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Adsorption Air Wells

Solar adsorption device for obtaining water
CN2573556 // CN2573555

[PDF]

Inventor: JI JIANGANG [CN] // LI LIXIN [CN] (+1)

The utility model relates to a solar adsorption type water obtaining device, which mainly solves the technical problems, such as the simplification of structure, etc. The utility model adopts the technical proposal that openings are arranged at the top part and on the side edges of a tank body, doors are arranged on the openings on the side edges, an adsorbent bed is contained in the tank body, the maximum size of the adsorbent bed is slightly smaller than the corresponding openings on the side edges, a photic glass plate is fixedly embedded on an opening at the neck part of the tank body, and a water guiding gutter which is connected with a water purifying device is arranged on the oblique lower side end of the tank body. The utility model is suitable for being used for obtaining water from air in the fields, such as desert, sea, or the field with insufficient water source, etc.

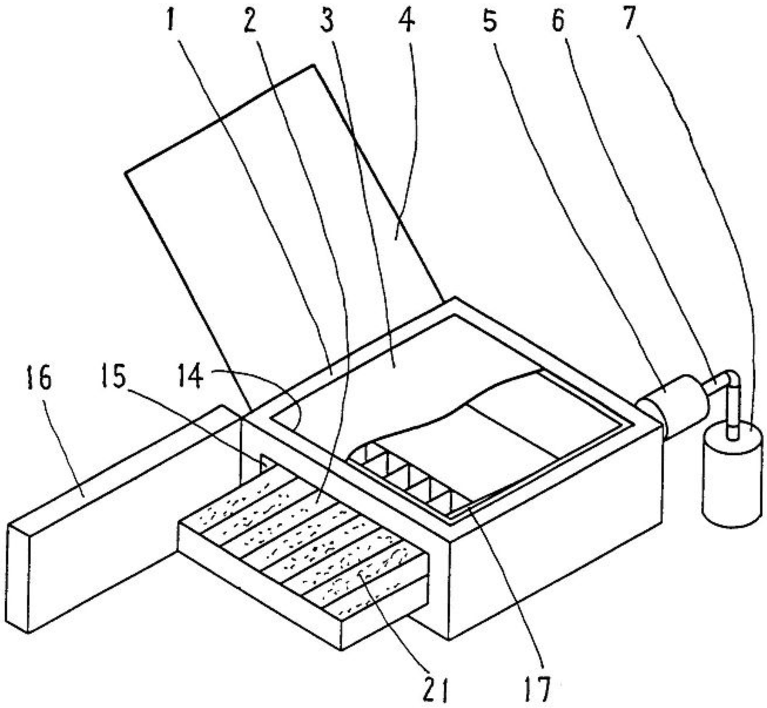
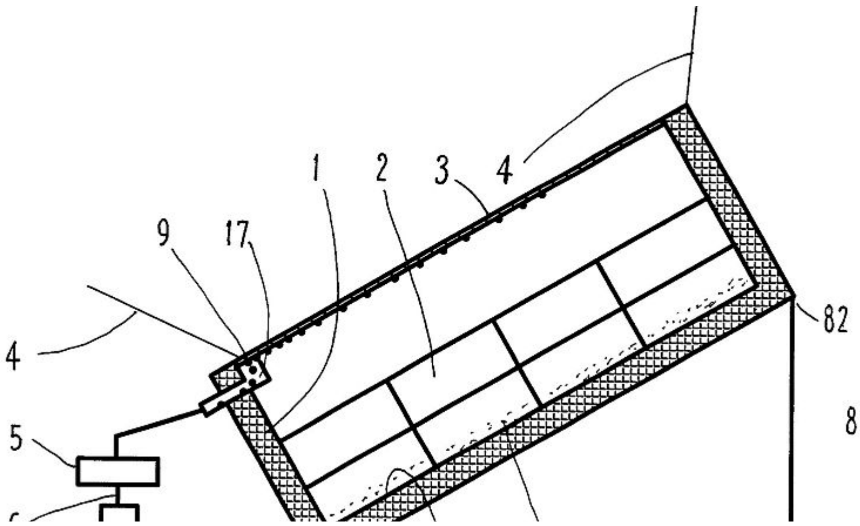


图 1



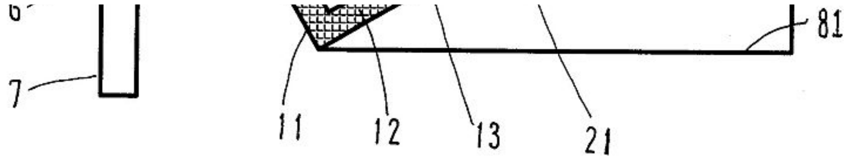


图 2

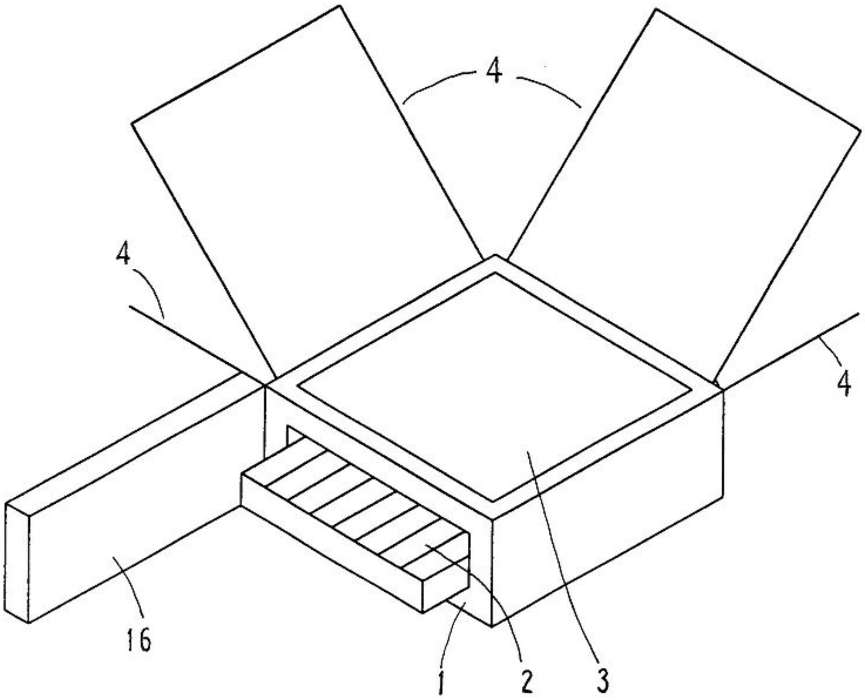


图 3

High-hydroscopicity adsorbent and its prepn
CN1403192

[PDF]

The present invention aims at solving the technological problem of raising the water adsorbing amount. The solution is using **superlarge molecular sieve HAM-W and calcium chloride** to constitute the high-hydroscopicity adsorbent. The preparation of the high-hydroscopicity adsorbent includes the steps of preparing material, mixing, sealed setting, rinsing, heating, etc. The adsorbent is suitable for drying article in industry and daily life, and may be used in adsorbing air to produce water.

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http://www.sciencedirect.com/science/article/pii/S0011916407002688

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New composite adsorbent for solar-driven fresh water production from the atmosphere

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Abstract - In this paper, a new highly-efficient water-selective composite adsorbent for solar-driven fresh water production from the atmospheric air is presented. It is synthesized by a patented **ultra-large pore crystalline material MCM-41** as host matrices and **calcium chloride** as a hygroscopic salt. Experimental data demonstrate that adsorption capacity of the new composites is as high as **1.75 kg/kg dry adsorbent**, which is higher than composites synthesized by silica-gel and calcium chloride, and the adsorption rate of the new composites is also found attractive. The desorption characteristics of the new composites are also studied, and it demonstrates that it **can desorb more than 90% of the adsorbed water at lower heating temperature at about 80°C**. A solar-driven water production test unit using the new adsorbent is also presented and tested. The experimental tests of this developed unit demonstrated a feasibility of the fresh water production with the daily water productivity more than **1.2 kg/m2 solar collector area**.

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Preliminarily Study of Extracting Water from Air Utilizing Ship's Waste Heat from Cylinder Jacket Cooling Water

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This paper appears in: Computer Distributed Control and Intelligent Environmental Monitoring (CDCIEM), 2011 International Conference on
(19-20 Feb. 2011) page(s): 1632 - 1636

Abstract -- Feasibility of extracting water from air on ship's environment was evaluated on a general cargo ship navigating between Dalian and Hamburg at May. Firstly, analysis of the energy equilibrium among the heat evaluated from fuel consumption rate and that distributed to different parts of the main engine system was carried out, an experimental unit employing the waste heat of the cylinder jacket water was then set up on the afterdeck nearby central air conditioning room. Two adsorption towers with the same size and capacity were design in consideration of the heat and mass transfer characteristic of the water vapor within the adsorbent bed of the silica gel and that of the composite compounded with calcium chlorate. Daily amount of water produced from the extracting unit and that from desalination plant were compared in terms of the main indices prescribed by the National Standard for Drinking Water. Results show that the waste heat of the cylinder jacket cooling water under normal working condition is enough to meet the need of the heat powering the extracting unit, **silica gel with pores larger than mesopore is a better adsorbent in marine environment**, the composite has a better performance in water vapor adsorption, but performance in both silica gel and the composite will be weakened on board. Results also reveals that the indices of water from the extracting unit and the desalination plant are all within the permissible range prescribed by the national standard. Conclusions are drawn that the monolith of the adsorbent and the flexible connection should be used to dampen the influence from the vibration and bumping of the ship.

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http://www.scirp.org/Journal/PaperInformation.aspx?paperID=4124
DOI: 10.4236/nr.2011.21002

Natural Resources, Vol.2 No.1, March 2011

Application of Solar Energy for Recovery of Water from Atmospheric Air in Climatic Zones of Saudi Arabia Open Access

Author(s) -- Ahmed M. Hamed, Ayman A. Aly, El-Shafei B. Zeidan

ABSTRACT -- In the present work, an investigation on the application of solar energy to heat a sandy bed impregnated with calcium chloride for recovery of water from atmospheric air is presented. The study also aimed at evaluating the effects of different parameters on the productivity of the system during regeneration. These parameters include system design characteristics and the climatic conditions. An experimental unit has been designed and installed for this purpose in climatic conditions of Taif area, Saudi Arabia. The experimental unit which has a surface area of 0.5 m2, comprises a solar/desiccant collector unit containing **sandy bed impregnated with calcium chloride**. The sandy layer impregnated with desiccant is subjected to ambient atmosphere to absorb water vapor in the night. During the sunshine period, the layer is covered with glass layer where desiccant is regenerated and water vapor is condensed on the glass surface. Ambient temperature, bed temperature and temperature of glass surface are recorded. Also, the productivity of the system has been evaluated. Desiccant concentration at start of regeneration is selected on the basis of the climatic data of Al-Hada region, which is located at Taif area, Saudi Arabia. Experimental measurements show that about **1.0 liter per m2** of pure water can be regenerated from the desiccant bed at the climatic conditions of Taif. **Liquid desiccant with initial concentration of 30% can be regenerated to a final concentration of about 44%**. Desiccant concentration at start of regeneration is selected on the basis of the climatic data of Al-Hada region. The climate of Taif city is dry compared with that for Al-Hada region. This method for extracting water from atmospheric air is more suitable for Al-Hada region especially in the fall and winter.

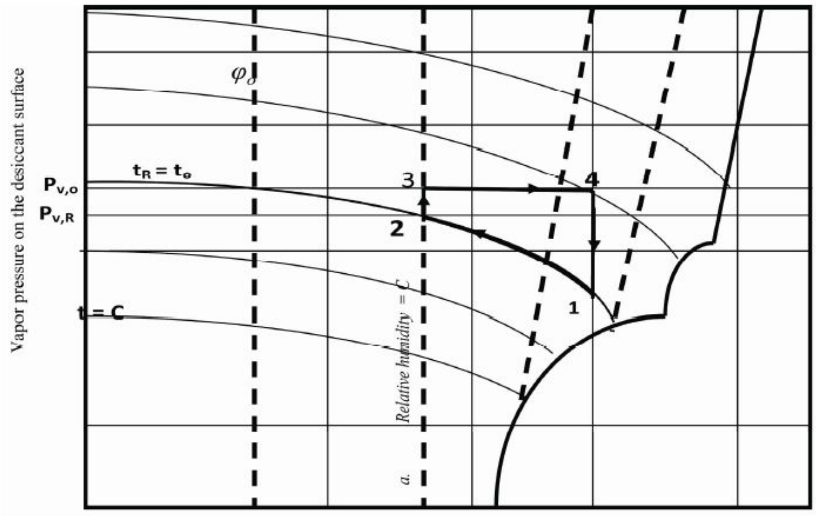


Figure 1. Absorption-regeneration cycle [1].

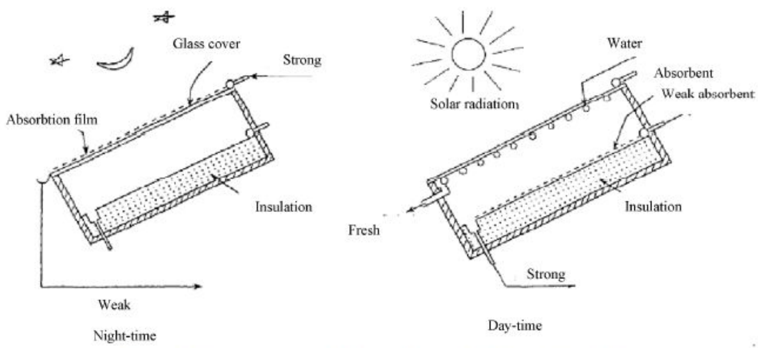
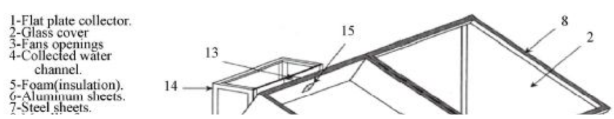


Figure 2. The system proposed by Abualhamayel, and Gandhidasan [14].



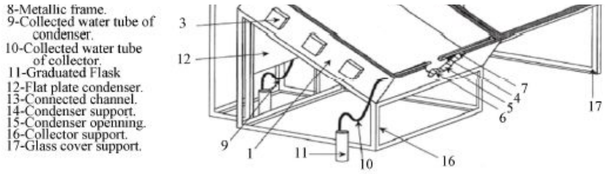


Figure 3. Schematic diagram of the experimental solar –desiccant collector for water recovery from air [15].

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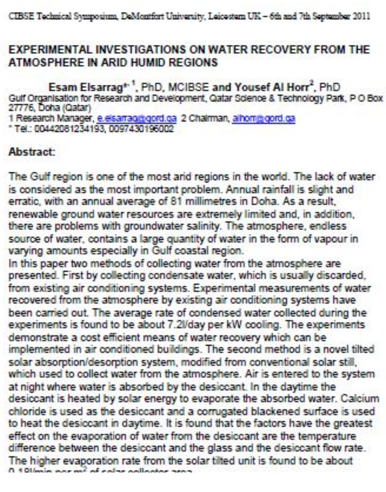
http://www.cibse.org/content/cibsesymposium2011/Water%20Recovery%20from%20the%20Atmosphere%20in%20Humid%20Climates_Reviewers%20comments.pdf

Experimental Investigations on Water Recovery from the Atmosphere in Arid Humid Regions

E. Elserrag & Y. Al Horr

[PDF]



CIBSE Technical Symposium, DeMontfort University, Leicester UK – 6th and 7th September 2011

EXPERIMENTAL INVESTIGATIONS ON WATER RECOVERY FROM THE ATMOSPHERE IN ARID HUMID REGIONS

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Abstract:

The Gulf region is one of the most arid regions in the world. The lack of water is considered as the most important problem. Annual rainfall is slight and erratic, with an annual average of 81 millimetres in Doha. As a result, renewable ground water resources are extremely limited and, in addition, there are problems with groundwater salinity. The atmosphere, endless source of water, contains a large quantity of water in the form of vapour in varying amounts especially in Gulf coastal region.
In this paper two methods of collecting water from the atmosphere are presented. First by collecting condensate water, which is usually discarded, from existing air conditioning systems. Experimental measurements of water recovered from the atmosphere by existing air conditioning systems have been carried out. The average rate of condensed water collected during the experiments is found to be about 7.2l/day per kW cooling. The experiments demonstrate a cost efficient means of water recovery which can be implemented in air conditioned buildings. The second method is a novel tilted solar absorption/desorption system, modified from conventional solar still, which used to collect water from the atmosphere. Air is entered to the system at night where water is absorbed by the desiccant. In the daytime the desiccant is heated by solar energy to evaporate the absorbed water. Calcium chloride is used as the desiccant and a corrugated blackened surface is used to heat the desiccant in daytime. It is found that the factors have the greatest effect on the evaporation of water from the desiccant are the temperature difference between the desiccant and the glass and the desiccant flow rate. The higher evaporation rate from the solar tilted unit is found to be about

0.18l/min per m^2 of solar collector area.

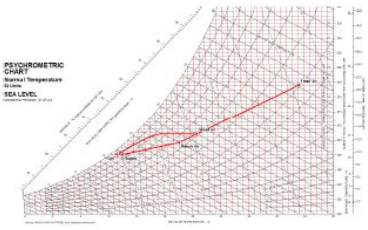

Fig 5 Air conditioning process in the psychrometric chart

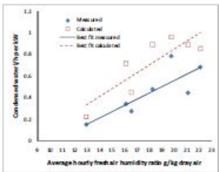

Fig 6 Relation between average hourly outdoor humidity ratio and collected water

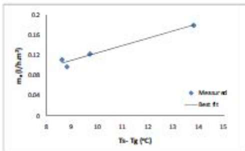

Fig 10 Relation between humidity ratio and evaporation rate

4.0 Conclusions

The lack of renewable water resources in Gulf Cooperation Council (GCC) countries is one of the most critical problems. A great portion of the freshwater demands is covered by desalinated water with a growth gap between supply and demand. Water of higher quality should be preserved for drinking purposes and should not be utilized for other purposes that may tolerate water of lower quality. The atmosphere in the Gulf coastal region contains large amounts of water.

This paper investigated experimentally two methods of water recovery from the atmosphere in hot humid climates. The water condensed from an existing 70kW air conditioning package unit was collected and compared with the calculated values. The quantity of water recovered showed a cost efficient means of water recovery, which can be implemented in the Gulf coastal regions as a means of water conservation.

A novel tilted solar absorption/desorption system, modified from conventional solar still, was tested to extract water from humid atmosphere. It was found that the main factors that have the greatest effect on the evaporation of water from the desiccant are the temperature difference between the desiccant and the glass, the desiccant flow rate. For higher evaporation rates it is vital to maximise the temperature difference between the plate and glass cover. Further investigations and modification to the tested system are essential to enable high evaporation rate and efficient condensate collection.

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http://www.mendeley.com/research/the-performance-of-two-adsorption-ice-making-test-units-using-activated-carbon-and-a-carbon-composite-as-adsorbents/

Carbon (2006), vol 44, Issue: 13, Pages: 2671-2680
DOI: 10.1016/j.carbon.2006.04.013

The performance of two adsorption ice making test units using activated carbon and a carbon composite as adsorbents

by L W Wang, R Z Wang, Z S Lu, C J Chen, K Wang, J Y Wu

USPAppln 2011232485
COMPOSITE DESICCANT AND AIR-TO-WATER SYSTEM AND METHOD

Inventor(s): **ELLSWORTH JOSEPH**

[See also : ELLSWORTH / Air Well]

A composite desiccant material is formed by a porous, absorbent substrate of PVA foam or non-woven fibrous sheet is soaked in a solution of a hygroscopic desiccant such as CaCl. The desiccant is held in pores or fibrous entraining areas sized ranging from 50 microns to 1000 microns. Thin sheets are arranged in a stack in a multi-chamber system, while in an absorption state, uses this stack in a main chamber to absorb H2O from atmospheric gas flowing through that chamber. In a regeneration state atmospheric flow is stopped and low-grade energy releases the H2O from the desiccant into that chamber. Fans circulate moist air through the main chamber and into an adjacent chamber for H2O transfer through or past a partially permeable barrier into a cooling/condensing area. Both H2O and dry gas may be produced.

FIELD

[0002] The subject relates to materials, methods, and apparatus for extracting water vapor from a gas. Particularly it includes methods and devices related to extracting water from atmospheric air via a hygroscopic material dispersed within an absorbent sheet material of effective form factor for sorption and for regeneration.

BACKGROUND

[0003] There are many materials identified as desiccants and many known configurations and systems employing desiccants to dry a gas. Systems include those using a solid desiccant and those using a liquid desiccant. In the case of systems based upon liquid desiccants, many existing concepts increase the exposed surface area of desiccant by spraying the desiccant in a mist. Besides the mechanism and energy required for such schemes the resulting chemical mist might, undesirably, be present in the output gas and output water. Solid forms of desiccant avoid these problems but generally do so at the cost of a relatively small exposed surface area per unit of mass leading to inefficiencies. Solid desiccants can also have relatively long regeneration times.

[0004] There is a need for a form of desiccant that provides a high ratio of surface area to mass in a convenient to deploy form factor. Also needed are systems employing such a material to dry a gas, preferably using low-grade energy in an efficient manner.

SUMMARY

[0005] Deficiencies in previous desiccant and air-to-water systems can be solved by a desiccant subsystem that can include a stack of spaced-apart thin sorbent sheets of a composite desiccant. The composite desiccant can be a sheet of a porous material with small pores for retaining moisture and larger pores allowing the flow of moist gas within its structure. The composite desiccant material is made up of a substrate of the sorbent sheet that contains dispersed particles of a hygroscopic chemical.

[0006] To enhance water retention capacity, the stack can be mounted perpendicular to the direction of gravity or acceleration. This can engender a more even distribution of held water with no low spot for water to collect and drip from.

[0007] A system of efficiently extracting water from air can be constructed with the desiccant stack attracting and retaining moisture in air fed to it and through it by fans. A control system can chose to operate the fans when conditions of humidity and the remaining capacity of the desiccant stack are conducive to efficient charging operation. A control system can further initiate a regeneration cycle when the availability of low-grade heat energy and the fullness of the desiccant stack are conducive to efficient regeneration operation. Further, a control system can initiate a condensing mode when the degree of moisture in a regeneration chamber is high enough relative to the temperature of an available cold source for efficient condensing operation. The condensing operation can involve a filter or membrane to differentially engender the passage of water molecules to be condensed versus other warm gases.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1A shows a photomicrograph at a magnification of 400* of a PVA foam dry;

[0009] FIG. 1B shows a photomicrograph at a magnification of 400* of the PVA foam of FIG. 1A damp;

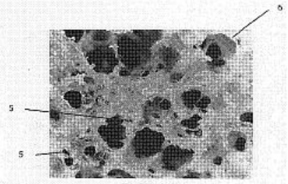


FIG. 1A

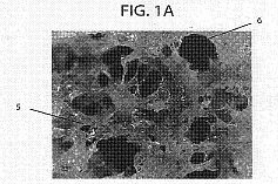


FIG. 1B

[0010] FIG. 1C shows a photomicrograph at a magnification of 400* of the PVA foam of FIG. 1A saturated with water;

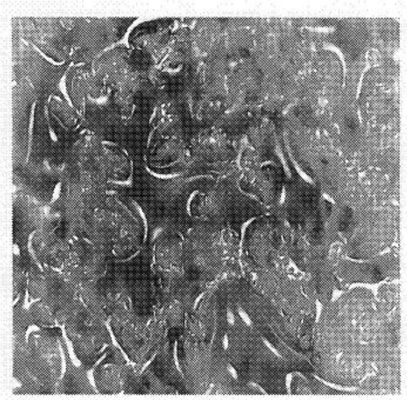


FIG. 1C

[0011] FIG. 2 shows a photomicrograph at a magnification of 400* of a human hair;

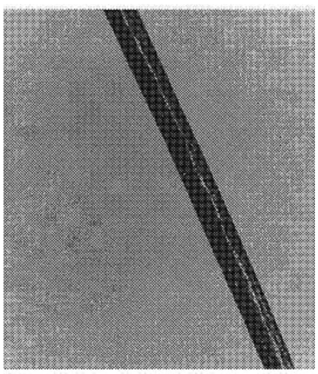
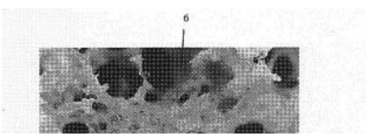


FIG. 2

[0012] FIG. 3A shows a photomicrograph at a magnification of 400* of a PVA foam with CaCl dispersed within its pores, dry;

[0013] FIG. 3B shows a photomicrograph at a magnification of 400* of the PVA foam with CaCl of FIG. 3A, damp;



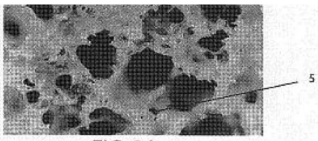


FIG. 3A

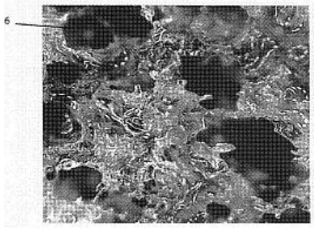


FIG. 3B

[0014] FIG. 3C shows a photomicrograph at a magnification of 400* of a non-woven rayon fabric, dry;

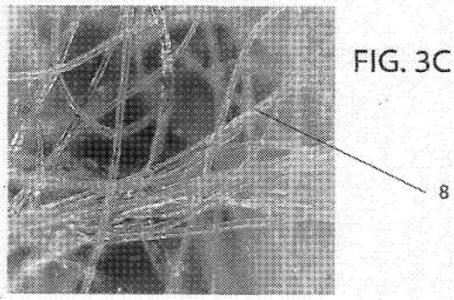


FIG. 3C

[0015] FIG. 4 schematically illustrates a sheet of a composite desiccant formed from a PVA foam with disbursed CaCl;

[0016] FIG. 5 schematically shows a stack of desiccant sheets in perspective and an airflow direction;

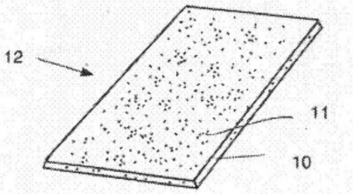


FIG. 4

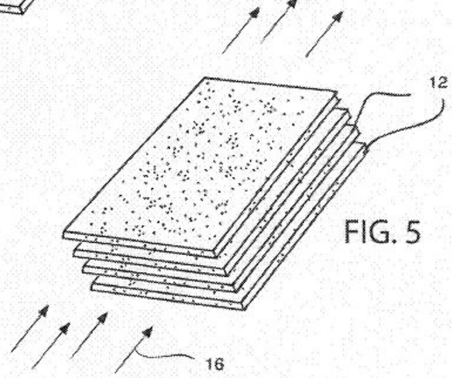


FIG. 5

[0017] FIG. 6 illustrates, in elevation, a stack of desiccant sheets mounted together by spacers with openings; the stack viewed from the front, air input side;

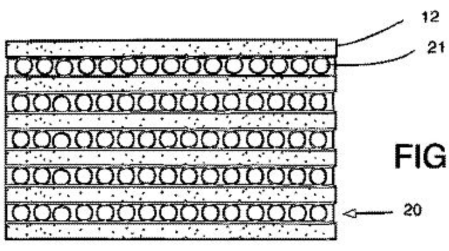
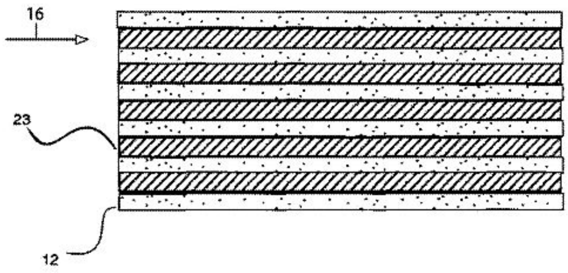


FIG. 6

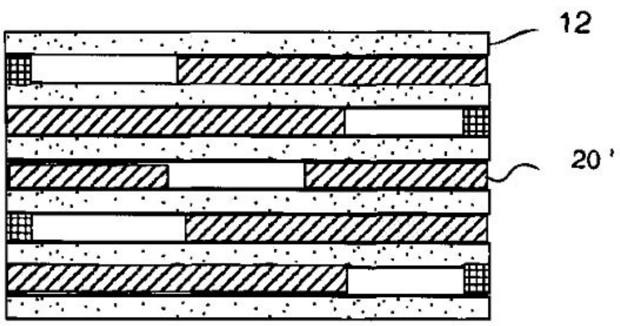
[0018] FIG. 7 shows a side view of the desiccant stack of FIG. 6;

FIG. 7



[0019] FIG. 8 illustrates an alternative stack of desiccant sheets mounted together by solid spacers that extend partially over the width of the stack viewed from the front, which is the air input side;

FIG. 8



[0020] FIG. 9 is a plan view of the stack of FIG. 8 seen with the uppermost sheet removed;

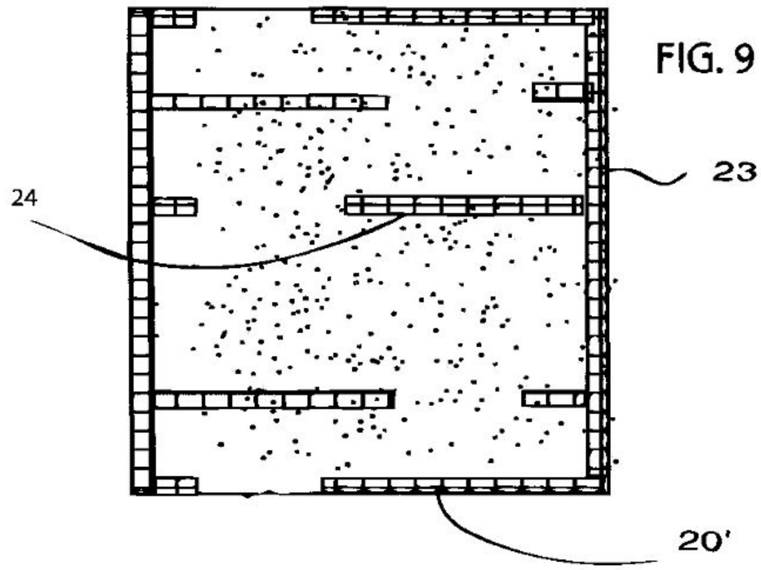
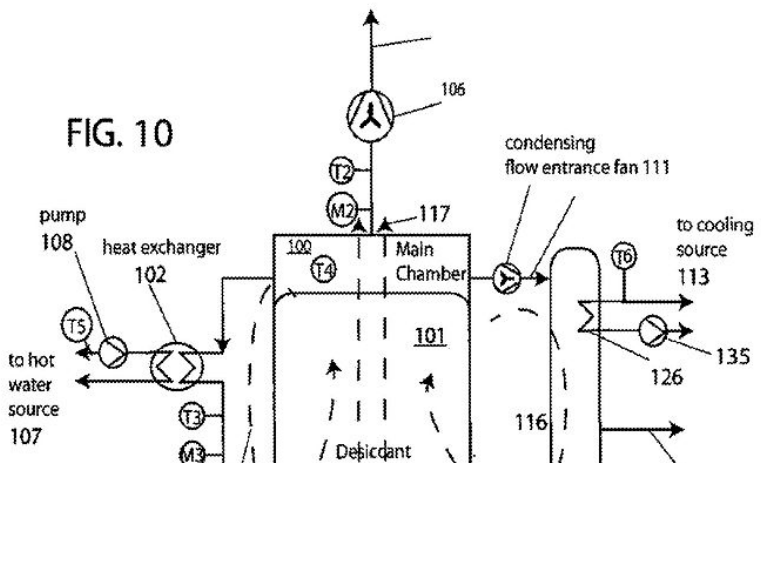
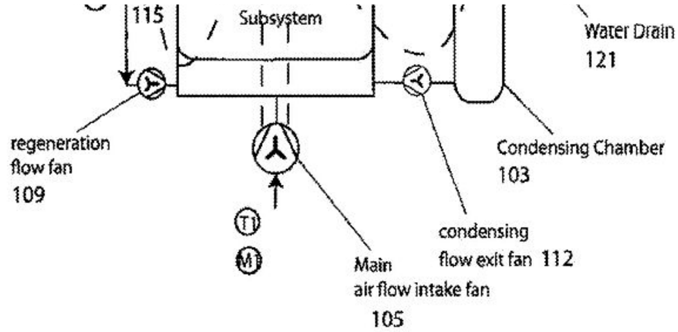


FIG. 9

[0021] FIG. 10 is a schematic diagram of a system for extracting water from air showing the air circulation patterns in three distinct modes;

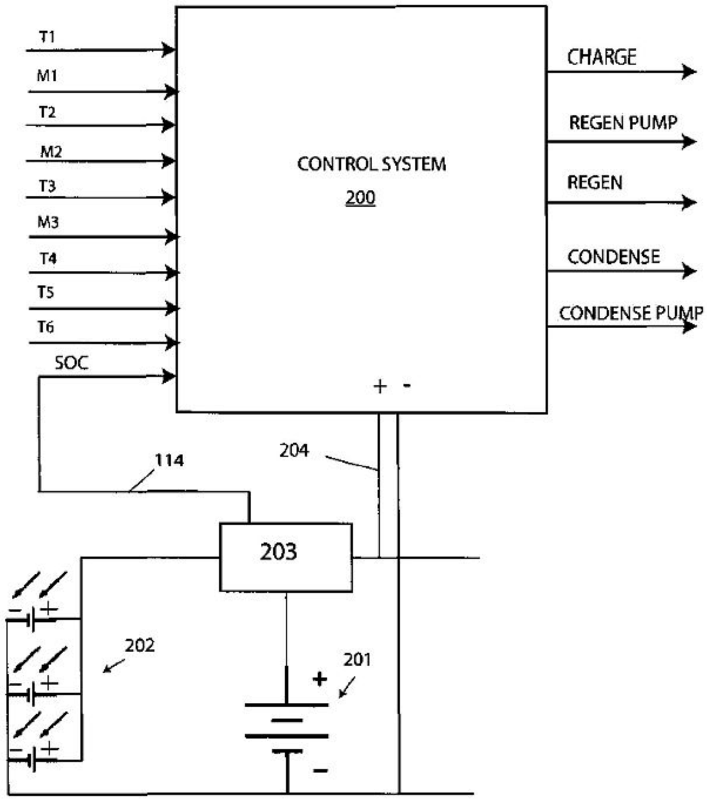
FIG. 10





[0022] FIG. 11 is a block diagram view of a control system for an air-to-water system;

FIG. 11



[0023] FIG. 12 is a schematic diagram of a condenser portion of the system of FIG. 10 with a filter;

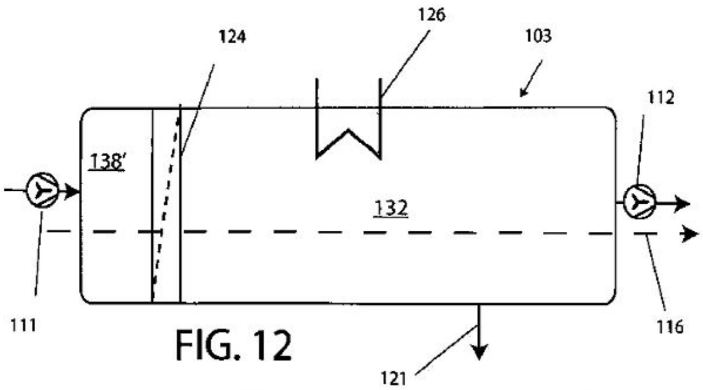
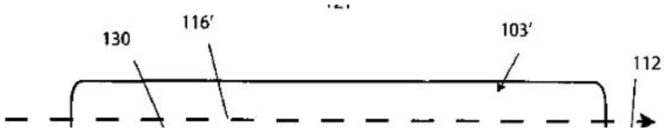


FIG. 12

[0024] FIG. 13 is a schematic diagram of an alternate condenser portion of the system of FIG. 10 with a membrane;



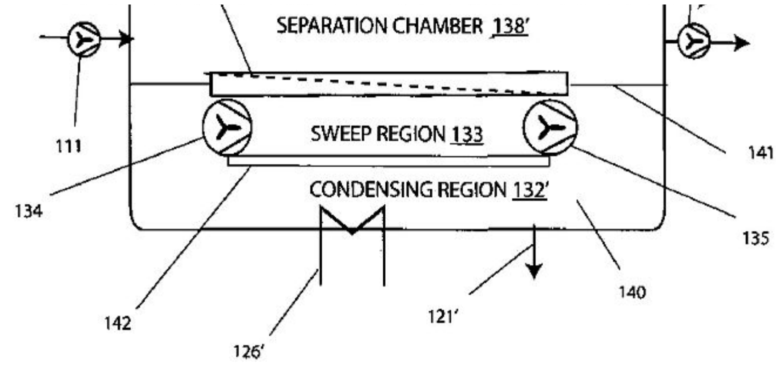
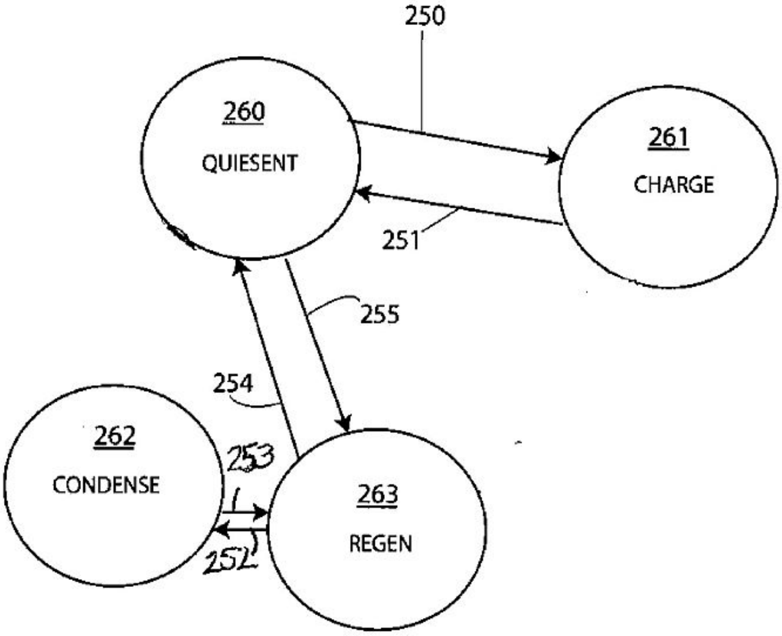


FIG. 13

[0025] FIG. 14 is a state diagram of the states of the control system of FIG. 11;

FIG. 14



[0026] FIG. 15 is a table showing criteria for transitioning states;

	FROM STATE			
TO STATE	Quiescent	Charge	Regen	Condense
Quiescent	----	Battery less than minimum charge OR Light sensor indicates heating conditions.	Battery less than minimum charge OR Light sensor indicates non-heating conditions. AND Temp in chamber (adjusted for calculated dew point) is less than 5-degree F over ambient or coolant	-----
Charge	Light Sensor indicates Dark or Non-Heating. AND Humidity Measured is > than calculated Humidity AND Battery is over minimum charge	----	------	------
Regen	Battery is over minimum Charge AND Temp in chamber is at > 10F over ambient or coolant AND light sensor indicates heating conditions.	----	----	Calculated humidity level in chamber yields dew point lower than 5-degree F over ambient or coolant
Condense	-----	----	Humidity > Z AND Calculated Humidity Level in chamber allows condensing >= 5-degree F over ambient or coolant	-----

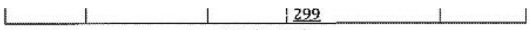


FIG. 15

[0027] **FIG. 16 is a flow chart of the actions of the system of FIG. 10 and FIG. 11 in the charging mode;**

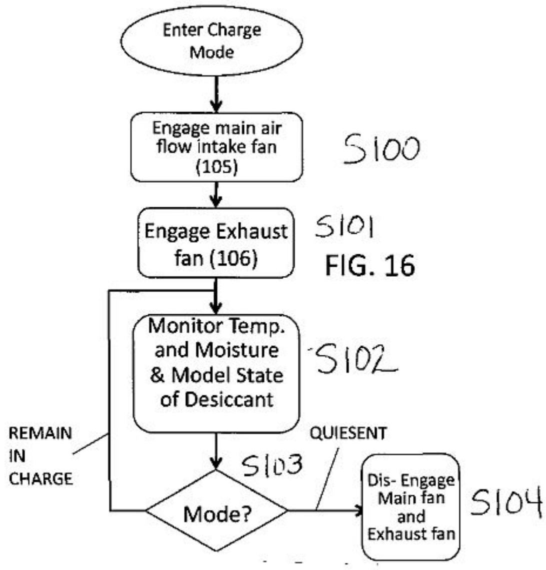


FIG. 16

[0028] **FIG. 17 is a flow chart of the actions of the system of FIG. 10 and FIG. 11 in the regeneration mode;**

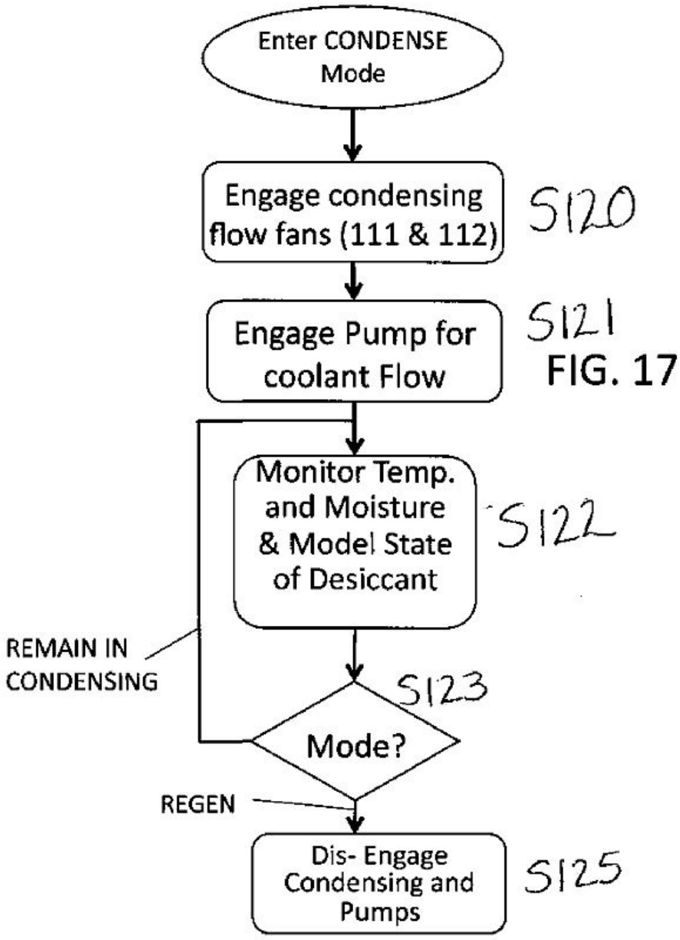
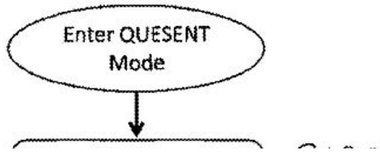


FIG. 17

[0029] **FIG. 18 is a flow chart of the actions of the system of FIG. 10 and FIG. 11 in the condensing mode;**



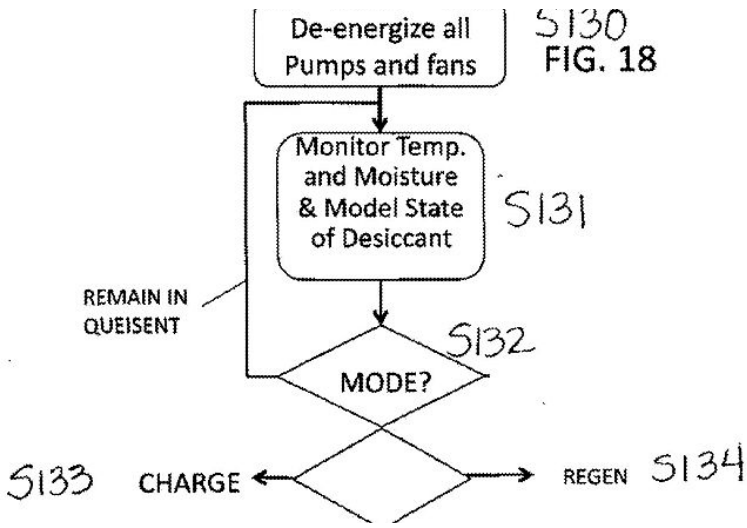


FIG. 18

[0030] FIG. 19 is a flow chart of the actions of the system of FIG. 10 and FIG. 11 in the quiescent mode;

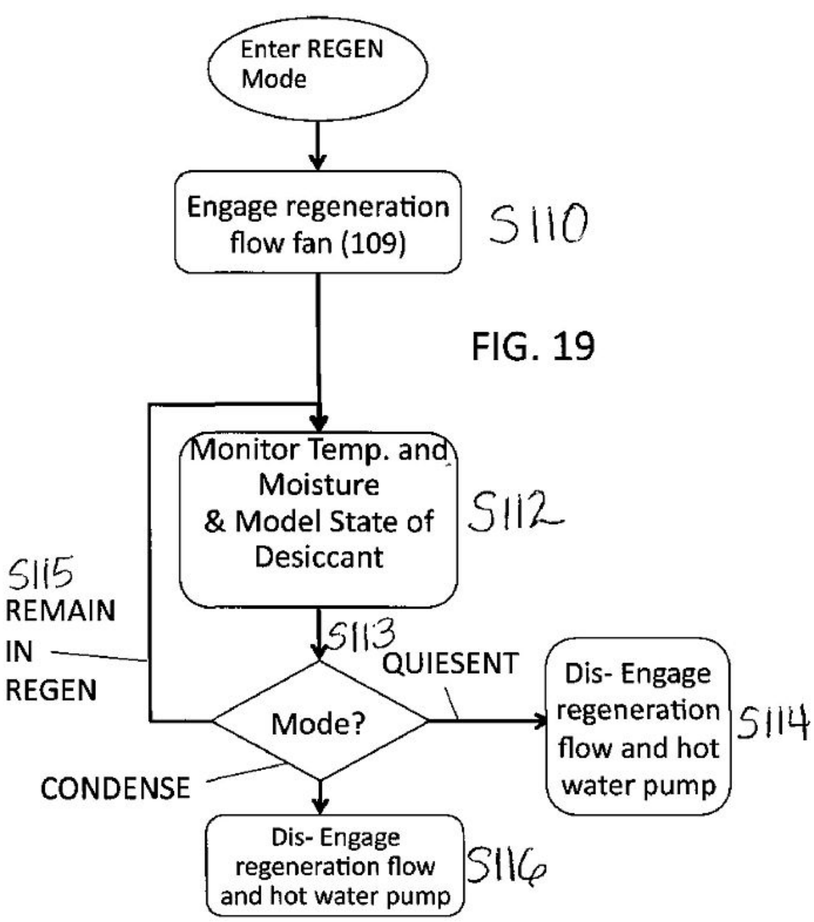


FIG. 19

[0031] FIG. 20 illustrates an embodiment of a split system air-to-water system;

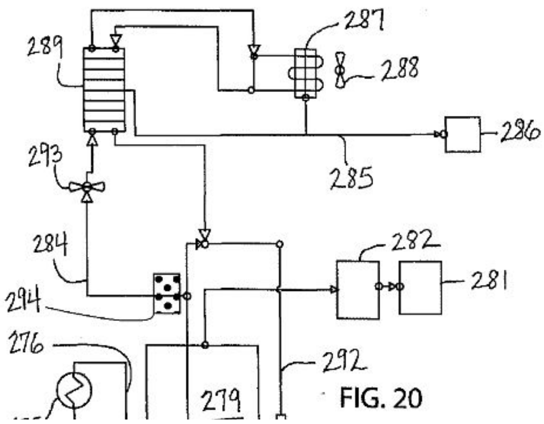
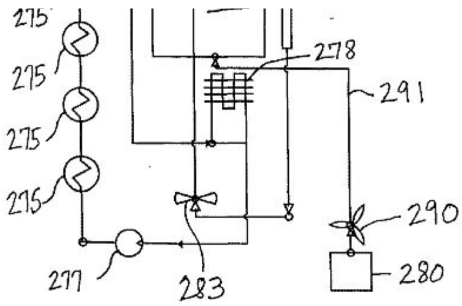


FIG. 20



[0032] FIGS. 21-23 illustrate a compact embodiment of an air-to-water system with a membrane

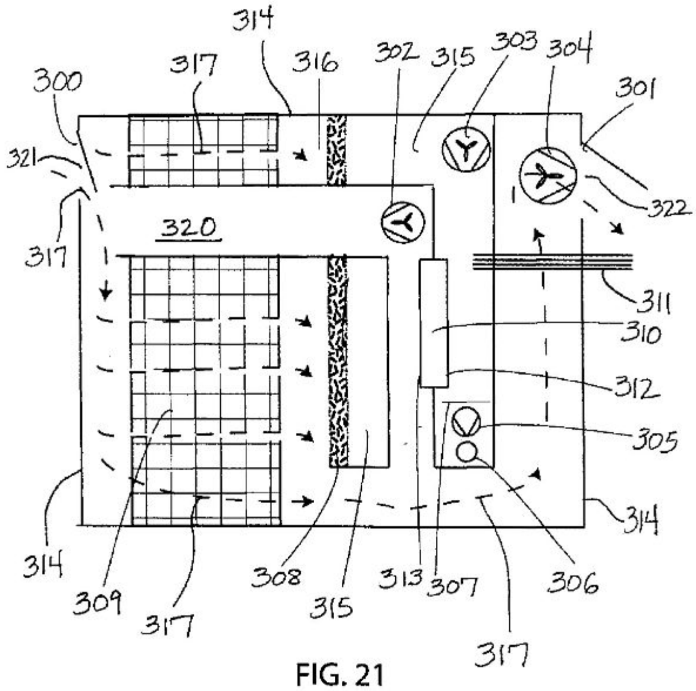


FIG. 21

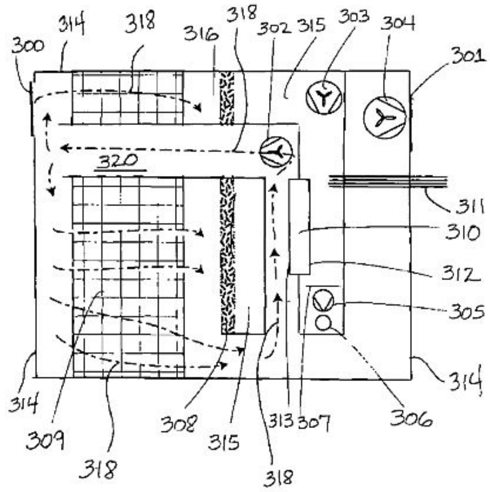
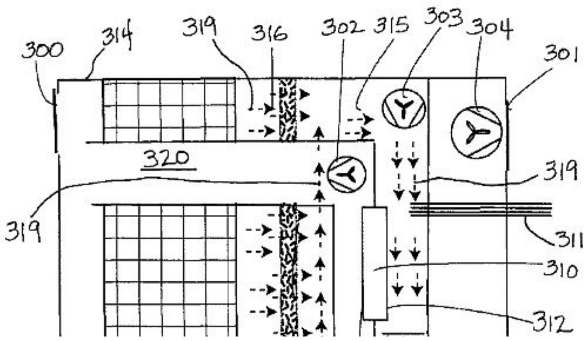


FIG. 22



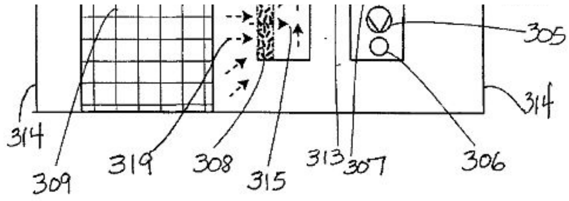


FIG. 23

DETAILED DESCRIPTION

[0033] In conjunction with the included drawings, this detailed description is intended to impart an understanding of the teachings herein and not to define their metes and bounds.

Introduction

[0034] One aspect of the present invention is a composite desiccant material in an effective form factor. Another aspect is a desiccant subsystem based upon that composite desiccant material, and a third aspect includes systems and methods of extracting water from air employing the subsystem.

Structure

Desiccant Material and Subsystem

[0035] The desiccant composition includes a porous support material and a hydroscopic absorbent dispersed within the porous support material. The porous support material has pores or pore-like small random gaps of a wide range of sizes. Small pores include pores of about 70 microns to large pores of about 1000 micrometers. This porous support material can include a material such as PVA foam or a non-woven fabric such as rayon. The desiccant composition disbursed with the support material includes a hygroscopic absorbent such as CaCl.

[0036] Another aspect of these teachings is directed to a method for producing a desiccant composition comprising the steps of: (a) providing a porous support material having a range of pores from 70 micros to 1000 microns; (b) contacting the porous support material with a flowable medium comprising a hygroscopic absorbent, for a time sufficient to substantially fill porosity in the porous support material and then drying the porous support material to remove liquid from the flowable medium and form a desiccant composition comprising the absorbent dispersed on the porous support. A supporting PVA sheet 10, seen in photomicrographs in FIGS. 1A, 1B, and 1C, is a preferred support material. That material then has embedded, but not positionally captivated, particles of a chemically active desiccant.

[0037] Appropriate soaking of the porous support material in a liquid solution of a chemical such as CaCl, Ethyl Glycol, and Lithium Bromide followed by drying the material can be an effective manner of producing such a composite. This is generally taught in Type "Salt-in-a-Porous-Matrix" Sorbents in Hydrocarbon Processing, by E. A. Buluchevskii. This article is found in the Russian Journal of General Chemistry 2007, Vol. 77, pp. 2284-2291. Pleiades Publishing, Ltd., 2007. Other related teachings are seen in U.S. Pat. No. 6,559,096, May 6, 2003, of Smith et. al. In contrast with these and other "salt in a porous matrix" materials, herein is taught a non-captive entrainment of the adsorbent salt in the absorbent material. The desiccant salt particles and brine can migrate within the absorbent substrate due to the larger pores and can be mechanically removed from the substrate.

[0038] FIG. 1A is a 400* microphotograph of PVA foam in a dry state. The PVA foam used in this example was purchased from Ninbo Goldtime Household Necessaries CO LTD, item SP703-1 called PVA towel 66*43*0.2 cm, dark gray. The pore structure is seen to include both relatively small pores 5 and relatively larger pores 6. In FIG. 1B the same material is shown damp, but not saturated. Generally smaller pores are filled with water, held by surface tension while relatively larger pores are open, allowing the passage of moist air from the environment. The same material is seen in FIG. 1C in a saturated state. Substantially all pores contain brine. For size comparison purposes, FIG. 2 shows a human hair.

[0039] The same PVA foam, after the disbursement of CaCl by soaking in a solution and then drying, is seen in a dry state in FIG. 3A, and a damp state in FIG. 3B.

[0040] FIG. 3C shows a non-woven rayon fabric in a dry state. It has air gaps that effectively act as pores. It has a range of gap sizes formed by the random pattern of threads 8. The particular material tested and shown in FIG. 3C was purchased from Hefei Telijie Sanitary Material Co., Ltd. Their designation is: Nonwoven Cleaning Cloth. Material: Dipping nonwoven fabric; Size: 110 cm width; Length: 50M; Thickness: Around 3.4 mm; Packing: 50M/Roll; G.W.: 69 KGs. Not pictured is another material tested which is: TSV-5, purchased from ShopMicrofiber.com.

[0041] The amount of fluid retained in the absorbent material increases as the desiccant absorbs water. It is possible for the amount of fluid to exceed the holding capacity of the absorbent material that can result in dripping of the brine out of the absorbent. The amount of fluid can be maximized if the absorbent is composed in a sheet 12 form as depicted in FIG. 4 and, in use, is oriented with its major plane perpendicular to the vector of gravity. The sheets are generally flexible and should be held in a frame to minimize sagging or the fluid will drip out of the low points. For this composite material to provide a high ratio of H2O holding capacity to mass, the support material should have particular properties including a rapid rate of absorbing H20, a high capacity for absorbing H20, a rapid wicking of H20, and a rapid drying of absorbed H20. Some materials that have been tested include a PVA foam, a loose weave Rayon fabric, a microfiber fabric, an unwoven fabric, cellulose foams, and various other foams including M11.

[0042] Some of these substrate materials as tested by the inventor, have been seen to have the following properties: Total absorption of liquid water into dry media held in horizontal plane ranges from 400% to 1,000% of the weight of the dry media's weight. The media can hold more water when oriented in thin sheets held on a horizontal plane that ranges from 200% to 700% of the amount of water retained when the absorbent sheet is held on the vertical plane.

[0043] Thinner sheets with wider gaps present more effective airflow, but yield lower total absorption capacity at higher labor assembly costs. The effective thickness will range from 0.4 mm through 12 mm. Testing has shown that thickness over 12 mm will not regenerate in effective times and also experience an increased incidence of the desiccant collecting in the lower portion of the sheet and dripping out even when the sheet is maintained in the horizontal plane.

[0044] Because the absorbent media is not rigid when desiccant is in the fluid state, the airflow rate should be low enough to prevent flapping which would fatigue and eventually destroy the media. Higher airflows can be tolerated by using thicker media and by adding more supports. In general, the maximum airflow effective in embodiments will not exceed 30 MPH gas flow across the media surface.

[0045] Chemical Hygroscopic Desiccant

[0046] Most testing has been done with CaCl as the prime hygroscopic desiccant. Other compounds with hygroscopic properties such as glycol might be used with success. A combination of CaCl and glycol has been seen to be advantageous. Lithium bromide, magnesium chloride, and lithium chloride have also been demonstrated as effective desiccants.

[0047] Composite Desiccant Element

[0048] Soaking the support material in a solution of CaCl and then drying the support material can disburse the chemical in the pores and structure of the support material. Other methods to produce the composite are possible. Since a goal of the composite is to maximally expose the surface area of the hygroscopic desiccant to any gaseous H2O in its environment, the sheets shown are relatively thin. One manner to produce a composite can be to soak a mounted sheet or sheets of a suitable support material in a ridged framework in a solution of CaCl and water with an equal weight of water to CaCl. The maximum CaCl that can be absorbed by water is dependent on the temperature of the solution. One way to obtain an effective mixture is to create a solution wherein some CaCl settles to the bottom at 65 degrees-F., but at 75 degrees-F. has all the CaCl in solution. In addition, it can be desirable to achieve a ratio in a composite of between 5%-300% CaCl to the total of CaCl plus substrate by weight. The total amount of CaCl that is recommended varies upon the conditions of operation. In general, environments that are more humid will require less CaCl to reach the point where they have absorbed all of the water possible without excessive dripping.

[0049] In dry locations, more CaCl can increase absorption. As known to those skilled in the art, and according to Dow Chemical, a supplier of industrial CaCl, the trend is that at lower humidity CaCl will absorb less than it will at higher humidity. Temperature also has an effect on the maximum absorption of CaCl. As a result, the CaCl loading density can be adjusted for local conditions to improve operations. In less humid locations the CaCl loading density might be higher and in sufficiently dry locations CaCl may remain in its solid form even though it is absorbing water and the process continues to work.

[0050] Desiccant Sub-System

[0051] As seen in FIG. 5 in a schematic manner, one way to deploy the composite material is as parallel sheets 12 with each sheet parallel to the flow direction 16 of a gas. This configuration exposes both sides of each sheet to the gas. The spacing and other details provided by a supporting structure can be such as to have a higher or lower air resistance to the flow. Thinner gaps between the sheets can increase total absorption per unit volume but may do so at the expense of increased airflow resistance. The gap between sheets might range from 2 mm to 40 mm in some embodiments. The configuration may also be such that a particular degree of turbulence is achieved, affecting the interaction of gaseous H2O and the desiccant composite sheet. FIGS. 6 and 7 depict an example structure for mounting stacked sheets. In FIG. 6, an end spacer 20, with significant area occupied by openings 21, is used to separate and support the multiple sheets. This might be constructed from a corrugated plastic. The back of this stack is identical to the front. While holes shown in the spacer are circular, they may be any shape. While the spacers are shown on the ends there may in fact be multiple spacers placed periodically along the length of the sheet to prevent sagging of the supported media. There are also one or more similar corrugated strips within the stack to provide intermediate supports. The side supporting spacers 23 are solid on each of the sides of the stack as seen in the side view of FIG. 7. An alternate way to construct the stack is by sandwiching a single spacer sheet with teeth extruded on both sides between each desiccant sheet.

[0052] In some versions, as seen in the front view of FIG. 8 and the plan view of FIG. 9 (the top sheet is removed), one or more baffles 24 can be used to create a turbulence-enhancing air path between the sheets. Those skilled in the art will recognize many alternate structures for supporting the parallel sheets and engendering a desired trade-off between pressure drop and a desired turbulent interaction. Material thickness of the desiccant substrate is predominantly limited by the material's moisture holding characteristics when oriented in a horizontal plane. Another factor for thickness determination is the rate of absorption.

[0053] A thicker sheet might be appropriate for a material with faster wicking and absorption. If the material is too thick it may then accumulate a saturating degree of fluid in its lower portions leaving the upper portions drier and can result in dripping. Overly thick sheets would also make inefficient use of the desiccant by weight and by volume. In general, the thickness of the material is chosen to allow the maximum absorption in a given environment consistent with the average 250 charging time. For an overnight charging system, a thickness from 2 mm through 10 mm can be effective. For a system delivering multiple batches per day, a material thickness as thin as 0.5 mm may be more effective. In systems for continuous drying of a gas, a sheet thickness of 0.1 mm to 0.5 mm and a spacing of between [1/2] and 1 times the thickness may be advantageous. Sheet spacing in embodiments with longer airflow channels may generally have wider gaps to maintain a particular flow at a desired low degree of pressure. Shorter channel systems can have lower gaps and maintain a comparable pressure drop. In practice, a spacing of between 1/64" and 2" would cover many applications. A narrower practical range, taking material sag and volume constraints into consideration, can be 1/16" to [1/2]". A smaller gap can be advantageous in allowing more sheets and therefore more desiccant mass in a given volume.

[0054] Those skilled in the art will understand that various mountings and stiffening schemes are available with different tradeoffs. Sheets used in a subsystem may be pre-dried and tested for dripping to a desired specification. A system could take advantage of that to cease operating in an absorption mode with a desired margin before dripping was likely to occur. In some cases, it may be advantageous to construct a stack of the substrate material and then soak the subsystem. In other cases the composite sheets might be created and then assembled into a stack. Systems can be manufactured over-saturated with desiccant that is then removed by operation on-site to allow for environmental differences at various sites. One implementation approach is to assemble the subsystem with untreated absorbent media and then soak the subsystem in the desiccant solution. The desiccant charge would then likely be substantially over-charged. The subsystem can then be conditioned in an environment that approximated the humidity and temperature 275 expected to occur in a target deployment location. This conditioning step allows the desiccant charge to absorb the maximum water it is likely to absorb in the field and allows excess solution to drip out to be re-used. The unit is then dried.

Operation

Desiccant Subsystem

[0055] The H2O holding capacity of the subsystem is affected by various factors 280 including the support material, the chemical desiccant, the sheet thickness, and the number of sheets. In addition, as the amount of H2O nears the capacity of the material, the liquid will appear at the surface and may drip. By keeping the sheet-stack parallel to the ground, the capacity before dripping that occurs is increased. Some mounting arrangements may provide a leveling indication and some may provide a leveling adjustment for the subsystem while others may provide a leveling indication and adjustment at the system level. In alternate inertial environments, the mounting orientation could be dynamically altered in order to maintain a perpendicular relationship with the vector of gravity/acceleration.

Structure

Air-to-Water System

[0056] A schematic view of an example air-to-water system is shown in FIG. 10. Its structure includes a main chamber 100 containing a desiccant subsystem 101. It also includes a heat exchanger 102 to provide energy in the regeneration phase and a condensing chamber 103 to harvest water freed during regeneration. There are three primary airflow paths (1) ambient in, dried air out 117 (2) recirculation hot air for regeneration 115, and (3) recirculation of moist air through a condenser 116. Fans engender the flows. Flaps (not shown in FIG. 10) associated with each of the three airflow patterns, respectively, prevent undesired flow. The system shown includes both temperature and moisture sensors in various locations.

[0057] An intake fan 105 can direct ambient air into the desiccant chamber and an exhaust fan 106 removes the dried air. Temperature T1 T2 and moisture M1 M2 sensors allow for measurement of the intake and exhaust air respective properties.

[0058] A source of heat 107 that might be hot water from a solar panel, or might be from a low-grade waste heat source is connected to the heat exchanger 102 to allow heating of recirculating airflow 105 through the desiccant subsystem 101 in the main chamber 100. In applications that produce drinking water, the metallic components of the heat exchanger 102 can be constructed from stainless steel. A pump 108 is shown in the hot water path. A regeneration flow fan 109 is in the recirculation airflow path that goes through the heat exchanger and the desiccant chamber.

[0059] Condensing occurs in a condensing chamber 103 that is coupled to the main chamber via two fans in the system of FIG. 10. One fan 111 is pulling air from the desiccant chamber while the second, exit fan 112, is pulling air through the condensing chamber and back into the main chamber and through the desiccant subsystem 101. A source of cooling 113 is provided to the condensing chamber coupled by a heat exchanger 126 and water is produced at a drain outlet 121.

[0060] A control system 200 is shown schematically in FIG. 11. The temperature and moisture sensors seen in FIG. 10 provide inputs to the control system. Another input is the state of charge 114 of the battery 201. The control system's various outputs signal the various phases of operation, enabling fans and pumps.

Operation

Air-to-Water System

[0061] A goal of many embodiments of these teachings is to produce drinking water from ambient air under a variety of conditions with a minimal expenditure of energy. In a typical operation cycle, photovoltaic panels 202 charge a bank of batteries 201 during the day.

[0062] At night, the system might start out in a quiescent state, neither charging, regenerating, nor condensing. From past operation, the control system has a stored value representative of the extent of H2O held in the desiccant subsystem. The stored electrical energy in the battery is used conservatively. The control system makes decisions based upon the degree of moisture in the ambient air measured by sensor M1, the temperature of the ambient air measured by sensor T1, the extent of H20 presently held in the desiccant subsystem 101, and the state-of-charge 114 of the batteries. The intake 105 and exhaust fans 106 are energized to further charge the desiccant only when "it is worth it". That is, if a modeling of the system by the control logic indicates that there will be an adequate addition to the held H20 by taking in ambient air, the CHARGE signal will be activated. This will engage both the intake fan 105 and the exhaust fan 106. This mode will stay in operation so long as the control systems models, according to predetermined rules, that further operation meets a criterion of efficiency. The other flow patterns are inactive and blocked by closed flaps.

[0063] When the held H2O in the desiccant subsystem 101 is at the maximum or if the ambient conditions are such that no charging or an ineffective degree of charging would take place, the charge mode ceases. In a system using solar water heating as its regeneration energy source, the temperature of the hot water source as measured by the sensor T5 will increase as the day goes on and the sun rises. To conserve battery power, the control system will not initiate regeneration mode until the hot water has achieved a temperature level that can efficiently cause regeneration of the desiccant. This computation is based on the present state of the desiccant chamber. When the criteria are met, the control system will energize the REGEN signal.

[0064] In regeneration mode the hot water source pump 108 is engaged as well as the fan that engenders the regenerating flow pattern 115. That pattern is through the heat exchanger 102 and through the desiccant subsystem 101 in a closed-circuit manner. In this mode the other patterns of flow are inactive and blocked by flaps. The regeneration mode's function is to release held H2O out of the desiccant and into the atmosphere of the main chamber. This mode is continued as long as the heat provided through the heat exchanger is continuing to effectively release additional H2O. One parameter involved with this calculation is the humidity or moisture content of the atmosphere within the main chamber 100. While this may be measured directly, the harsh conditions in this system have proven to be destructive to the useful life of many conventional sensors. In the system of FIG. 10 and FIG. 11, only a temperature sensor T4 is located in the main chamber. In that example system, the moisture level within the closed chamber is determined by modeling the system, starting with the known state of the amount of H2O held in the desiccant and taking into account the input ambient air, output air and the degree of heat energy injected via the regenerative flow and amount of moisture condensed.

[0065] The condensing mode is entered when the atmosphere within the main chamber 100 is sufficiently saturated as to be effectively condensable given the temperature delta between that of the main chamber and that of the cold source 113 whose temperature is measured by a temperate sensor T6. When the criteria are met, the control system will activate the CONDENSE signal. If a criteria set according to predetermined rules is met, the control system will enter the condensing mode. In this mode, energizing the condensing flow fans 111 112 will engender the condensing air pattern. Closed flaps prevent the other airflow patterns.

[0066] This condensing airflow pattern 116 is a recirculation flow through the desiccant subsystem 101 and the condensing chamber 103. Due to the temperature drop provided by the cold source, water condenses and is available to exit the chamber at a drain point 121. This mode is continued as long as the moisture level on the main chamber and the temperature difference between the main chamber and the cold source 113 provide for effective continued production of water.

[0067] FIG. 12 shows a more detailed schematic of the condensing chamber 103 and its entrance and exhaust fans of this first example system. Air is pulled from one end of the main chamber by an entrance fan 111 and pushed back into the other end of the desiccant chamber by the exit fan 112. Within the condensing chamber 103 the hot moist air first enters a separation area 138 and then a portion of the moist air passes through a filter 124. In this example system it is a HEPA filter. One purpose of the filter 124 is to prevent particulate contamination of the water being produced. The H2O is condensed in the condensing region 132 from the air via a heat exchanger 126 connected to a cold source. This might be a fluid pumped through a ground loop, ambient air, or other source of relative coldness. The condensed water is available at a drain point 121.

Alternative System Embodiments

[0068] Alternative Condensing Chamber-With Membrane

[0069] FIG. 13 shows a schematic view of an alternative condensing chamber 103'. In this version a membrane 130 separates an initial separation region 138 from the actual cold condensing region 132'. Rather than direct the recirculating air pattern through the condensing region itself, the recirculation is done in the separation sub-chamber with the path having a sidewall 141 comprising an H2O permeable membrane 130. The recirculation flow 116' is parallel with the length of the membrane rather than being directed to the membrane.

[0070] On the opposite side of the membrane 130 is a sweep region 133. On the side of the membrane opposite to that abutting recirculating flow, two sweep fans 134 135 direct airflow 140 in parallel to the membrane. The sweep region is a plenum defined by the membrane and a plenum wall 142. H2O molecules will permeate the membrane assisted by the turbulent flows on both sides. However, the other components of the hot moist air will not substantially permeate the membrane. This provides multiple benefits. One is that there is a minimum of mass heat transfer from the hot side of the membrane to the condensing side of the membrane. While it is necessary to cool the H2O water vapor to condense it to liquid water, it is desirable that the bulk of the recirculating flow 116' not be cooled since it is being fed back into the main chamber 100. The main chamber must be kept hot in order to keep the H2O in its atmosphere rather than in the desiccant.

[0071] A second benefit of the membrane version is that a partial vacuum is created as the H2O expands on the sweep region 133 side of the membrane. This pressure differential further enhances the flow of H2O molecules through the membrane. Several materials can be used in the composition of a suitable membrane. One is Nafion. An alternate material that has been successfully tested is a monolithic urethane material, part number PT1700S by Deerfield Urethane. The sweep flow circulates through the sweep region 133 and back through the actual condensing region 132. There the flow is in communication with the cold source via the heat exchanger 126'.

Method of Operation

[0072] FIGS. 14-19 show states, criteria, and steps involved in the operation of the system of FIGS. 10-13. In FIG. 14 a state diagram illustrates the four major states of the system: Quiescent 260, Charging 261, Regenerating 263 and Condensing 262.

[0073] While in the Quiescent 260 state:

(a) Detection of high moisture content in the ambient air with a remaining water holding capacity of the desiccant subsystem 101 is a condition that will cause a transition 250 to the Charge state 261.
(b) Detection of significant held water in the desiccant subsystem in conjunction with a sufficient source of low-grade heat is a condition that will cause a transition 255 to the Regen state 263.

[0076] When in the Charge state 261:

(a) Detection of low moisture content in the ambient air OR a low remaining water holding capacity of the desiccant subsystem is a condition that will cause a transition 251 to the Quiescent state 260.

[0078] When in Regen state 263:

(a) Detection of insufficient low-grade energy to efficiently release moisture from the desiccant subsystem will cause a transition 254 to the Quiescent state 260.
(b) Detection of significant held water in the desiccant subsystem in conjunction with a sufficient source of low-grade heat is a condition that will cause a transition 252 to the Condense state 262.

[0081] When in Condense state 262:

(a) Detection of insufficient moisture in the main chamber 100 will cause a transition 253 to the Regen state 263.

[0083] State Transition

[0084] Various conditions detected by logic and system state modeling in the control system 200 cause state transitions. The state transition logic is shown in the state table FIG. 15.

[0085] The box for the criteria for moving from regeneration to condensing mode 299 requires additional explanation. When using waste heat or split collectors then rather than measuring light sensor for heating conditions this simply measures input of heating fluid.

[0086] Calculated dew point of humidity in the chamber, Z, is based on the calculated dew point, humidity, and temperature of the highest 2-hour average humidity as measured in input air during prior charge period. This is used to calculate a minimum temperature delta between the ambient temperature and the condensing dew point. This is used as the minimum condensing delta. Minimum condensing Delta is increased by a set constant such as 10-degrees F. for each hour regeneration is run, to allow for reduced humidity available in desiccant because of water reclaimed. The adjustment per hour is tuned for local conditions and known over-sizing of desiccant stack. Larger oversized desiccant stack will allow a lower increase per hour while smaller desiccant stacks will require a higher increase per hour.

[0087] Charge Mode

[0088] In FIG. 16 the steps of Charge mode are seen. First, the main intake and exhaust airflow fans or blowers are energized and engaged S100 S101. Then a loop is entered where the temperature sensors and moisture sensors are monitored and the information used to continually update a model of the state of the desiccant subsystem and the relative humidity of the chambers S102. Within this loop, the criteria described above regarding causes of state transitions is reevaluated S103. If the conditions are such as to cause a transition to the Quiescent state, the main intake and exhaust fans are dis-engaged and the Quiescent state is entered S104. If no transition is called for by the conditions, the loop continues.

[0089] Condense Mode

[0090] In FIG. 17 the steps of Condense mode are seen. First the condensing entrance 111 and exit fans 112 are engaged S120, and the coolant flow pump 135 to cause cold water to flow through the heat exchanger 126 is engaged S121. Then a loop is entered where the temperature sensors and moisture sensors are monitored and the information used to continually update a model of the state of the desiccant subsystem and the relative humidity of the chambers S122. Within this loop, the criteria described above regarding causes of state transitions is reevaluated S123. If conditions dictate a transition to the Regen state, condensing entrance and exit fans and coolant flow pump are dis-engaged, and the Regen state is entered S125. If no transition is called for by the conditions, the loop continues.

[0091] Quiescent Mode

[0092] In FIG. 18 the steps of Quiescent mode are seen. First the all pumps and fans are disengaged S130. Any flaps are closed. Then a loop is entered where the temperature sensors and moisture sensors are monitored and the information used to continually update a model of the state of the desiccant subsystem and the relative humidity of the chambers S131. Within this loop the criteria described above regarding causes of state transitions is reevaluated S132. If the conditions are such as to cause a transition to the Charge state, that state is entered S133. If conditions dictate a transition to the Regen state, that state is entered S134. If no transition is called for by the conditions, the loop continues.

[0093] Regen Mode

[0094] In FIG. 19 the steps of Regen mode are seen. First, the regeneration, recirculation fan 109 is energized and engaged S110. In this same step, the pump 108 is engaged. Then a loop is entered where the temperature sensors and moisture sensors are monitored and the information used to continually update a model of the state of the desiccant subsystem and the relative humidity of the chambers S112. Within this loop the criteria described above regarding causes of state transitions is reevaluated S113. If the conditions are such as to cause a transition to the Quiescent state, the regeneration fan and hot water pump are dis-engaged and the Quiescent state is entered S114. However if conditions dictate a transition to the Condense state, the regeneration fan and hot water pump are dis-engaged and the Condense state is entered S116. If no transition is called for by the conditions, the loop continues S115.

Further, More Detailed Embodiments

[0095] Although those skilled in the art will understand the materials and techniques used in the design and construction of systems according to these teachings, two specific implementations are described below.

[0096] Split System

[0097] The version diagramed in FIG. 20 is a "split system" in that the subcomponents of the system may be located other than immediately adjacent to each other. Because of this flexibility a wide range of physical embodiments are possible by one skilled in the field. This specific version gets much of its energy input from solar and wind power.

[0098] Solar collectors 275, possibly located on a roof, are used to create a heated fluid 276 which a circulating pump 277 can bring to a heat exchanger 278 in a chamber with the desiccant stack 279 in a charging mode. Air is pushed in a charging flow 291 by the charge blower 290 from an inlet charge port 280, through the heat exchanger 278, and then through the stack out to a roof-mounted passive exhaust fan 281. A controlled damper 282 opens this path in a charge mode.

[0099] For regeneration, a fan 283 forces airflow 292 through the desiccant stack 279 in a continued loop. As detailed above, regeneration continues until a desired set of conditions causes a mode transition to a condensing mode. In the condensing mode, the regeneration flow path is diverted through a filter 294 into a condensing airflow path 284. This condensing airflow is caused by the condensing fan 293. The condensed water goes to a drain 285 and out an outlet 286. The condensation is promoted by a primary condenser 287 being cooled by a fan 288. That primary condenser provides a flow of a cold fluid to the heat reclaiming condenser 289.

[0100] Small Unit with Membrane

[0101] One compact embodiment using a thermoelectric semiconductor 310 is shown in simplified two-dimensional form in FIGS. 21, 22, and 23. Referencing FIG. 21 its structure includes an outer enclosure 314 with several sub-chambers and air conduits 320. The major sub component with the enclosure include a desiccant stack 309 and a membrane 308 that allows water vapor but not other molecules of the air to pass. In this example, the heating for regeneration and the cooling for condensing are both caused, literally, by two-sides of the same semiconductor. When an electric current flows through the thermoelectric device 310 the by the Peltier effect, one side becomes hot 313 while the opposite side becomes cold 312. To achieve the compact design an air conduit 320 provides a path from one side of the desiccant stack 309 to the other side of the stack for the regeneration recirculating flow 318. In these two-dimensional views the conduit appears to bifurcate the stack into two regions. This is not the case. The conduit does not extend across the whole width in the third dimension. Therefore, it does not bifurcate the desiccant stack nor does it block the condensing pathway 315. The three fans shown include one fan for charging airflow 304 at the exhaust port 322, a second regeneration-recirculating fan 302 and a condensing mixing fan 303. A tray 307 at the base of the condensing area 315 provides for the collection of condensed water that can exit the unit out of the water outlet 306.

[0102] Small Unit Operation

[0103] The charging state is seen in FIG. 21. The charging exhaust fan 304 is energized. That pulls external air into the inlet, pushing open both the inlet flap 300 and the outlet flap 301. The charging flow 317 is shown coming in the inlet, flowing through the desiccant stack 309, around the side of the membrane 308 and past the condensing area. Finally, the charging air flow exits via the exhaust port. Charging leaves the desiccant stack in a water-holding state. The heat pipe does not block the exit flow since it does not extend to fill the space in the third dimension.

[0104] In FIG. 22, the regeneration flow is diagramed. In this recirculation flow 318 the inlet and outlet flaps 300 301 are closed since the exhaust fan 304 is not energized. However, the recirculating fan 302 is energized. The recirculating flow goes through the desiccant stack 309, around the membrane and back up a recirculation channel to the air conduit 320. During this mode the thermoelectric device 310 is energized to heat the recirculating air to pull the stored moisture out of the desiccant stack.

[0105] In FIG. 23, the condensing flow 319 is shown. In this mode the only energized fan is the condensing mixing fan 303. Hot, moist air is drawn from the area of the desiccant stack 309 towards one face of the membrane 308 by a partial vacuum initiated by the pump 305. The water vapor penetrates the membrane but the bulk of the air (and heat) does not. This allows the hot air to remain hot to continue regeneration, while the water proceeds to the condensing area. As the water vapor emerges from the opposite side of the membrane, the partial vacuum is reinforced, further enhancing the "pull" of moisture through the membrane and reducing the work required by the pump. The hot water vapor first passes through an area that provides initial cooling in a passive manner via a heat pipe 311. The heat pipe extends to the outside of the enclosure 314. Then the partially cooled water vapor is actively cooled by the cold side 312 of the thermoelectric device 310. As mentioned above, a shelf 307 holds the condensed water until it is brought out of the unit by action of the pump 305.

[0106] Those skilled in the art will be aware of materials, techniques and equipment suitable to produce the example embodiments presented as well as variations on the those examples. Alternate materials that can be used for the sheet substrate include: microfiber, woven or nonwoven bamboo, or cotton, or hemp, woven or nonwoven stainless, woven or nonwoven propylene. This teaching is presented for purposes of illustration and description but is not intended to be exhaustive or limiting to the forms disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiments and versions help to explain the principles of the invention, the practical application, and to enable others of ordinary skill in the art to understand it. Various embodiments with various modifications as are suited to the particular application contemplated are expected.

[0107] In the following claims, the words "a" and "an" should be taken to mean "at least one" in all cases, even if the wording "at least one" appears in one or more claims explicitly. The scope of the invention is set out in the claims below.