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EFFECT OF REGENERATION AIR TEMPERATURE ON DESICCANT WHEEL PERFORMANCE

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ABSTRACT

Desiccant wheels are used as an air dehumidifier in air-conditioning and industrial applications. Desiccant wheel performance determines the size and cost of the whole system. A good desiccant wheel is one that saves energy usage. This article presents an experimental investigation on the effects of varying the regeneration air temperature, viz., 50, 60 and 70°C, on desiccant wheel performance. Three performance criteria were considered, namely condition of process outlet air, dehumidifier efficiencies and dehumidification rate. Two kinds of efficiency of the desiccant wheel dehumidifier were examined, namely thermal and dehumidification efficiency. Results of the experiments show that increasing the regeneration air temperature increases the dry bulb temperature of the process outlet air. However the moisture content of the process outlet air is reduced. The dehumidification efficiency of the desiccant wheel decreases with increasing regeneration air temperature, i.e., 46.7, 45.8 and 45.3 % for 50, 60 and 70°C, respectively. In contrast, the dehumidification rate increases with an increase in the regeneration air temperature, namely 32.6, 37.1 and 40.2 g/h for 50, 60 and 70°C, respectively.

Keywords: Desiccant wheel; Air dehumidifier; Process air; Regeneration air

1. INTRODUCTION

The desiccant wheel (DW) has been used as an air dehumidifier since the 1930s for industrial applications such as product dying and corrosion prevention (Bareschino et al., 2015). It has also been used in hospitals, clean rooms, museums and other areas requiring a low humidity level, and in outdoor air hotels, office buildings, fast food restaurants and medical facilities to reduce highly humid conditions. Nowadays, to save energy, the desiccant wheel is also used in the air-conditioning system to reduce the latent cooling load. The DW combined with air-conditioning systems has been used in hotels, office buildings, medical facilities, retirement homes and ice rinks (Waugaman et al., 1993). In regions with hot and humid outdoor conditions, use of the DW/air-conditioning system leads to significant energy savings (Kodama et al., 2001; Angrisani et al., 2013).

A simple DW air dehumidifier consists of an adsorbent, a heater, a wheel and a blower. The adsorbent (usually made of silica gel) is placed as a desiccant in a rotating wheel. The desiccant

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adsorbs moisture from the air flowing past it. A hot air stream or regeneration air is made to flow through a portion of the desiccant wheel to remove moisture from it. Performance of the DW dehumidifier depends on the process and regeneration air conditions. The aim of study is to investigate the effects of generation air temperature on DW dehumidifier performance for a given process air inlet temperature.

If the DW dehumidifier is combined with an air-conditioning system for energy-saving purposes, an effective DW would remove more moisture from the air before the air enters the air handling unit (AHU) of the air-conditioning system. The more moisture is removed from the air, the better the DW dehumidifier should perform. To achieve higher moisture reduction, a higher temperature of the heater is required to heat the regeneration air that flows pass the desiccant wheel.

2. DESICCANT WHEEL

There are two types of desiccants: liquid and solid. Solid desiccant is compact and less subject to corrosion. The desiccant wheel is constructed of a honeycomb structure made of aluminum foil and driven by a motor. A schematic diagram of a desiccant wheel in the air dehumidifier is shown in Figure 1. As seen in this figure, points 1 and 2 represent the process air inlet and outlet, while points 3 and 4 show the air leaving the heater and exiting the desiccant wheel, respectively. The process air (point 1) comes from the outdoors, while the regeneration air (point 3) represents outdoor air that is heated and used to regenerate the desiccant material.

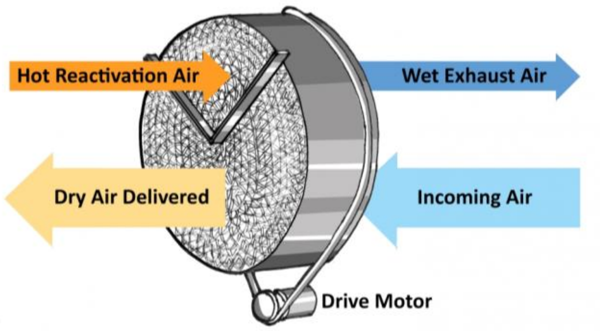

Figure 1 Schematic diagram of desiccant wheel in an air dehumidifier

Figure 2 shows the conditions of process and regeneration air on a psychometric chart. The ideal lines for process and regeneration air are from point 1 to 2 and from point 3 to 4, respectively. Meanwhile, the actual process lines for process and regeneration air are from point 1 to 2’ and from point 3 to 4’, respectively.

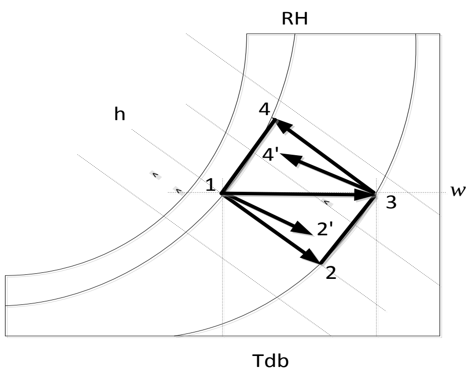

Figure 2 Conditions of process and regeneration air on a psychometric chart

To assess the DW dehumidifier performance, three wheel parameters were considered: the condition of process outlet air, dehumidifier efficiencies and dehumidification rate (D_{rt}). The two kinds of dehumidifier efficiency are thermal (η_{Th}) and dehumidification (η_{Dh}). The parameters are given in the Equations 1, 2 and 3.

$$\eta_{Th} = \frac{(T_{2'} - T_1)}{(T_3 - T_1)} \tag{1}$$

$$\eta_{Dh} = \frac{(\omega_1 - \omega_{2'})}{(\omega_1 - \omega_{2,ideal})} \tag{2}$$

$$D_{rt} = \dot{m}(\omega_1 - \omega_{2'}) = \rho VA(\omega_1 - \omega_{2'}) \tag{3}$$

in which T and ω are temperature and moisture content of the air, while ρ, V and A are the density, air flow velocity and cross-sectional area of the air flow passage, respectively.

3. EXPERIMENTAL AND PROCEDURE

A unit of solid desiccant air dehumidifier (Bry-Air Model FBB-300) was used in the experimental work. A psychrometric chart was used to show the paths of the processes experienced by the air, as depicted in Figure 2. Equations 1, 2 and 3 were used to assess the efficiencies of the air dehumidifier unit. The type and accuracy of measuring equipment used during the experiment is presented in Table 1.

Table 1 Specification of measuring apparatus

Measurements	Accuracy	Type
Dry bulb temperature	±0.1^{o}C	K-type thermocouple
Wet bulb temperature	±0.1^{o}C	K-type thermocouple
Air velocity	±0.1 m/s	Pitot tube anemometer

During the experiment, the blower speed and thus the flow velocity of the process air was kept constant in each run. Also, the temperature of inlet process air was maintained at a constant value of 32.8^{o}C at all times. The dry-bulb (T_{db}) and wet-bulb (T_{wb}) temperatures of process and regeneration air, at both the inlets and outlets, were measured seven times. The average values of these temperatures were used in the calculations to determine the dehumidifier's efficiency. To measure the air flow velocity (V), the probe of the pitot tube was placed at the center of the ducting, which has an internal diameter of 107.5 mm. The dry-bulb and wet-bulb temperatures values were used to determine the relative humidity (RH) and specific enthalpy (h) of the air.

4. RESULTS AND DISCUSSION

The experimental results are shown in Table 2. These are the average values of the dry- and wet-bulb temperatures of the process air inlet, dry-bulb temperatures of the process air outlet and regeneration air inlet, and the air velocities. The values of specific humidity of the process air inlet and outlet and the corresponding values for the ideal processes were obtained from the psychrometric chart.

Table 2 Experimental results

T_1 (°C)		T_2' (°C)	T_3 (°C)	ω_1	$\omega_{2'}$	$\omega_{2,ideal}$	V
32.8	26.0	43.7	50	20.5	17.0	13.0	9.50
32.8	26.0	49.1	60	20.5	16.6	12.0	9.50
32.8	26.0	54.3	70	20.5	16.2	11.0	9.50

The thermal efficiency of the solid desiccant dehumidifier unit was determined using the temperatures shown in Table 2. The dehumidification efficiency was determined using the specific humidity values obtained from the psychrometric chart. Figure 3 shows plots of dry-bulb temperature and specific humidity of the process air outlet versus the regeneration air temperature. In can be observed that the dry-bulb temperature of the process air outlet increases with increasing the regeneration air temperature. In contrast, the specific humidity of the process air outlet decreases as the regeneration air temperature is raised. It can also be seen that both curves exhibit a linear trend.

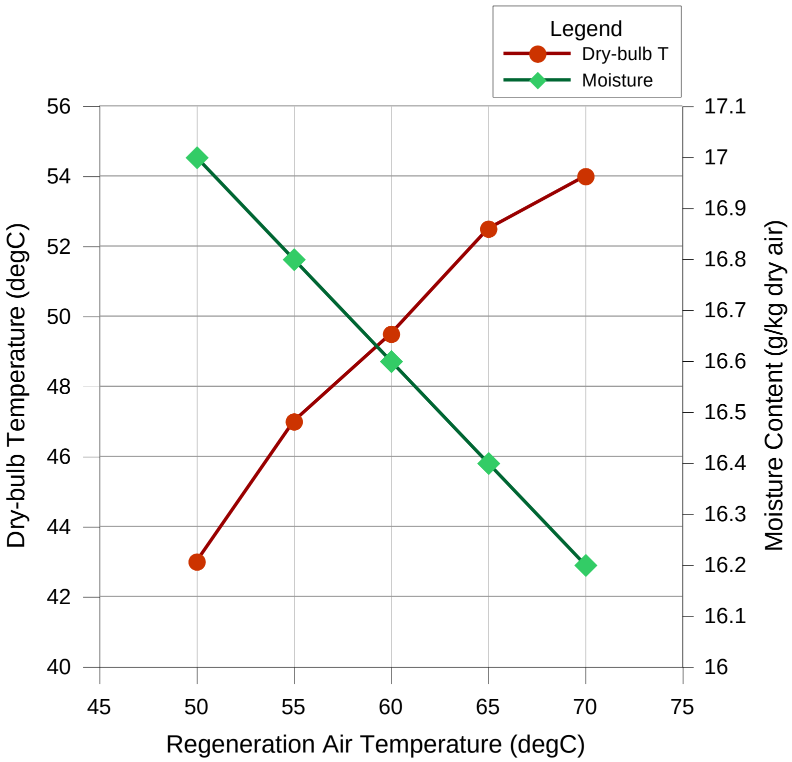

Figure 3 Effects of regeneration air temperature on process outlet air

The above findings indicate that the sensible heat of the process air is increased as it flows passed the desiccant wheel while its latent heat is being reduced. If the air dehumidifier unit is incorporated into an air-conditioning system, the increase in the sensible heat of the process air outlet would cause an increase in the cooling load for the air-conditioning system. The trend of plots seen in Figure 3 is similar to the results reported in the literature (Ali et al., 2013; Yamaguci & Saito, 2013).

The thermal and dehumidification efficiencies of the solid desiccant air dehumidifier were calculated using Equations 1 and 2. Figure 4 shows plots of these efficiencies against the regeneration air temperature. As seen from this figure, both efficiencies decrease as the regeneration air temperature increases. The thermal efficiency represents ability of the air dehumidifier unit to remove the sensible heat from the incoming process air. This process depends on the temperature difference between the desiccant wheel and the process air. As the regeneration air temperature increases, the available temperature difference becomes smaller. This results in the decrease in the ability of the unit to remove sensible heat from the incoming process air. Hence the thermal efficiency of the unit decreases.

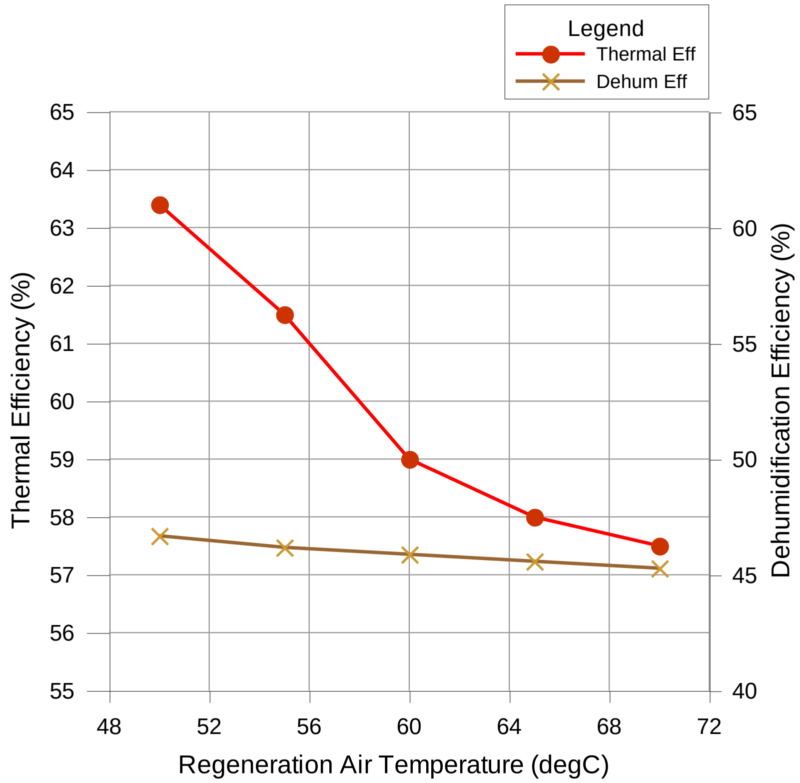

Figure 4 Effects of regeneration air temperature on thermal and dehumidification efficiencies

Dehumidification efficiency is a measure of how well the desiccant material removes moisture from the process air that passes through it. This ability is also affected by the temperature difference between the desiccant material and the process air. As the desiccant wheel material increases due to the increase in the regeneration air temperature, the ability of the desiccant material to absorb moisture reduces. Hence the dehumidification efficiency of the air dehumidifier unit decreases when the regeneration air temperature is raised. However, the rate of reduction in the thermal efficiency can be seen to be slightly higher than that of the dehumidification efficiency. It is desirable to incorporate a dehumidifier unit with high dehumidification efficiency with an air-conditioning system as the latent heat load of the system would be reduced. This would eventually lead to saving in the energy required to operate the air-conditioning system.

Equation 3 was used to calculate dehumidification rate of the solid desiccant air dehumidifier unit. Figure 5 shows a plot of the dehumidification rate versus regeneration air temperature obtained from the experiment. It can be observed that the rate of dehumidification increases when the temperature of regeneration air is increased. This finding seems to suggest that the solid desiccant dehumidifier works more efficiently at a higher regeneration air temperature. A comparison between the experimental results and results obtained by Ali et al. (2013), using a Dynamic Modeling Laboratory (Dymola) is also shown in Figure 5. A similarity can clearly be seen in the trend of both curves. However, for a given regeneration air temperature, the experimental values are slightly higher than those of the Dymola model.

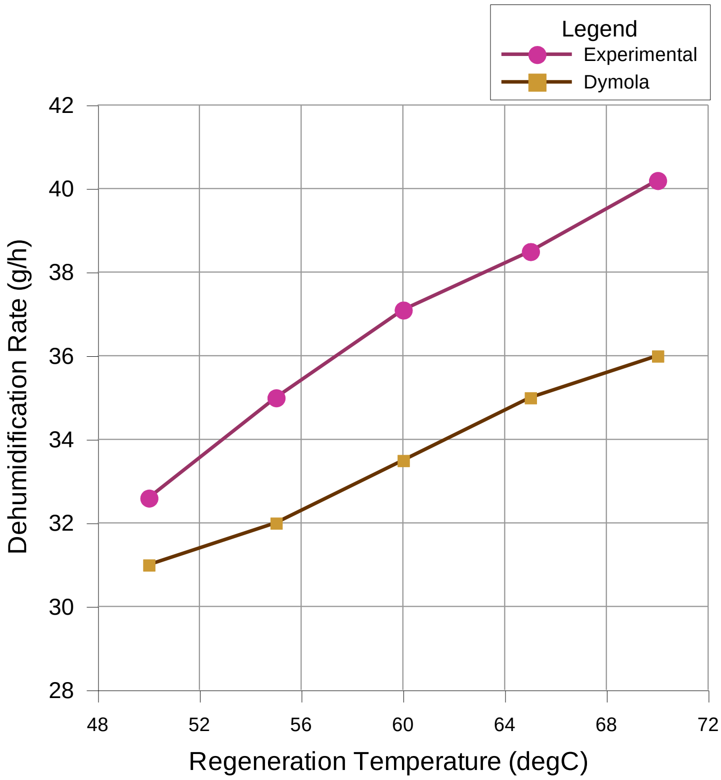

Figure 5 Effects of regeneration air temperature on dehumidification rate

5. CONCLUSION

In this study, experiments were carried out on a solid desiccant air dehumidifier model FBB 300. The goal was to examine the effects of varying regeneration air temperature on the thermal and dehumidification efficiencies and the dehumidification rate of the air dehumidifier unit. It was found that both thermal and dehumidification efficiencies are reduced as the regeneration air temperature is raised. The rate of reduction in the thermal efficiency is slightly greater than that of the humidification efficiency. The dehumidification rate increases as the regeneration air temperature is raised and the trend obtained agrees well with the data obtained from the Dymola model.

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