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Design and Fabrication of Desiccant Wheel Dehumidifier

Er. Amit Tiwari
Asst. Professor, Dept. of M.E Dungarpur College of Engg. and Tech., Dungarpur (Raj), India

Abstract
Experimental investigations on several commercially available and newly fabricated rotors are conducted in two different laboratories to evaluate performance trends. Experimental uncertainties are analyzed and the parameters determining the rotor performance are investigated. It is found that the optimal rotation speed is lower for lithium chloride or compound rotors than for silica gel rotors. Higher regeneration air temperatures lead to higher dehumidification potentials at almost equal dehumidification efficiencies, but with increasing regeneration specific heat input and enthalpy changes of the process air. The influence of the regeneration air humidity was also notable and low relative humidity increase the dehumidification potential. Finally, the measurements show that rising water content in the ambient air causes the dehumidification capacity to rise, while the dehumidification efficiency is not much affected and both specific regeneration heat input and latent heat change of the process air decrease. For desiccant cooling applications in humid climates this is a positive trend.

Keywords
Desiccative cooling, desiccant wheels, adsorption, dehumidification

I. Introduction

A conventional air conditioner consumes large amont of electrical energy especially in hot and humid climatic conditions due to high latent load which is decide by the outside contents. Desiccant wheel based hybrid air conditioning system is one of the promising alternative to handle the high latent load efficiently where sensible and latent heat of air are being removed separately. A desiccant wheel is very similar to a thermal wheel, but with a coating applied for the sole purpose of dehumidifying or 'drying' the air stream. The desiccant is normally Silica Gel. As the wheel turns, the desiccant passes alternately through the incoming air where the moisture is adsorbed, and through a "regenerating" zone where the desiccant is dried and the moisture expelled. The wheel continues to rotate and the adsorbent process is repeated. Regeneration is normally carried out by the use of a heating coil, such as a water or steam coil, or a direct-fired gas burner.

Thermal wheels and desiccant wheels are often used in series configuration to provide the required dehumidification as well as recovering the heat from the regeneration cycle. A desiccant material can be described as a material that naturally attracts moisture from both gases and liquids. This moisture is then adsorbed or retained within the desiccant and can be released again when heated. There are various types of desiccant available on the market, but all Aggreko dehumidifier's use what is known as Silica Gel as the desiccant within the drying wheels. Strangely silica gel is not a "gel" as the name implies, but in fact a porous granular form of silica which is made from sodium silicate. The internal structure of each silica granule is made up of a network of interconnecting microscopic pores, which by a process called physical adsorption or capillary condensation, attract and holds moisture within each granule. This trapped moisture can then, with the addition of heat, be released from the desiccant. This desiccant can then be used again and again. As low ambient temperatures do not restrict the material, it makes it a more all season drying system.

A thermal wheel, also known as a rotary heat exchanger, or rotary air-to-air enthalpy wheel, or heat recovery wheel, is a type of energy recovery heat exchanger positioned within the supply and exhaust air streams of an air handling system, or in the exhaust gases of an industrial process, in order to recover the heat energy. Other variants include enthalpy wheels and desiccant wheels. A cooling-specific thermal wheel is sometimes referred to as a Kyoto wheel.

A. Description

1) A thermal wheel consists of a circular honeycomb matrix of heat-absorbing material, which is slowly rotated within the supply and exhaust air streams of an air handling system. As the thermal wheel rotates heat is picked up from the exhaust air stream in one half of the rotation, and given up to the fresh air stream in the other half of the rotation. Thus waste heat energy from the exhaust air stream is transferred to the matrix material and then from the matrix material to the fresh air stream, raising the temperature of the supply air stream by an amount proportional to the temperature differential between air streams, or 'thermal gradient', and depending upon the efficiency of the device.

2) Heat exchange is most efficient when the streams flow in opposite directions, since this causes a favourable temperature gradient across the thickness of the wheel. The principle of course works in reverse and 'cooling' energy can be recovered to the supply air stream if so desired and the temperature differential allows.

3) The heat exchange matrix is normally manufactured in aluminium, which has good heat transfer properties, but can also be manufactured from plastics and synthetic fibres. The heat exchanger is rotated by a small electric motor and belt drive system. The motors are often inverter speed controlled for improved control of the leaving air temperature. If no heat exchange is required then the motor can be stopped altogether.

4) Because of the nature of thermal wheels in the way that heat is transferred from the exhaust air stream to the supply air stream without having to pass directly through or via an exchange medium, the gross efficiencies are usually much higher than that of any other air-side heat recovery system. The shallower depth of the heat exchange matrix, as compared to that say for a plate heat exchanger, means that the pressure drop through the device is normally lower in comparison.

5) Generally a thermal wheel will be selected for face velocities between 1.5 and 3.0 m/s, and with equal air volume flow rates gross 'sensible' efficiencies of 85% can be expected. Although there is a small extra energy requirement to rotate the wheel, the motor energy consumption is usually very low and has little effect upon the seasonal efficiency of the device. In addition, the ability to recover 'latent' heat, depending upon the materials and coatings used, can improve gross efficiencies by some 10% to 15%.

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6) Energy transfer process: Normally the heat transfer between airstreams provided by the device is termed as 'sensible', which is the exchange of energy, or enthalpy, resulting in a change in temperature of the medium (air in this case), but with no change in moisture content. However, if moisture or relative humidity levels in the return air stream are high enough to allow condensation to take place in the device, then this will cause 'latent' heat to be released and the heat transfer material will be covered with a film of water.
7) Despite a corresponding absorption of latent heat, as some of the water film is evaporated in the opposite airstream, the water will reduce the thermal resistance of the boundary layer of the heat exchanger material and thus improve the heat transfer coefficient of the device, and hence increase efficiency. The energy exchange of such devices now comprises both sensible and latent heat transfer; in addition to a change in temperature, there is also a change in moisture content of the air streams.
8) However, the film of condensation will also slightly increase pressure drop through the device, and depending upon the spacing of the matrix material, this can increase resistance by up to 30%. This will increase fan energy consumption and reduce the seasonal efficiency of the device. Aluminium matrices are also available with an applied hygroscopic coating, and the use of this, or the use of porous synthetic fibre matrices, allows for the adsorption and release of water vapour, at moisture levels much lower than that normally required for condensation and latent heat transfer to occur.
9) The benefit of this is even higher heat transfer efficiency, but it also results in the drying or humidification of airstreams, which may also be desired for the particular process being served by the supply air.For this reason these devices are also commonly known as an Enthalpy Wheel.

B. Definition of Air Cooler

An evaporative cooler (also swamp cooler, desert cooler and wet air cooler) is a device that cools air through the evaporation of water. Evaporative cooling differs from typical air conditioning systems which use vapour-compression or absorption refrigeration cycles. Evaporative cooling works by employing water's large enthalpy of vaporization. The temperature of dry air can be dropped significantly through the phase transition of liquid water to water vapour (evaporation), which can cool air using much less energy than refrigeration. In extremely dry climates, evaporative cooling of air has the added benefit of conditioning the air with more moisture for the comfort of building occupants.A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power-plants, plants, petrochemical, petroleum-refineries, natural gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air. Air cooling is a process of lowering air temperature by dissipating heat. It provides increased air flow and reduced temperatures with the use of cooling fins, fans or finned coils that move the heat out of a casing such as a computer case.

C. Hygroscopic Material

Hygroscopy is the ability of a substance to attract and hold water molecules from the surrounding environment. This is achieved through either absorption or adsorption with the absorbing or adsorbing material becoming physically "changed" somewhat, by an increase in volume, stickiness, or other physical characteristic of the material, as water molecules become "suspended" between the material's molecules in the process. While some similar forces are at work here, it is different from capillary attraction, a process where glass or other "solid" substances attract water, but are not changed in the process (for example, water molecules becoming suspended between the glass molecules).
Hygroscopic substances include cellulose fibres (such as cotton and paper), sugar, caramel, honey, glycerol, ethanol, methanol, diesel-fuel, sulphuric-acid, methamphetamine, many fertilizer chemicals, many salts (including table salt), and a wide variety of other substances. Zinc and calcium-chloride, as well as potassium hydroxide and sodium hydroxide (and many different salts), are so hygroscopic that they readily dissolve in the water they absorb: this property is called deliquescence. Not only is sulphuric acid hygroscopic in concentrated form but its solutions are hygroscopic down to concentrations of 10 Vol % or below. A hygroscopic material will tend to become damp and "cake" when exposed to moist air (such as the salt inside salt shakers during humid weather). Because of their affinity for atmospheric moisture, hygroscopic materials might require storage in sealed containers. When added to foods or other materials for the express purpose of maintaining moisture content, such substances are known as humectants.

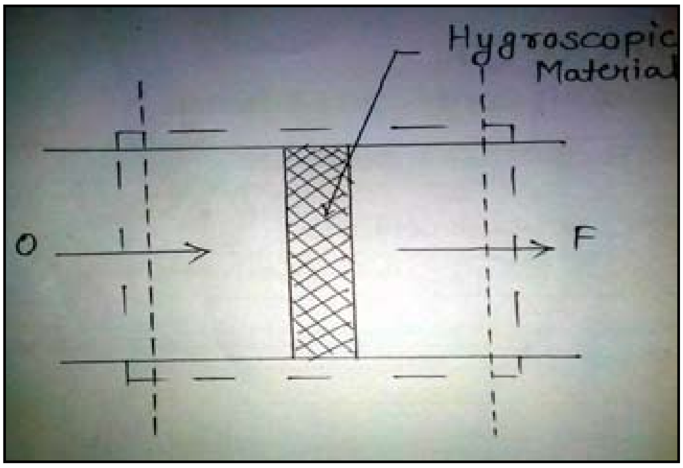

Fig. 1.4.1: Hygroscopic Material

Descriptive of a substance that has the property of adsorbing or absorbing moisture from air. The water vapour molecules are held by or bound within the molecules of the hygroscopic material. Desiccants are hygroscopic materials, e.g. silica gel, molecular sieve, lithium chloride or calcium chloride. Some other examples are dry powders as used in pharmaceuticals, baked goods, and confectionery ingredients. Other materials include cardboard including cardboard boxes used as containers for stored goods.

D. Desiccant Wheel

A desiccant wheel is very similar to a thermal wheel, but with a coating applied for the sole purpose of dehumidifying or 'drying' the air stream. The desiccant is normally Silica Gel. As the wheel turns, the desiccant passes alternately through the incoming air where the moisture is adsorbed, and through a "regenerating" zone where the desiccant is dried and the moisture expelled. The wheel continues to rotate and the adsorbent process is repeated.

Regeneration is normally carried out by the use of a heating coil, such as a water or steam coil, or a direct-fired gas burner.

A thermal wheel, also known as a rotary heat exchanger, or rotary air-to-air enthalpy wheel, or heat recovery wheel, is a type of energy recovery heat exchanger positioned within the supply and exhaust air streams of an air handling system, or in the exhaust gases of an industrial process, in order to recover the heat energy. Other variants include enthalpy wheels and desiccant wheels. A cooling-specific thermal wheel is sometimes referred to as a Kyoto wheel.

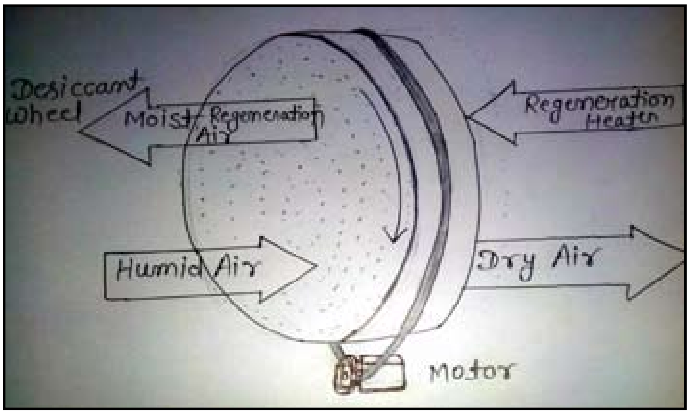

Fig. 1.5.1: Desiccant Wheel

A thermal wheel consists of a circular honeycomb matrix of heat-absorbing material, which is slowly rotated within the supply and exhaust air streams of an air handling system. As the thermal wheel rotates heat is picked up from the exhaust air stream in one half of the rotation, and given up to the fresh air stream in the other half of the rotation. Thus waste heat energy from the exhaust air stream is transferred to the matrix material and then from the matrix material to the fresh air stream, raising the temperature of the supply air stream by an amount proportional to the temperature differential between air streams, or 'thermal gradient', and depending upon the efficiency of the device. Because of the nature of thermal wheels in the way that heat is transferred from the exhaust air stream to the supply air stream without having to pass directly through or via an exchange medium, the gross efficiencies are usually much higher than that of any other air-side heat recovery system. The shallower depth of the heat exchange matrix, as compared to that say for a plate heat exchanger, means that the pressure drop through the device is normally lower in comparison .Generally a thermal wheel will be selected for face velocities between 1.5 and 3.0 m/s, and with equal air volume flow rates gross 'sensible' efficiencies of 85% can be expected. Although there is a small extra energy requirement to rotate the wheel, the motor energy consumption is usually very low and has little effect upon the seasonal efficiency of the device.

E. The Drying Process

1) The desiccant wheel rotates slowly. As air is drawn through the wheel, the water molecules are removed and retained by the silica gel that is impregnated within the wheel itself.
2) The air is now dry and is blown into the room or building. This dry air encourages evaporation to take place and therefore buildings, etc. become dry.
3) The water now trapped in the wheel is removed by heating the wheel and the vaporised water is blown outside. The basic idea of the Munster's desiccant drying wheel (Rotor) is very simple: Air is blown though the rotor structure and the humidity in the air is absorbed by the desiccant.
4) The air leaves the rotor as Dry Air. A drive motor turns the rotor around slowly (6-10 times an hour). The rotor structure passes a separate sector where hot (reactivation) air is blown through the rotor to remove the accumulated moisture. The resulting wet air (which contains the removed moisture) is blown away outside.
5) The rotor consists of a corrugated fibreglass structure, which contains a hygroscopic material (desiccants such as silica gel or lithium-chloride). Munster's innovative rotor design is constantly ongoing and 6 different rotor types are available to suit our customer's individual requirements.

II. Air Cooler

- Air cooling is a process of lowering air temperature by dissipating heat. It provides increased air flow and reduced temperatures with the use of cooling fins, fans or finned coils that move the heat out of a casing such as a computer case.
- The technique involves increased airflow over the target that needs to cooled, or increasing the surface area of the object to help disburse heat.
- There are various techniques used that include cooling fins, fans or finned coils. Components in many electronics produce mass amounts of heat that can cause damage. A central processing unit (CPU) uses a cooling fan or heat sink to disperse heat that is clipped or mounted on top of the CPU. CPUs also add fins as part of their heat sink.
- Air cooling is limited by heat density. It has low density and cannot sufficiently cool a small overheated component. Because air has limited mass, it can heat up in confined areas. Air cooling is ideal with components that have a larger mass and bigger surface area.

A. History of Evaporative Cooling Technology

Civilizations throughout the ages have found ingenious ways to combat the heat in their region. An earlier form of air cooling, the wind catcher was invented in Persia (Iran) thousands of years ago in the form of wind shafts on the roof, which caught the wind, passed it over subterranean water in quanta and discharged the cooled air into the building. Nowadays Iranians have changed the wind catcher into an evaporative cooler (Cooler Abe) and use it widely. There are 9 million evaporative coolers in central Iran, and in just the first two months of year 1385 in the Persian/Iranian calendar (April–May 2006) 130,000 evaporative coolers were sold in Iran.

The evaporative cooler was the subject of numerous US patents in the 20th century; many of these, starting in 1906, suggested or assumed the use of excelsior (wood wool) pads as the elements to bring a large volume of water in contact with moving air to allow evaporation to occur.

A typical design, as shown in a 1945 patent, includes a water reservoir (usually with level controlled by a float valve), a pump to circulate water over the excelsior pads and a squirrel-cage fan to draw air through the pads and into the house. This design and this material remain dominant in evaporative coolers in the American Southwest, where they are also used to increase humidity. In the United States, the use of the term swamp cooler may be due to the odour of algae produced by early units.

Evaporative cooling was in vogue for aircraft engines in the 1930s, for example with the Beardmore Tornado airship engine. Here the system was used to reduce, or eliminate completely,

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the radiator which would otherwise create considerable drag. In these systems the water in the engine was kept under pressure with pumps, allowing it to heat to temperatures above 100°C, as the actual boiling point is a function of the pressure. The superheated water was then sprayed through a nozzle into an open tube, where it flashed into steam, releasing its heat. The tubes could be placed under the skin of the aircraft, resulting in a zero-drag cooling system.

However these systems also had serious disadvantages. Since the amount of tubing needed to cool the water was large, the cooling system covered a significant portion of the plane even though it was hidden. This added complexity and reliability issues. In addition this large size meant it was very easy for it to be hit by enemy fire, and practically impossible to armour.

British and U.S. developers used ethylene glycol instead, cooling the liquid in radiators. The Germans instead used streamlining and positioning of traditional radiators. Even the method's most ardent supporters, Heinkel's Günter brothers, eventually gave up on it in 1940.

Externally-mounted evaporative cooling devices (car coolers) were used in some automobiles to cool interior air often as aftermarket accessories. Until modern vapour-compression air conditioning became widely available.

B. Air Cooling

Air-Cooling is the oldest and, in many ways, the easiest method of cooling electronics, whether it is through fan-driven forced convection or simply natural convection. However, with the increasing speed of processors, shrinking of form factors, and expansion of device functionality, air-cooling has begun to find itself on the outside looking in as new cooling technologies are sought, and new developments in solid-state cooling, such as thermo electrics, and liquid cooling, such as two-phase micro channels, have become more popular in the heat transfer research community. Yet, because it is cheap, easy-to-implement, and a "known quantity," forced convection air-cooling remains a very attractive approach for thermal management. Further, since in most cases, particularly in portable electronic devices, the entire heat load is eventually dissipated to ambient air, it will always be a critical component of any cooling solution.

C. Dehumidifier

A dehumidifier is generally a household appliance which reduces the level of humidity in the air, usually for health or comfort reasons, or to eliminate musty odour. Excessively humid air can cause mould and mildew to grow inside homes, both of which pose numerous health risks. Humid climates, or humid air within buildings, make some people extremely uncomfortable, causing excessive body perspiration that can't evaporate in the already-moisture-saturated air. It can also cause body moisture precipitation that can disrupt sleeping, create a situation where the cold pipes in this area begin to drip (from the condensation), and can prevent laundry from drying thoroughly enough to prevent mustiness. Lower humidity is also preferred because it limits the population of most pests, including clothes moths, fleas, cockroaches, woodlice and dust mites. Relative humidity in dwellings is preferably 30 to 50 per cent.

By their operation, dehumidifiers extract water from the conditioned air. This collected water (usually called condensate) cannot be used for drinking, so it must be discarded. Some designs, such as the ionic membrane dehumidifier, dispose of excess water in a vapour rather than liquid form. The energy efficiency of dehumidifiers can vary widely.

D. Desiccant Dehumidification

Dehumidification is the removal of moisture from air. Thought of in another way, dehumidification is the drying of air. The degree of dehumidification varies with the application requirements and greatly influences the type of equipment utilized. Most engineers are familiar with mechanical dehumidification. A process of cooling an air-stream to below its dew point temperature causing moisture to condense from the air. This process frequently requires re-heating of the air to avoid supplying saturated air to a space.

Desiccant dehumidification is becoming more familiar. Many engineers are just becoming knowledgeable concerning the use of desiccants for dehumidification. Desiccant dehumidifiers utilize a "sorption" material to attract and hold moisture from air. Once the sorption material, called a desiccant, is "saturated" with moisture, it can be reactivated or regenerated. Reactivation is usually accomplished by thermal means and restores the desiccant's dehumidification capacity. The mass exchange of the moisture from and to an air. Desiccant dehumidifiers are required for use below the frost point where mechanical refrigeration type dehumidifiers experience freezing on the coil surface or when dehumidification is required, but cooling is not, such as for dry goods storage or preservation requirements.

Desiccant dehumidification is also utilized to provide for humidity control independent of temperature control in occupied spaces. Desiccant dehumidifiers are available with either dry or liquid desiccants. Dry desiccants are available with either adsorption or absorption desiccants. Desiccant dehumidifiers utilize a dry adsorption type desiccant. The removal of water vapours from air. Dehumidification can be accomplished by cooling an air stream to below its dew point temperature causing the condensation of vapours or by desiccant adsorption/absorption resulting in removal of humidity from air in the vapour phase.

Desiccant dehumidification is an important "air-conditioning" process by which many industrial processes or products are improved or even possible. And now, desiccant dehumidification is being utilized in commercial HVAC applications too. Improvements in desiccant performance and manufacturing are currently encouraging. With these improvements, desiccant-based equipment holds the promise of successful incorporation into more and more commercial HVAC applications. Such equipment is intended to reduce the adverse affects of untreated humidity contained in ventilation air as well as generated sources of humidity from within commercial buildings.

Dehumidified ventilation air allows the HVAC designer another option towards improving Indoor Air Quality (IAQ) which may have been adversely affected by moisture allowing the growth of mould and mildew, etc. Dehumidified air does increase the efficiency of sensible cooling equipment and increases the comfort and productivity of building occupants.

Advantages & Limitations of Desiccants (Compared to Mechanical DH) are given as follows:-

Advantages of Desiccants:

- Dries easily below 40°F dew point
- Dries deeply - desiccant unit size usually smaller than mechanical DH
- Responds in minutes - precise control is easy
- Dries in cold weather - advantage for unheated storage and

building drying
- Can use cheap heat - reducing electric usage
- Equipment sometimes costs less

Limitations:
- Poor efficiency - 1500 to 4000 Btu/lb of water removed
- Needs supplemental cooling in most applications
- Support depends mostly on manufacturer (limited 3rd-party service)
- Equipment sometimes costs more

E. Working Process
In a typical dry desiccant system, the desiccant is mounted on a rotating wheel. As the wheel turns, the desiccant passes alternately through the incoming process air where the moisture is adsorbed and through a "regenerating" zone where the desiccant is dried and the moisture expelled. The wheel continues to rotate and the adsorbent process is repeated. Typically, about three-fourths of the desiccant wheel is exposed to the incoming air throughout the process. During regeneration, the desiccant is heated by a direct-fired gas burner or indirect-fired water or steam coil.

Moisture Removal:
The moisture removal capacity of a desiccant dehumidifier is related to several parameters. One parameter is the amount of "surface" area of the desiccant that is exposed to the air-stream. Each rotor contains hundreds of square feet of sheet area per cubic foot of rotor volume. This surface area multiplied by the "internal" pore surface area results in thousands of square feet of area of desiccant available for adsorption. This tremendously high ratio of surface area to volume is one of the significant reasons for the excellent performance of the desiccant dehumidifier. The rotor speed is also optimized such that a maximum amount of desiccant is "rotated" through the process air-stream without causing over heating of the desiccant. By selecting the optimum speed of rotation, the adsorption cycle is carefully balanced against the de-sorption cycle. All desiccant dehumidification rotors are bearing supported for long life and dependable mechanical support. Rotors with a diameter larger than 20-inches are shaft mounted and bearing supported. The full weight of the rotor and the adsorbed moisture are supported by the shaft and bearing arrangement.

Adsorption:
Adsorption occurs when the attractive forces of a desiccant capture water vapour. The vapour is drawn to and adheres to the surface of the desiccant. The vapour is then drawn into the macro-pores and then the micro-pores by capillary action. In the process the moisture converts adiabatically from vapour to a quasiliquid and is stored within the desiccant. (An adiabatic process occurs without the external addition or removal of heat.) It is important to distinguish between the vapour quasi-phase changes as opposed to a desiccant phase change.

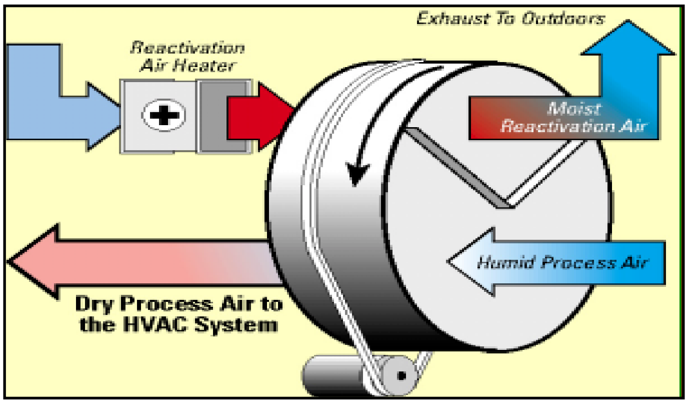

Fig. 2.5.1: Desiccant Wheel Dehumidifier

Desiccants, such as lithium chloride, which undergo a phase change, are known as absorbents. Desiccants like silica gel do not undergo a phase change during the adsorption process. Heat equivalent to the "heat-of-vaporization" and the "heat-of-wetting" taken together as the "heat of adsorption" is released to the air-stream as vapour is adsorbed by the desiccant.
This is similar to a mechanical process such that when vapour is condensed to liquid, the heat of vaporization is given up in the process. This explains why latent cooling requires more "tons of refrigeration" than does sensible cooling. The greater the amount of humidity adsorbed the higher the temperature rise of the dehumidified air-stream. This increase in sensible temperature is due to the conversion of latent heat to sensible heat by the action of the desiccant. The more efficient the dehumidification process, the warmer the temperature of the dehumidified air-stream will be.

Process Inlet:
Air to be dried. May be outside air, inside air or, more commonly, a mixture of air with high humidity content.

Process Outlet:
Air is dried by desiccant wheel. May be cooled, filtered or otherwise handled. Relative humidity is substantially lower and temperature slightly raised.

Reactivation Inlet:
Air flow, usually outside air, that drives moisture off wheel. Reactivation air is heated by direct-fired gas burner or indirect-fired water or steam.

Reactivation Outlet:
Hot, wet air from wheel is exhausted outside or passed through an air-to-air heat-exchanger. Using a heat exchanger to preheat incoming process air offers substantial savings in northern climates.

Dehumidification:
Active dehumidification is mechanical moisture removal intended to maintain comfort and protect building materials. There are two primary ways to actively dehumidify: by condensing moisture using a heat pump refrigerant-based DEH and by adsorbing moisture using a desiccant wheel - desiccant DEH. (We use the less-familiar term adsorption to describe how water molecules adhere to the surface of a material; absorption, in contrast, occurs uniformly throughout a material.) In refrigerant-based DEH

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units, the warm, moist air flows past metal coils cooled using a compression-expansion cycle; water condenses on the coils and collects in a reservoir or is piped to a drain. The cool, dry air then flows past the warm condenser section of the heat pump, leaving the dehumidifier dryer and warmer than when it entered.

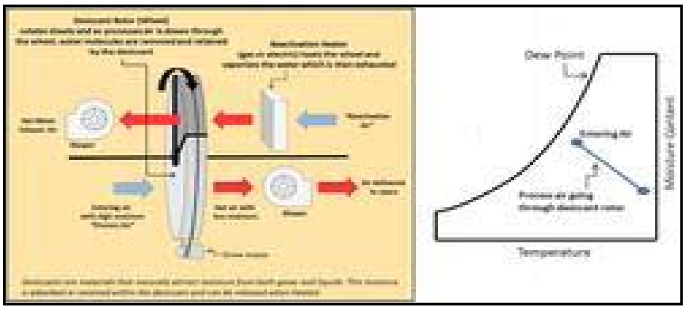

Fig. 2.5.2 : Dehumidification Process

Desiccant-based DEH units move interior moisture-laden air through a porous wheel, where a desiccant made of a material such as silica gel, activated charcoal, or other "molecular sieves" adsorbs water. After the moisture has been taken up by the desiccant, the wheel, rotating constantly, moves the moisture-laden section of the wheel to face another air stream called the reactivation air. This hot air drives the moisture off the wheel. While there is no condensate to manage, the damp reactivation air must be exhausted from the building. Both types of DEH require energy: to power fans that move air over the coils or through the wheel; to power the heat pump of the refrigerant-based DEH; to heat up the reactivation air of the desiccant-wheel DEH; and to drive the motor rotating the desiccant wheel. Both make the dried interior air warmer. The refrigerant-based heat pump, unlike an air conditioner, releases its waste heat into the interior air. The reactivation air of the desiccant-wheel unit heats up the wheel, with some of that heat staying with the wheel as it rotates back into the interior air stream. Both can be (and often are) tied in with active air conditioning, leading to more energy use. The unavoidable temperature rise of dehumidified air often means cooling it back down for occupant comfort. Operating a dehumidifier rather than a cooling or heating system to save energy is a strategy often used in storage buildings and in seasonally occupied or often-unoccupied buildings like schools, vacation homes, or condominiums (the waste heat is not an occupant comfort problem).
Refrigerant-based dehumidifiers are available as standalone equipment or can be ducted into a whole-building forced-air system. The standalone configuration, used commonly in residential basements, is probably the most familiar.
Desiccant-wheel units must have a ducted pathway for the regeneration air flow and to dump the warm, moist air to the outdoors. For this reason, desiccant wheel systems are almost always ducted into a whole-building forced-air system. When ducted into a forced-air system, both types of DEH are configured in parallel and not in series with the rest of the system, since both typically use lower flow rates (guaranteeing more contact time) to improve moisture removal.

F. Energy Transfer Process

Normally the heat transfer between airstreams provided by the device is termed as 'sensible', which is the exchange of energy, or enthalpy, resulting in a change in temperature of the medium (air in this case), but with no change in moisture content. However, if moisture or relative humidity levels in the return air stream are high enough to allow condensation to take place in the device, then this will cause 'latent' heat to be released and the heat transfer material will be covered with a film of water. Despite a corresponding absorption of latent heat, as some of the water film is evaporated in the opposite airstream, the water will reduce the thermal resistance of the boundary layer of the heat exchanger material and thus improve the heat transfer coefficient of the device, and hence increase efficiency.

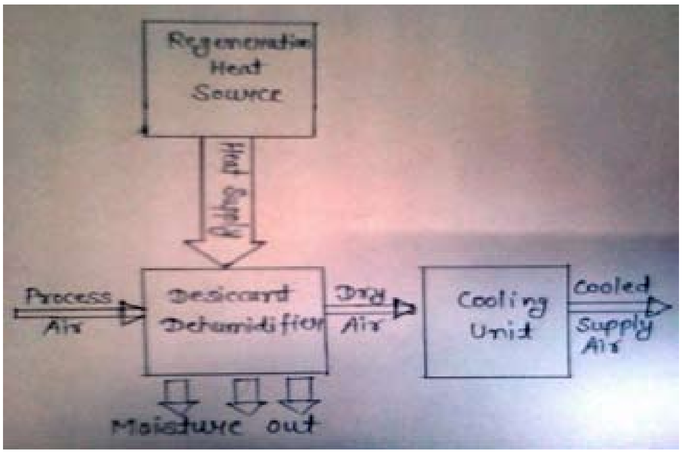

Fig. 2.6.1: Energy Transfer Process

The energy exchange of such devices now comprises both sensible and latent heat transfer; in addition to a change in temperature, there is also a change in moisture content of the air streams. However, the film of condensation will also slightly increase pressure drop through the device, and depending upon the spacing of the matrix material, this can increase resistance by up to 30%. This will increase fan energy consumption and reduce the seasonal efficiency of the device.

III. Problem Domain

- Objective is to produce comfort conditions for summer season using the approach of Desiccant Wheel Dehumidifier.
- Other system or machines are costly compare than Desiccant Wheel Dehumidifier.
- Comfort condition for summer season not provided by cooling system in effective way.
- More Maintenance required in other dehumidifier.
- Other machines consume more power to produce comfort condition for human beings.

IV. Material Requirement

- Fan
- Aspen pads
- Pipes
- Water tank
- Desiccant wheel
- Motor
- Hygroscopic material (silica gel)
- Heating coil
- Grills
- Pump
- Motors
- Nut and bolt
- Wires
- Switches
- Clamps

A. Methodology Of Desiccant Wheel Dehumidifier

1. Designing
2. Cooler frame making.
3. Motor fitting for direct evaporation.
4. Fan's fitting.
5. Grill's fitting outside of fans for safety purpose.
6. Switches and wire arrangement.
7. Pump connected through switch.
8. Aspen pads arrangement.
9. Making of water tank with tin sheets.
10. Iron frame on which water tank is situated.
11. Making of duct with plywood
12. Placing of GI sheet inside the duct
13. Cutting the desiccant wheel.
14. Placing the hygroscopic material i.e. silica gel.
15. Motor and pulley arrangement to rotate desiccant wheel
16. Connecting the desiccant wheel to the duct
17. Connecting the duct to the cooler grill.
18. Wire arrangement for all the motors and fan and Arrangement for heating coil.

V. Desiccantdehumidificationprocess

Desiccant Dehumidification Process can be achieved by using a hygroscopic material, which absorbs or adsorbs the water vapor from the moisture. If this process is thermally isolated, then the enthalpy of air remains constant, as a result the temperature of air increases as its moisture content decrease. The absorption of water by the hygroscopic material is an exothermic reaction. Theoretically the use of absorbent or chemical dehumidification to remove water vapour from an airstream is simply the reverse of the adiabatic humidification process and is shown in Figure. In HVAC this would typically be undertaken by a slowly rotating (**1** to **10** revolutions per minute) framework with a matrix packing coated with absorbent on a wheel. The actual performance will be determined by the effectiveness of the regeneration of the absorbent – the heating process that removes the moisture from the absorbent so that it can then be reused to absorb water vapour from the incoming air.

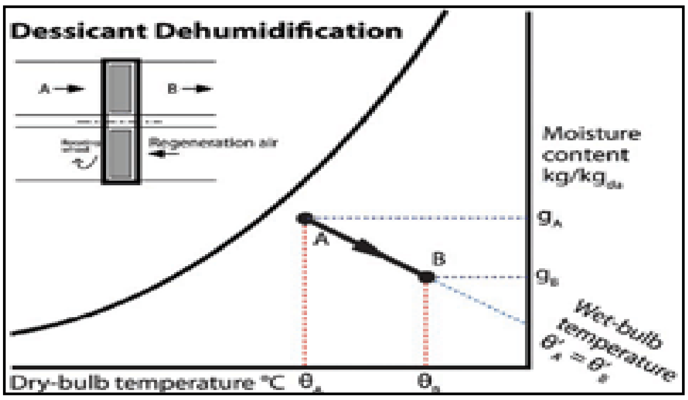

Fig.5.1: Desiccant Dehumidification Process

When considering heat recovery components in HVAC systems they will exchange either sensible heat, or both sensible and latent heat, from typically the discharge room air into the air being introduced from outdoors. An example of a sensible heat recovery process is shown in Figure. This is the psychrometric process that would characterise **sensible only** heat recovery in a plate heat exchanger, a (regenerative) thermal wheel or a run-around coil. The process is similar to that of a basic sensible heating or cooling process – depending on the temperature of the opposing airstream (and this air would be typically the air that is being extracted from the conditioned space). If the temperature of the incoming air, A, is below the dew point temperature, of the extracted air, θ_X, there may be some condensation in the airstream that is coming from the occupied space so providing increased heat exchange but, in the case of a simple plate heat exchanger, no transfer of water vapour.

A. Principle of Evaporative Cooling

The rudimentary basis for understanding any air conditioning, dehumidification and evaporative cooling is psychometrics. Psychometric consists of the interactions between heat, moisture and air. It is basically the study of air-water mixtures and is an essential foundation for understanding, how to change air from one condition to another. As air temperature rises, its capacity to hold moisture rises also; and warmer air becomes less dense. This makes moisture a very influential factor for heat gain, both for comfort and in calculations. The knowledge of systems consisting of dry air and water vapour is essential for the design and analysis of air conditioning devices, cooling towers, and industrial processes requiring close control of the vapour content in air. Air moisture and heat interactions are rather complex; fortunately, these interactions can be combined in a single chart (see figure below). However before explaining the details of how to use the chart, some terms, definitions, and principles used in the study of systems consisting of dry air and water must be introduced.

1. Dry Bulb Temperature (DBT)

The Dry Bulb Temperature refers to the ambient air temperature measured using a normal thermometer freely exposed to the air but shielded from radiation and moisture. It is called "Dry Bulb" because the air temperature is indicated by a thermometer not affected by the moisture of the air. The dry bulb temperature is an indicator of heat content of the air. As the DB temperature increases, the capacity of moisture the airspace will hold also increases. The dry bulb temperature is usually given in degrees Celsius (ºC) or degrees Fahrenheit (F). The SI unit is Kelvin (K). Zero Kelvin equals to -273 ºC.

2. Wet Bulb Temperature (WBT)

The Wet Bulb temperature is the temperature measured by using a thermometer whose glass bulb is covered by a wet wick/cloth. The wet bulb temperature is indicator of moisture content of air. Wet bulb temperature is very useful in evaporating cooling processes as the difference between the dry bulb and wet bulb temperature is a measure of the cooling efficiency. At 100% relative humidity, the wet bulb temperature equals dry bulb temperature.

3. Humidity

The term humidity describes the quantity of water vapour in air. If the air holds 50% of its capacity, the humidity would be 50%. If the humidity is low, then the capacity to hold more water is higher, and a greater amount of evaporation takes place. It can be expressed as an absolute, specific or a relative value.

4. Dew point

The Dew Point is the temperature at which water vapour starts to condense out of the air and becomes completely saturated. Above this temperature the moisture will stay in the air. The dew point temperature is an indicator of the actual amount of moisture in

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air. The dew-point temperature is expressed in degrees and like humidity ratio; it represents an absolute measure of the moisture in the air at a constant pressure. If the dew-point point is well below the air temperature, the relative humidity is low.

5. Sensible Heat

The heat used to change the temperature of the air. Sensible heat will always cause a change in the temperature of the substance.

6. Latent heat

Latent heat is the heat energy involved in the phase change of water. The heat will only change the structure or phase of the material without change to temperature.

7. Direct Evaporative Cooling (open circuit)

Direct evaporative cooling introduces water directly into the supply airstream (usually with a spray or some sort of wetted media). As the water absorbs heat from the air, it evaporates and cools the air. In direct evaporative cooling the dry bulb temperature is lowered but the wet bulb temperature remains unchanged. In operation, a blower pulls air through a permeable, water-soaked pad. As the air passes through the pad, it is filtered, cooled, and humidified. A recirculation pump keeps the media (pad of woven fibres or corrugated paper) wet, while air flows through the pad. To ensure that the entire media is wet, more water is usually pumped than can be evaporated and bottom into a sump. An automatic refill system replaces the excess water drains from the evaporated water.

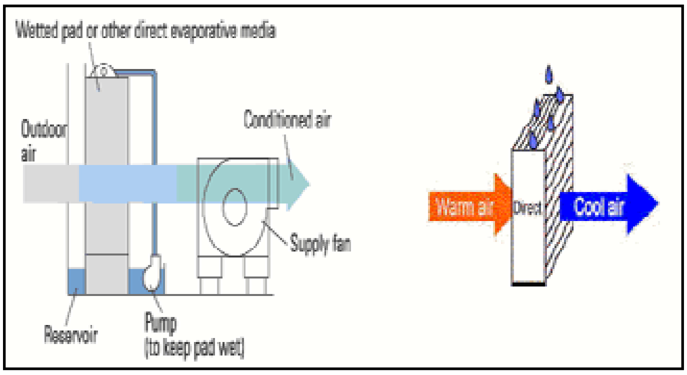

Figure 5.2 : Direct Evaporative Cooling System

The efficiency of direct cooling depends on the pad media. A good quality rigid cellulose pad can provide up to 90% efficiency while the loose aspen wood fibre pad shall result in 50 to 60% contact efficiencies.

B. Calculation

1. Specifications

- Direct contact evaporation-
- Height of upper body - 30 inches
- Width of upper body - 24 inches
- Length of upper body - 20 inches

Fig. 5.3 : Fabrication of cooler

2. Duct specification

- Length - 18 inch
- Width - 13 inch
- Height - 17 inch

Fig. 5.3.2:- Fabrication of Duct

3. Wheel specification-

- 18 inch diameter

Fig. 5.3.3: Fabrication of Desiccant Wheel

Fig. 5.3.4 : Complete Fabrication of Desiccant Wheel Dehumidifier

5.3.2 CMM & CFM

CFM - Cubic Feet per Minute
CMM - Cubic Meter per Minute

- Room Dimensions = 225sq feet
- Room dimensions = 225*11 cubic feet
- Room dimension = 2475 cubic feet
- Cooler for this dimension can be made as
- 2475/no of circulation
- No of circulation for ideal conditions = 20

So the air will be circulated 60 times in one hour
1 min air circulation = (60/20) = 3

5.3.3 RPM of Desiccant wheel

$N_1/N_2 = D_2/D_1$
$120/N_2 = 18/3$
$N_2 = 20$
Here, N_1 = revolutions of motor
N_2 = revolutions of desiccant wheel
D_1 = diameter of motor
D_2=diameter of desiccant wheel

5.3.4 Humidity measurement

Once the wet bulb temperature and the dry bulb temperature are identified, the cooling performance or leaving air temperature of the cooler may be determined:

$T_{LA} = T_{DB} – ((T_{DB} – T_{WB}) \times E)$
T_{LA} = Leaving Air Temp
T_{DB} = Dry Bulb Temp
T_{WB} = Wet Bulb Temp
E = Efficiency of the evaporative media.

With a typical summer day of 42°C DB/28°C WB or about 36% relative humidity, the leaving air temperature of the cooler would be:

T_{LA} = 42° – ((42° – 28°) x 85% efficiency) T_{LA} = 30°C
After direct contact evaporation,
Dry bulb temperature=30°C
Wet bulb temperature=27°C
Humidity=80%
After dehumidification, the readings are
DBT=32°
WBT=23°
Humidity=45%

5.3.5 Comparison

Condition of air	DBT (°C)	WBT (°C)	RH (%)
Atmospheric dry air	42	28	36
Cooled Air	30	27	80
Dehumidified air	32	23	45

VI. Effectiveness

Evaporative air-cooling creates cooler temperatures a number of ways:

It lowers effective temperature - the temperature you feel - by at least an additional 4º to 6º. In some cases, the temperature will be lowered more, depending on relative humidity. The rapid motion of cool air increases skin surface evaporation resulting in body heat loss. “... dry bulb temperature reduction due to the evaporation of water always results in a lower effective temperature, regardless of the relative humidity level” and that “. . . Evaporative cooling can provide relief cooling of factories almost regardless of geographical location.”

It reduces radiated heat- The constant flow of cool air absorbs heat from all exposed surfaces and results in a reduction of the heat radiated to the human body.

A. Advantages

1. Less expensive to install
   - Estimated cost for installation is about half that of central refrigerated air conditioning.
2. Less expensive to operate
   - Estimated cost of operation is 1/4 that of refrigerated air.
   - Power consumption is limited to the fan and water pump. Because the water vapor is not recycled, there is no compressor that consumes most of the power in closed-cycle refrigeration.
   - The refrigerant is water. No special refrigerants, such as ammonia, sulphur or CFCs, are used that could be toxic, expensive to replace, contribute to ozone depletion and/or be subject to stringent licensing and environmental regulations.
3. Unmatched dehumidification efficiency.
4. Temperature-neutral operation provides effective refrigeration capacity.
5. Capable of lower dew points than conventional technology.
6. Prevents mould, mildew and dust mite growth.
7. Independent humidity control maintains comfort at higher dry-bulb set point.
8. preserves building materials by lowering equilibrium moisture content.
9. Eliminating condensation or other collected water.

B. Disadvantages

Thermal wheels are not suitable for use where separation of supply total and exhaust air streams is required, since air will bypass at the interface between the air streams at the heat exchanger boundary, and at the point where the wheel passes from one air stream to the other during its normal rotation. Matrices made from fibrous materials, or with hygroscopic coatings, for the transfer of latent heat, are far more susceptible to damage and degradation by ‘fouling’ than for plain metal or plastic materials, and are difficult or impossible to effectively clean if dirty.

1. Performance

- High dew point (humidity) conditions decrease the cooling capability of the evaporative cooler.
- No dehumidification. Traditional air conditioners remove moisture from the air, except in very dry locations where recirculation can lead to a build-up of humidity. Evaporative cooling adds moisture, and in humid climates, dryness may improve thermal comfort at higher temperatures.

2. Comfort

- The air supplied by the evaporative cooler is typically 80–90% relative humidity; very humid air reduces the evaporation rate of moisture from the skin, nose, lungs, and eyes.
- High humidity in air accelerates corrosion, particularly in the presence of dust. This can considerably shorten the life of electronic and other equipment.

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- High humidity in air may cause condensation of water. This can be a problem for some situations (e.g., electrical equipment, computers, paper, books, and old wood).

3. Water

- Evaporative coolers require a constant supply of water to wet the pads.
- Water high in mineral content will leave mineral deposits on the pads and interior of the cooler. Depending on the type and concentration of minerals, possible safety hazards during the replacement and waste removal of the pads could be present. Bleed-off and refill (purge pump) systems may reduce this problem.

4. Mosquitoes

- An evaporative cooler is a common place for mosquito breeding. Various authorities consider a poorly maintained cooler to be a big threat to public health.

VII. Conclusion

Performance of the desiccant wheel based hybrid air conditioning system is evaluated conclusion can be made. For a chosen regeneration temperature, hybrid air conditioning system is economically up to certain humidity level compared to window air condition alone. If the regeneration temperature increase the load get completely separated there by performance of cooling coil improve a lot 70% to 80% performance of cooling coil is significantly governed by latent load. Hybrid air conditioning can be good option when the humidity level is high.

VIII. Future Scope Of The Project

- This desiccant wheel dehumidifier reduces the moisture level from the cooling air in more effective way compare than other system.
- This system is less costly compare than other system such as Air- Conditioner.
- This system has a good future because of its effectiveness and easier to use.
- This system is eco-friendly and because of this, the cooler covering the market at great level.
- This system is very useful in industries and party places.
- The improved design can make this a good domestic cooling system.
- The mechanism of desiccant wheel can be applied to coolers which have been made before.
- The whole mechanism can be adopted in one system and the body can be rotated around one axis at 180 degree.

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