wheel and increasing the speed of rotation of the L-wheel. Unlike most air conditioning systems, in both the heating and cooling cycles, an MEC unit can utilize 100 percent outside air. In addition, because of the use of the water curtain, removal of dust and pollen from the air can be achieved before it enters the conditioned space.

These units are not without their problems. For one, they are relatively large and heavy and consume both water and gas, as well as an electric power source for rotation of the wheels and air handling by means of fans.

It is typical in conventional MEC units to utilize an open burner system in the heating section to provide the heat input to the regenerating air for drying of the L-wheel. However, this open burner system has many serious drawbacks. Primary among these is the possiblity that flue products will enter the incoming air. This occurs in two ways: first, if the air pressure in the regeneration half of the unit is greater than the pressure in the incoming half, gas leakage onto the incoming side might occur between the baffles and seals dividing the unit into the two halves, the incoming and regeneration halves. The second manner in which the flue products might enter the incoming air is due to the fact that as the L-wheel rotates into the incoming side from the regneration side, a small amount of gas is trapped in the actual passages through the wheel.

A second drawback to the open burner system is that reaction can occur between the flue products and the salts used as drying agent desiccants in the L-wheel. Typical salts are lithium bromide or chloride. However, the high temperatures and flue products components could react with such salts, liberating halogen which even in a few parts per million would not be tolerable in the conditioned space. Further, an open flame is both difficult to modulate and requires relatively complex ignition systems because the burner is located in a moving air stream.

Still further, the S-wheel typically is of asbestos coated with a wax overcoat to prevent moisture absorption or adsorption thereon. However, the typical wax coating is highly flammable, and the flammability of this coating requires the S- and L-wheels to be spaced relatively far apart, thus increasing the size of the unit.

In the case of large MEC units, for example, on the order of 3-ton sizes used for residential air conditioning, it is difficult to house a burner delivering the required 100,000 BTU/hr. capacity in a reasonably sized unit.

Open-flame burners also suffer from the fact that a uniform heat flux is very difficult to impart to the regenerating air stream because of the changes in the air flow patterns. The primary prior art approach to the solution of these problems has been to provide indirect heat sources in the form of burner tubes. These are shown typically in U. S. Pat. Nos. 3,144,901 to Meek and 3,251,402 to Glav. Typically, these burner tubes are inverted U-shaped tubes, one end of which is flared to receive a gas burner therein. The gas burner is oriented so that the flame extends into the tube. Typically, the opposite end of the tubes is either open, or holes are drilled along the length of the tube to provide flue gas a heat outlet. The open end of the tube or the holes provide, in coaction with the moving air stream, a negative pressure which helps aspirate the burner and draw the flame around the U-shape of the tube. In addition, complex fin patterns of unequal spacings are disposed along the tubes to compensate for non-uniform air flow. However, in some systems the tubes are still open for exhausting the flue products into the regenerating air stream. Thus, the possibility still exists for flue products to enter the incoming air and for reaction to occur between flue products and the haologenated salts used as drying agents on the L-wheel.

Further, where such conventional indirect heaters are used, the heat transfer is very inefficient and thermal response is quite slow. Thus, in the case where outside conditions can change relatively rapidly, the amount of heat required for adequate drying of the L-wheel may increase or decrease faster than the heating tubes can adjust to the changed requirements. Where the heat output is required to be rapidly increased and the indirect heaters are too slow in response, the L-wheels do not adequately dry and the temperature of air delivered to the interior rises rapidly. Conversely, where the heat required is lowered because outside air is drier, the indirect sources may deliver too much heat, thus causing breakdown of the halogenated salts, liberating noxious bromine or chlorine, in part into the incoming air stream.

THE INVENTION

Objects

It is among the objects of our invention to provide an improved environmental control unit having a more efficient, safer, and more easily controllable heat transfer unit.

It is another object of this invention to provide an improved apparatus and method for regenerating the L-wheel in an environmental control unit.

It is still another object of our invention to provide a heat source which overcomes the difficulty present in the prior art with open-flame heat sources and indirect heat units.

It is another object of our invention to provide an improved heating means for heating the regeneration air stream, which is self-adjustable and responsive to varying conditions of the air passing in contact therewith.

Still further and other objects of our invention will be evident from the description, which has reference to the following figures:

FIG. 1 is a schematic perspective view of our invention;

FIG. 2 is a plan view of the invention shown in FIG. 1; and

FIG. 3 is a view of the heating section of one embodiment of our invention taken along the line 3—3 in FIG. 1.

SUMMARY

We provide an improved environmental control unit which employs a bank of heat pipes in the heating section of the unit. One end of the heat pipes extends into the regenerator heating region and delivers heat to the air passing through the regenerative half of the unit. The other ends of the heat pipes extend into a separately enclosed fire box wherein there is disposed a gas burner. The burner is in flame contact with the evaporative end of the heat pipe. The heat evolved by the burner first melts, and then vaporizes, a heat transfer material, such as sodium, mercury or water contained within the sealed heat pipe. The vapor then migrates to the condenser end of the heat pipe disposed in the heating section of the environmental control unit. Air passing over the condenser into the pipes extracts heat therefrom causing the vapor of sodium, mercury or water to condense on the walls and flow back as liquid sodium, mercury or water to the evaporative end wherein the cycle is repeated.

The heat pipes are self-adjusting because they are responsive to the total heat quantity required by the air. Thus, as the air temperature drops, or the volume of air increases in a given section, the pipe in that region becomes relatively cooler and more sodium vapor will condense at that point. As the sodium condenses, it returns as liquid sodium to the evaporative end of the pipe. At the same time, more hot sodium vapor will migrate to the cold spot, thus delivering up more latent heat of condensation as the vapor condenses. Conversely, where the air flow is lower or the air is warmer, less vapor will condense. Thus, the air downstream of the heat pipe, entering the L-wheel, is relatively more uniformly heated than with ordinary open flames or indirect heat sources. The mercury or water-containing heat pipes operate the same way.

It should be understood that the heat pipe is a unique device, and although not per se part of this invention, it is not to be confused with an indirect heat source. In indirect heat sources, there is no simple means of rapid thermal response and the indirect heat sources are not selfregulating, as just above described with respect to the heat pipe. Typically, heat pipes are sealed tubes containing a material which at ordinary room temperatures is a solid or a liquid (such as water or mercury) but which may be heated through at least one phase change, e.g., from the liquid to the vapor phase. The heat pipe is completely sealed and only partially filled with the heat transfer material, so that upon vaporizing the pipe may retain the pressure of the vapor. The temperature of the evaporative end of the heat pipe is ordinarily adjusted so that it is slightly above the boiling point of the heat transfer material. Thus, the heat transfer is ordinarily that of the change in phase from vapor to liquid at the condenser end of the pipe, rather than the transfer of the heat capacity of the vapor itself. Preferably, the heat transfer material has a high latent heat of condensation to provide effective thermal transfer to the air. Optionally, the heat pipe may have fins for control of air flow thereover, or for efficient heating of the tube in the evaporative end. The burner, being in its own firebox, vents the flue products directly to the outdoors rather than into the regenerating air

stream, thus obviating the difficulties of flue products reacting with the desiccant materials or escaping into the incoming air stream.

DETAILED DESCRIPTION

Turning now to the figures, and particularly with reference to FIGS. **1** and **2**, MEC unit **1** is enclosed in a housing **2** which comprises an L-wheel **3** and an S-wheel **4** laterally displaced, but axially aligned as indicated. Baffles **20, 20'** disposed perpendicular to the central axes **21, 21'** of the wheels divides the housing into an inlet half **5** and a regenerative half **6.** Outside air is drawn into the unit **1** by means of fan **10** wherein it passes through the input side of the L-wheel **3.** The air is dried and its temperature raised by the latent heat of absorption. The heated, dehumidified air in inlet side **5** than passes through the S-wheel **4** where it is cooled and remains relatively dry. Thereafter, the air passes through the inlet side evaporative pad **9,** and thence through the conditioned air inlet **7** into the room to be conditioned. The E-pad **9** further cools the air and humidifies it to the desired degree for use in the conditioned space.

On the regenerative half of the cycle, air from the space to be conditioned passes through the exhaust outlet **8,** through E-pad **9'** where it is further cooled and its humidity increased. The air then passes through the S-wheel which has rotated counter-clockwise as shown in FIG. **1.** The wheel, having picked up heat from the incoming air, is thus relatively hot and is cooled by the relatively cool, moist air passing through the evaporative pad **9'.** The cooled S-wheel is thus regenerated for return to the incoming side of the unit to complete its portion of the cycle. The air passing through the S-wheel is heated. This relatively warm, moist air then passes in contact with the condenser end **12** of the heat pipe **13** disposed in the heating section **11** of the unit. The heat picked up from the heat pipe raises the temperature of the air so that it is quite hot and therefore relatively dry. This relatively dry, hot air then passes through the moist L-wheel **3** which has rotated counterclockwise from the inlet half of the unit to the regenerative half. The hot air, being relatively dry, picks up more moisture from the wheel, thus drying out the wheel for return to the inlet side and thus completing its half of the cycle. The exhaust air is drawn out from the regenerative half by fan **10'** and exhausted to the outdoors as very hot, very moist air.

Disposed in firebox **16** adjacent to the MEC unit housing **2** is burner **15** in flame contact with the evaporative end **14** of heat pipe **13.** The condenser end **12** and evaporative end of the heat pipe is connected by an intermediate section which provides for the migration of the vapor of the heat transfer material in the heat pipe. The burner **15** is provided with fuel gas line **22,** and the firebox is provided with flue **17.** As can be seen from FIG. **1,** the flue **17** does not communicate with the exhaust air in the regenerative half of the MEC unit. In a preferred embodiment, as shown in FIG. **2,** the firebox will be disposed out-of-doors so that the flue **17** can exhaust directly thereto. However, it should be understood that the firebox may be integrated within the MEC unit housing **2** so long as the burner is not exposed to the moving air stream and the flue does not exhaust to the regenerative air stream or the inlet side of the MEC unit.

As can be seen by comparing FIGS. **1** and **2,** the evaporative end of the heat pipes may be disposed spaced apart horizontally, while the condenser end may be disposed vertically in the same plane, but spaced apart from each other. Thus, the heating section of the MEC unit can be made substantially smaller since it needs to be only sufficiently wide to accommodate the condenser end of the heat pipes and not the burner section. Optionally, the fuel gas line **22** may be provided with valve **23** which, via electrical connection or line **24,** is responsive to the temperature downstream of the L-wheel on the regenerative half of the unit, as by thermocouple **25.** As the temperature is sensed by thermocouple **25,** the flow of fuel to the burner may be increased or decreased as desired in any preset cycle. The thermocouple **25** may be replaced by a humidity sensor, and the burner likewise controlled in relation thereto, if desired.

Referring to FIG. **3,** the L-wheel is shown disposed within housing **2** from a position upstream of the heat pipe **13** disposed in the heating section **11.** In this particular embodiment, the condenser end of the heat pipe **12** is finned to provide for laminar air flow thereover. Likewise, the evaporative end of the heat pipe also has fins **18** thereon for a good thermal contact and heat transfer from the burner **15** disposed in firebox **16.** Alternatively, as shown in FIG. **2,** upstream louvers **28,** pivoted on pins **29** may adjustably regulate the air flow over the condenser ends of the heat pipes. The fins or louvers **28** may be adjusted by link **32** actuated by solenoid or other actuating means **33** in response to downstream conditions via line **31,** or in response to the gas flow to the burner via line **30.**

In addition to, or instead of, the fins, the baffles **19** may be disposed to cover a portion of the regenerative half of the L-wheel for control of the air flow or air amount. It should be understood that while baffling **20, 20'** divides the L-wheel in half, the input or regeneration "half" of the wheel need not be a 180° section of the wheel and may be more or less than that amount. In addition, as seen in FIG. **3,** a portion **19'** of the baffles may extend into the input side to provide for proper exhausting of the L-wheel as it rotates into the input side. In addition, this will prevent the very hottest portion of the L-wheel from being used, permitting it to be temperature equilibrated before use in drying the incoming ambient air.

In a MEC unit, the temperature of the regeneration air should be as high as is necessary to produce the required degree of dryness in the L-wheel, while at the same time it should not exceed temperatures that will injure the wheel. This is true regardless of the moisture load being handled by the drying wheel. At the same time, in order to conserve heat, the temperature of air leaving one section of the wheel should not reach its upper limit until that section of the wheel approaches the very end of the regeneration section as it rotates into the inlet side of the unit. This combination of characteristics requires that a regeneration heating means provide a stream of uniformly heated gases controlled at a constant temperature measured before entering the wheel, and controlled in volume in response to temperature sensed on the outlet of the wheel section close to where the regeneration section ends and the purge section, delimited by baffle **19'** (in FIG. **3**), begins. The air used for regeneration is also that used to provide some of the sensible heat removal from the dried air.

With this usage, a constant volume is necessary. Therefore, in regulating regeneration, any throttling of air to control the L-wheel temperature must be accompanied by the opening of the bypass to provide a constant total air flow. For control of the air volume, butterfly valve **26,** rotatable on pivot **27,** is provided to permit air to bypass the L-wheel. This bypass and valve assembly may be in a hollow central hub of the wheel shown as **34** in FIG. **3.** BY temperature sensing mechanism analogous to that shown for control of valve **23** in association with the burner **15** and fuel line **22,** the opening of the valve can be adjusted responsive to a thermocouple (not shown) disposed on the outlet side of the L-wheel near the dividing line between the regeneration section and the purge section, delimited by baffle **19'**.

One advantage of our invention lies in the fact that the heat pipe may be arranged to absorb the heat from a conventional atmospheric gas burner without particular concern as to the uniformity of heat distribution over the entire evaporative end of the heat pipe. In addition, the use of an external atmospheric burner permits the use of a simple ignition system which will be less likely to fail than the complex ignition systems presently required to ignite a gas burner located in the moving air stream. The heat dissipating, or condenser, end **12** of the heat pipe **13** has a uniform temperature due to the uniform pressure of the vapor in the tube. The tube may be configured, as by bending as seen in FIG. **3,** so that it will impart uniform temperature to the flowing air. The creation of hot spots or of general overheating is greatly reduced due to the self-regulating nature of the condensation which occurs within the tube. Temperatures below the drying wheel can be controlled by a simple thermostat. The volume of regenerating air and consequent exit temperature from the wheel can be regulated by the temperature controlled bypass **26.** Pressure differentials between the inlet half **5** and the regenerative half **6** are no longer critical since there is no danger of contamination of room air by flue gases. Likewise, there is no danger of contaminating or degrading the desiccant material since the condenser end of the heat pipe is not a source of flue gas exhausting therefrom. Likewise, there is no open flame or direct radiation hazard to the S-wheel, thus preventing flame hazards and providing for a shortening of the distance between the L- and S-wheels.

These general principles are further shown by reference to the following specific example which is meant to be illustrative and not limiting of the invention.

SPECIFIC EXAMPLE

A **2**-ton MEC unit is provided with a heat pipe having a condenser end length of 30 inches in the configuration shown in FIG. **3.** Within the regenerative section, the effective outside surface temperature of the heat pipe is 1200° F, which provides an average temperature of air leaving the heating section of 350° F. This is an increase from the average temperature of the air leaving the S-wheel of 180° F for an air flow to the heating section and heat pipes disposed therein of 2682 lb./hr. The required heat input for the **2**-ton unit is 80,000 BTU/hr., resulting in a log mean Δt of 910° R. The hA value is 88 BTU/hr. —° F. For laminar flow with low pressure drop, the h value would be 30 BTU/hr.— ft.^{2}—° F. The area required would thus be approximately 3 square feet. The 30 inch length heat pipe in the condensing section provides 7.9 sq. ft. of primary area which is more than twice required.

The heat conductive material in the heat pipe is sodium, which has a designed thermal power output of 185 BTU/hr.—in^2. For the required heat input of 80,000 BTU/hr., 433 sq. in. of primary area is required. This is easily satisfied by the 7.9 sq. ft. of primary area which is 1140 sq. in. Thus, all conditions of the MEC unit are met without overloading the heat pipe.

It should be understood that modifications and variations in the specific embodiments of our invention described above can be made without departing from the spirit thereof.

We claim:

1. An environmental control unit comprising a housing; baffle means disposed within said housing, dividing it into an inlet section and a regeneration section having a regeneration air stream passing therethrough; an S-wheel and an L-wheel disposed in said housing to rotate between said inlet section and said regeneration section; a heating section disposed in siad regeneration section and between said L-wheel and said S-wheel, which further includes:

a a plurality of heat pipes, each heat pipe having an evaporative section, a condenser section and an intermediate portion connecting said evaporative and condenser sections,

b each of said heat pipes being disposed with its condenser section in said heating section in a vertical plane in vertical, spaced apart alignment with each of the other condenser sections,

c means defining a firebox disposed exteriorly of said regeneration section and having disposed therein a fuel gas burner creating a flame in contact with and in heat transfer relation with the evaporative section of each of said heat pipes, such evaporative sections being spaced apart from each other horizontally in said fire box,

d said firebox being disposed with relation to said regeneration air stream to isolate the burner combustion products from said air stream,

e a flue for exhausting combustion products from said burner exteriorly of said regeneration section and without passing through said regeneration section,

f louver means comprising a plurality of pivotally mounted louvers disposed in the heating section upstream of the condenser sections of the heat pipes for controlling the volume of air flowing through said regeneration section and to provide laminar air flow over said heat pipes in a predetermined path,

g said fuel gas burner having a fuel gas line provided with a valve means for regulating the flow of fuel gas to said fuel gas burner,

h temperature sensing means disposed in said regeneration section adjacent the outlet side of said L-wheel for sensing the temperature of the gas in said regeneration section exiting said L-wheel,

i operating means operatively connected to said louver means for adjustable pivoting said louvers for adjustably regulating air flow over said condenser sections,

j actuating means coupled between said temperature sensing means and said valve means for controlling the flow fo fuel gas to said fuel gas burner in re-

sponse to the temperature sensed by said temperature sensing means, and

k said actuating means being further coupled between said temperature sensing means and said operating means for controlling the position of said louvers in response to the temperature sensed by said temperature sensing means, and

l said louver means, condenser sections and said heating section being so operatively constructed and arranged that all of the air passing between the louvers flows in laminar air flow heat exhange relationship over said condenser sections in said predetermined path,

Whereby said heat pipes provide a relatively uniform heating of said regeneration air stream and are thermally selfadjusting and rapidly responsive to temperature and volumetric air flow changes in said regeneration air stream.

2. An improved environmental control unit as in claim **1** which includes baffles disposed in association with the configuration of said pipe to direct air flow thereover in a predetermined manner.

3. An environmental control unit as in claim **1** wherein said heat pipe contains a material selected from sodium, mercury or water as the heat transfer material.

4. An environmental control unit as in claim **1** wherein said means defining a firebox is located exteriorly of said environmental control unit housing.

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