Experimental Analysis of Solid Desiccant Wheel Dehumidifier

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ABSTRACT

Solid desiccant wheel dehumidifier is used for dehumidifying the ventilation air of an air conditioning system. Desiccant wheel dehumidifier has a wheel which is filled with solid desiccants, usually silica gel or activated alumina. It looks like honeycomb structure which is open on both ends. Air passes through the honeycomb passages, giving up moisture to the solid desiccant present in the wheel. The wheel constantly rotates through two separate air streams. The first air stream which is called the process air is dried by the desiccant. The second air stream called reactivation or regeneration air is heated and dries the desiccant. The performance of desiccant wheel at different air flow rates, regeneration temperature and at different inlet conditions has been conducted and the graph of Effect of Inlet Humidity Ratio on Outlet Humidity Ratio, Effect of Air Mass Flow Rate on Outlet Humidity Ratio, Effect of Regeneration Temperature on Outlet Humidity Ratio, Effect of Inlet Humidity Ratio on Outlet Temperature has been studied. It can be seen that when air is more humid entering the dehumidifier, it will be more humid leaving the unit. Process air outlet temperature is higher than inlet air temperature because the heat of sorption of moisture is removed from the air and converted to sensible heat and if air must be dried very deeply, a large unit (slower air velocities) must be used. The effect of regeneration temperature on outlet humidity ratio is also studied and it can be seen that as regeneration temperature increases more moisture is removed from the process air.

Keywords: *Desiccant Wheel, Desiccants, Humidity Ratio, Regeneration Temperature, Silica Gel.*

1. INTRODUCTION

Desiccant based air-conditioning systems offers a promising alternative to vapour compression refrigeration air-conditioning systems especially, under conditions involving high latent loads. This technique allows the use of low-temperature industrial waste heat or solar power to drive the cooling cycle. Therefore, it attracted increased research attention during the last two decades. Desiccants are chemicals with great affinity to moisture. They absorb/release moisture because of the variation in vapour pressure between the surface of the desiccant and the surrounding air. Dehumidification will occur when the vapour pressure of the surface of the desiccant is less than that of the environmental air. Dehumidification continues till the desiccant material reaches equilibrium with the surrounding air. Regeneration of this desiccant will occur when the vapour pressure of the desiccant is larger than that of the surrounding air, which is usually accomplished by heating the desiccant to its regeneration temperature and exposing it to an air stream. Desiccants can be classified as adsorbents which absorb moisture without considering physical and chemical changes or absorbents which absorb moisture by considering physical or chemical changes. Desiccants can be solids or liquids and can hold moisture through adsorption or absorption . Most absorbents are liquids and most adsorbents are solids. Several types of solid desiccants are mostly used in desiccant cooling systems; silica gels, lithium chloride and molecular sieves. Different methods of dehumidification- In Air bypass control method a portion of the return air is bypassed from the cooling coil. This gives less reheat requirement. In Heat pipe system method, precooling of mixed air and reheating of conditioned air can be achieved by introducing a heat pipe between the above air streams. This is also an energy saving device. In Air reheat system method, by selecting the dew point temperature of the coil and reheating the conditioned air to achieve the desired temperature and humidity. This method was widely adopted earlier. It is an energy inefficient method and many countries have banned this method. In Desiccant cooling systems moisture in air is removed by a desiccant that absorbs the moisture when air passes through it.These desiccants can be either solid or liquid. They can be used efficiently to overcome the latent part of the cooling load. Desiccant technology for moisture removal is appropriate where sensible heat ratio (SHR) is low as in high humid locations and applications where precise humidity control is required.

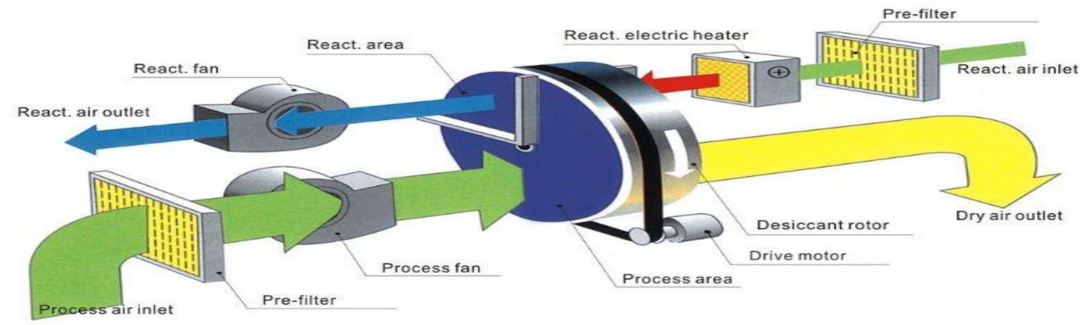

Figure 1. Working of Desiccant Wheel Dehumidifier

In desiccant wheel dehumidifier, the desiccant material usually a silica gel or some type of zeolite, is impregnated into a supporting structure. This looks like a honeycomb which is open on both ends. Air passes through the honeycomb passages, giving up moisture to the desiccant present in the walls of the honeycomb cells. The wheel constantly rotates through two different air streams. The first stream, namely the process air, is dried by the desiccant. During this process the heat of absorption is released to the air. The second air stream, called reactivation or regeneration air, is heated. It dries the desiccant. The regeneration air can be heated by solar collectors, electric heaters, gas burners, or waste heat sources.

2. LITERATURE REVIEW

Many experiments have been carried out to use both liquid and solid desiccants in air conditioning systems. M.A. Mandegari and H. Pahlavanzadeh [1] concluded that the solid desiccants show considerable promise producing a higher degree of the humidification than the liquid desiccants. The electrical energy requirement can be very low comparing with conventional cooling systems. The origin of thermal energy can be distinct (i.e., solar, waste heat, natural gas) [2]. Having low coefficient of performance can be considered as the main disadvantage for desiccant cooling systems. COP values ranging from 0.8 to 1 are commonly predicted for this cycle. COP or coefficient of performance is defined as the ratio of space cooling to thermal energy required to regenerate the desiccant. Kodama A, Goto M, Hirose T, Kuma T. [3] showed that the dehumidifier is the prime component of a desiccant cooling system and the cooling COP (coefficient of performance) is significantly improved by enhancing the performance of this component.

T.S. Ge, Y. Li, [4] et al studied the performance of a novel two-stage rotational desiccant cooling (TSRDC) system. Newly developed compound desiccant (silica gel–haloids) was carried out in the system. An experimental set-up was made and used to test the system performance under three typical

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environmental states. System performances were calculated in terms of moisture removal and thermal coefficient of performance COPth. It has found that the needed regeneration temperature of TSRDC system is low and COPth of the system is high. Regeneration temperatures from 65 ºC to 80 ºC, 65 ºC to 75 ºC and 80 ºC to 90 ºC were recommended for each environmental condition. Niu et. al [5] have done the modeling of a desiccant wheel used for dehumidifying the ventilation air from an air-conditioning system. The simulation of the combined heat and mass transfer processes that occur in a solid desiccant wheel is carried out. Using the numerical method, the performance of an adiabatic rotary dehumidifier is parametrically studied, and the favourable rotational speed is determined by examining the outlet adsorption-side humidity profiles**.**

3. EXPERIMENTAL SETUP

A wheel of 30 cm diameter has been constructed using mild steel flat. Wheel has been constructed by using five 12.5cm width and 3cm depth flat by welding such that it has a groove for V belt drive. Wheel has been divided into 8 by welding spokes in between rim and shaft .Desiccant material Silica gel is stuffed in place between the spokes in the wheel. A box has to design so that wheel has kept inside it. Box has made in square shape with 38 cm mild steel sheets. There is a separation in box dividing into top and bottom halves for that a steel plate is welded between them.

Figure 2. Solid Desiccant Dehumidifier Set Up

Top half is the region where process air to dehumidify flows and the bottom half where regeneration air flows. Two holes of diameter 4 inch were made on the either faces of the box. Two blowers of 2.3 m^3/min is bolted to the box at the outlet section of the either passage. The wheel has placed in the middle of the box and its running motor of 5 rpm is placed adjacent to it. A small gap is provided in the middle of the box for placing the wheel and smooth run of the wheel. The wheel and its supporting structure is weld to the bottom of the box. In the inlet side of regeneration side, an air heater is placed inside the GI pipe to heat the air in order to regenerate the Silica gel.

Figure 3. Desiccant Wheel

Silica gels are solid desiccants and adsorbents and they have numerous pores and capillaries in which water is condensed and kept. Silica gel has a very high capacity to absorb moisture and then release it at a higher temperature. A chemically inert, non flammable, non toxic material composed of amorphous silicon dioxide. It has an internal network of interconnecting minute pores, yielding a surface area of 700-800 square meters per gram. It has large intake capacity for water which has a high latent heat of vapourisation; up to 40% of its dry mass. Water molecules are absorbed or desorbed by these micro capillaries until vapour pressure equilibrium is achieved with the relative humidity of the surrounding air. When compared with other absorbents, silica gel can be regenerated at a relatively low temperature (typically around 8500C). It is low in cost and available in sizes from 3/16 inch beads to powder-like grains.

Fig 4. Silica Gel

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The rotational speed of a rotary desiccant dehumidifier is inversely proportional to the sorption time. The rotational speed of a rotary desiccant dehumidifier is most favourable when the average outlet humidity ratio of the process air flow is the minimum. When a desiccant wheel rotates much faster than optimum speed, the adsorption and regeneration processes are too small, which results in poor performance. Also, when the rotational speed is low, the adsorption and regeneration processes are too long and are less effective too. Therefore from experimental analysis optimum rotational speed of desiccant wheel is around 25-30 rph. In our experiment the optimum speed we choose is 27 rph.. For obtaining this rph a small ac synchronous motor of 5 rpm is used and a pulley of diameter 3 cm diameter is connected it to the shaft of ac motor the desiccant wheel is of 30 cm diameter and by using belt drive to drive the wheel and thereby obtaining the necessary speed reduction.

Table 1. Specification of the Measuring Devices

Devices	Types	Accuracy	Operating Range	Fluid
Thermometers	T-type thermocouples	1^0C	-200 to 350 C	Air and Liquid
Hygrometer	Capacitive probe	±2%RH	0 to 100% RH	Air
Air Flow meter	Vane type Anemometer	±2%	0 to 30 m/s	Air

4. RESULTS AND DISCUSSION

Process air outlet temperature is more than the inlet air temperature primarily because the heat of sorption of moisture being removed from the air is converted to sensible heat. The heat of sorption includes the latent heat of condensation of the removed moisture along with additional chemical heat, which varies depending on the desiccant type and process air outlet humidity. Also, some heat is transferred to the process air from the reactivation sector because the desiccant remains hot as it enters the relatively cooler process air. Generally, 80 to 90% of the temperature rise of process air is from the heat of sorption, and the balance is from heat carried over from reactivation. Below is the table showing inlet temperature and its corresponding outlet temperature measured during experiment.

Table 5.1: Experimental Values of Outlet and Inlet Temperature

Inlet Temperature(^{0}C)	Outlet temperature(^{0}C)
28.1	34.3
28.6	34.6
29.2	35.5
29.8	35.9
30.4	36.8
31.7	37.8
32.3	38.2
32.9	38.8

4.1 Effect of Inlet Humidity Ratio on Outlet Humidity Ratio

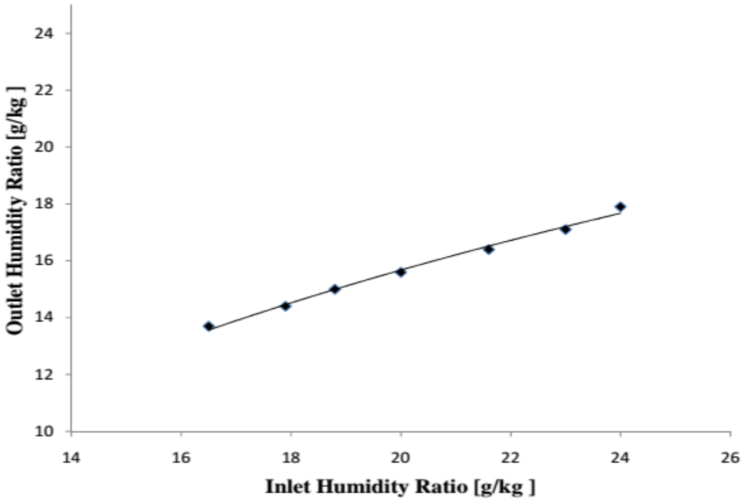

Figure 4.1 Variation of Outlet Humidity Ratio with Inlet Humidity Ratio

Process air inlet moisture content affects outlet moisture. If air is more humid entering the dehumidifier, it will be more humid leaving the unit. For example, Figure indicates that for an inlet humidity of 17 g/kg, the outlet humidity will be 13.75g/kg. If inlet moisture content rises to 23 g/kg, the outlet humidity rises to 17.25 g/kg. If moisture entering is higher than expected, the process air will be warmer than expected, so if a constant temperature leaving the system is important, additional cooling will be necessary. If moisture is less than expected, the air will leave drier than expected, so if constant moisture leaving the system is important, less air should be processed through the dehumidifier. Therefore, if constant outlet humidity is necessary, the dehumidifier needs capacity control unless the process inlet airstream does not vary in temperature or moisture throughout the year.

4.2 Effect of Air Mass Flow Rate on Outlet Humidity Ratio

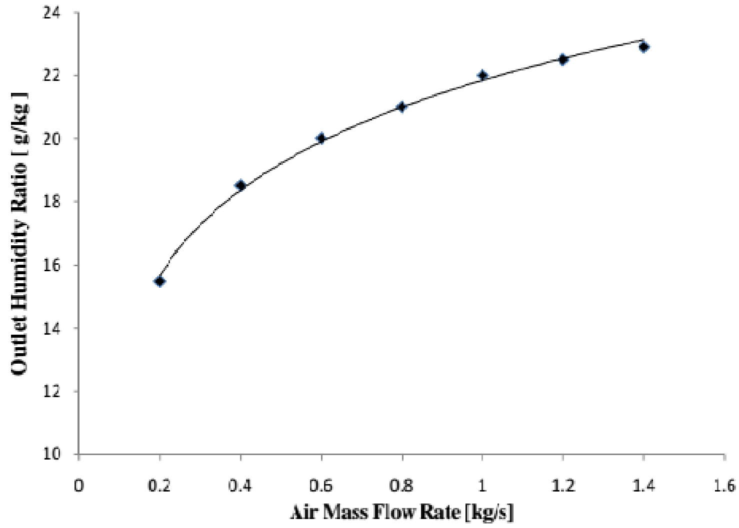

Figure 4.2 Variation of Outlet Humidity Ratio With Air Mass Flow Rate

The variation of the outlet humidity ratio with different mass flow rates is also plotted. It can be seen that the humidity ratio at the outlet increases with an increase in the air mass flow rate. This is because the residence time of the process air in the desiccant channels is reduced when the air velocity increases as a result more molecules escape the desiccant wheel without getting adsorbed into the desiccant wheel surface.

4.3 Effect of Regeneration Temperature on Outlet Humidity Ratio

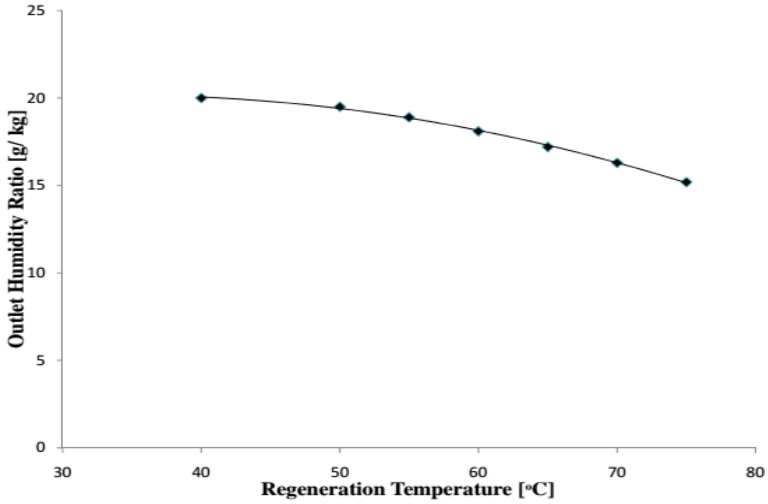

Figure 4.3 Variation of Outlet Humidity Ratio with Regeneration Temperature

In a rotational dehumidifier, the desiccant is heated by air entering reactivation. The hotter the desiccant, the more easily it vapourises the moisture, so the reactivation air temperature has a strong effect on performance. Essentially, drier the desiccant becomes in reactivation, more the moisture it can absorb when it rotates into the process air stream. The inlet temperature of the reactivation air changes the outlet moisture content of the process air. As more heat is added to the reactivation air, the desiccant dries more completely, which means that it can attract more moisture from the process air If reactivation air is only heated to 38 °C, process outlet moisture is 19.1 g/kg, or only 2.3 g/kg lower than the entering humidity. In contrast, if reactivation air is heated to 78 °C, the outlet moisture is 15.6 g/kg, or 6 g/kg lower than inlet humidity. If very dry outlet conditions are necessary, plan to use high reactivation temperatures.

4.4 Effect of Inlet Humidity Ratio on Outlet Temperature

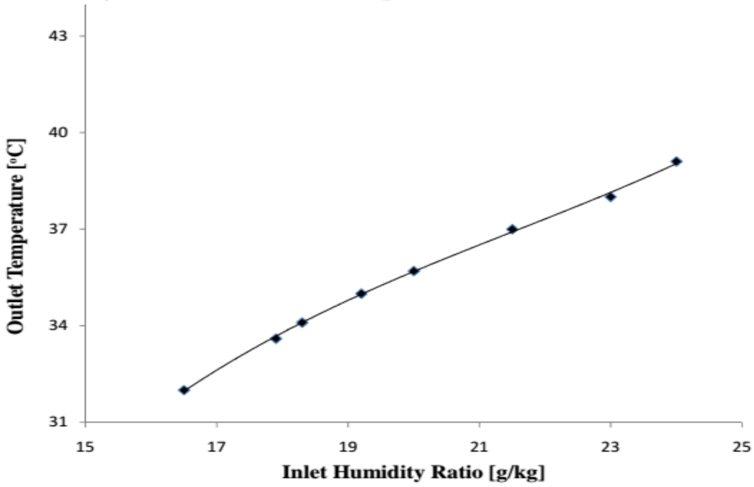

Figure 5.7 Variation of Outlet Temperature with Inlet Humidity Ratio

Process outlet temperature versus inlet humidity is illustrated in Figure 5.7. Note that as more moisture is removed (higher inlet humidity), outlet temperature rises. Air entering at inlet humidity ratio, 17 g/kg leaves the dehumidifier at 32.5 °C. If the dehumidifier removes more moisture, such as when the inlet humidity is 21.3 g/kg, outlet temperature rises to 36 °C. The increase in temperature rise is roughly proportional to the increase in moisture removal.

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5. CONCLUSION

Process air inlet moisture content affects outlet moisture; if air is more humid entering the dehumidifier, it will be more humid leaving the unit. More moisture is removed from the process air if the inlet humidity ratio is less. Therefore if a constant outlet humidity ratio is needed throughout the year it is necessary to have a capacity control of inlet humidity. Process air mass flow rate through the desiccant bed strongly affects leaving moisture. Outlet humidity ratio is less if process air flow rate is less. Thus, more moisture is removed when the air flow rate is less. So in order to obtain drier air at the outlet , either the velocity of process air or process air mass flow rate should be low.The effect of regeneration temperature on outlet humidity ratio is also studied and it can be seen that as regeneration temperature increases more moisture is removed from the process air due to the enhanced heating of the desiccant wheel surface.

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