Effect of Regeneration Air Temperature on the Performances of a Desiccant Wheel

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ABSTRACT

Desiccant wheels have been used as an air dehumidifier in air-conditioning and industrial applications. The performances of the desiccant wheel determine size and cost of the whole system. A good desiccant wheel is one that would save energy usage. This article presents an experimental investigation on the effects of varying the regeneration air temperature, viz., 50, 60 and 70°C, on performances of a desiccant wheel. 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., 46.67, 45.88 and 45.26 % for 50, 60 and 70°C, respectively. In contrast, the dehumidification rate increases with the increase in the regeneration air temperature, namely 32.60, 37.05 and 40.18 g/h for 50, 60 and 70°C, respectively.

Keywords

Desiccant wheel, air dehumidifier, process air, regeneration air

1. INTRODUCTION

The desiccant wheel (DW) as an air dehumidifier has been used since 1930s for industrial applications such as product dying and corrosion prevention [1]. It has also been used in hospitals, clean rooms, museums and other applications requiring low humidity level when the outdoor air hotels, office buildings, fast food restaurants, medical facilities, a high humidity conditions. Nowadays, for saving energy, the desiccant wheel is also used in the air-conditioning system to reduce the latent cooling load. Also, the DW combined with air-conditioning systems has been used in hotels, office building, medical facilities, retirement homes and ice rinks [2]. In the regions which have hot and humid outdoor condition, the use of DW combined with air-conditioning system would lead to energy saving significantly [3-4].

A simple DW air dehumidifier consists of an adsorbent, a heater, a wheel and a blower. The adsorbent as a desiccant, usually made of silica gel, is placed in a rotating wheel. The desiccant adsorbs the moisture from the air flowing passes it. To ensure continues operation on the system, hot air stream or regeneration air is made to flow through a portion of the desiccant wheel to remove the 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 the generation air temperature on the performances of the DW dehumidifier for a given process air inlet temperature.

If the DW dehumidifier is combined with the air-conditioning system for energy saving purposes, a good DW would remove more moisture from the air before the air enters the air handling unit (AHU) of the air-conditioning system. The more the moisture removed from the air, the higher would be the performances of the DW dehumidifier. To achieve higher moisture reduction a higher temperature on the heater is required, for heating the regeneration air that would flow pass the desiccant wheel.

2. DESICCANT WHEEL

There are two types of desiccants, namely liquid and solid. This study investigates the performances of solid desiccant that is made of silica gel, in the form of a rotating wheel. Solid desiccant is compact and less subject to corrosion. The desiccant wheel is constructed of a honeycomb structure which is made of aluminum foil and driven by a motor. Schematic diagram of desiccant wheel in the air dehumidifier is shown in Figure 1. As seen from the figure, points 1 and 2 represent inlet and outlet of the process air, while points 3 and 4 are the air leaving the heater and the air exiting the desiccant wheel. The process air (point 1) comes from the outdoor air while the regeneration air (point 3) is from outdoor air that is heated and to be used to regenerate the desiccant material. The conditions of process and regeneration airs on a psychometric chart are shown in Figure 2. The ideal process lines for process and regeneration airs are from 1 to 2 and 3 to 4, respectively. Meanwhile, the actual process lines for process and regeneration airs are from 1 to 2' and 3 to 4', respectively.

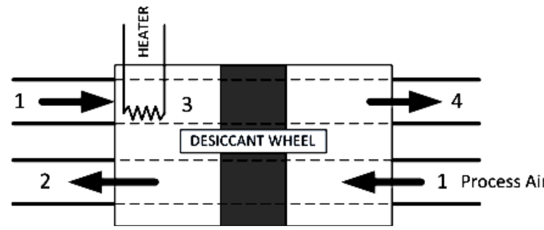

Figure 1: Schematic diagram of desiccant wheel in an air dehumidifier

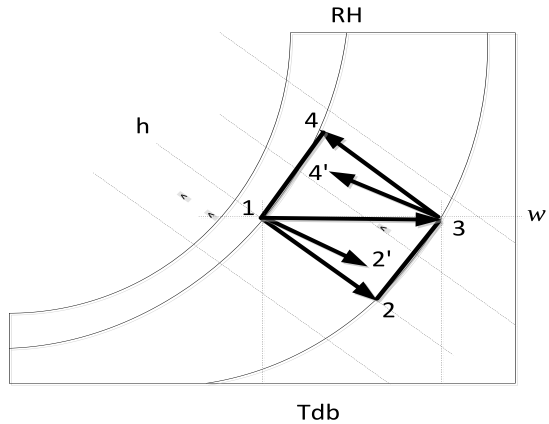

Figure 2: Conditions of process and regeneration airs on a psychometric chart

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

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

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

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

in which T and ω are temperature and moisture content of the air, respectively, 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 schematic diagram of the test equipment is shown in Fig.1. A psychrometric chart is employed to show paths of the processes experienced by the air, as shown in Fig. 2. Eqs. (1) – (3) we used to assess the efficiencies of the air dehumidifier. The type and accuracy of the measuring equipments used during the experimental work is presented in Table 1.

Table 1: Specification of measuring apparatus.

Measurements	Accuracy	Type
Dry bulb temperature	±0.1°C	K-type thermocouple
Wet bulb temperature	±0.1°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 and regeneration air was kept constant in each run. Also, the temperature of inlet process air was maintained constant at 32.8°C. 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 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 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 ideal process were found 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 performance of the solid desiccant dehumidifier was determined based on the temperature data given in Table 2 and Fig.2. Fig. 3 shows plots illustrating the effects of regeneration air temperature on the dry-bulb temperature and moisture content of the process outlet air. In can be observed that in general, increasing the regeneration air temperature results in the rise of the dry-bulb temperature and reduction in the moisture content of the process air. Linear relations are seen for both parameters. The above findings suggest that the sensible heat of the process air is increased as it flows passed the dehumidifier while its latent heat is reduced. An increase in the sensible heat results in the increase of cooling load for the air-conditioning system. The trend of plots seen in Figure 3 are similar to the results obtained by others as reported in the literatures [5,6].

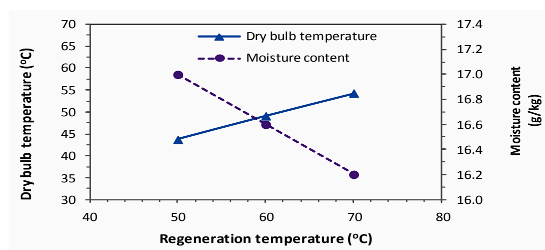

Figure 3: Effects of regeneration air temperature on process outlet air

The thermal and dehumidification efficiencies of the solid desiccant air dehumidifier were calculated using Eq. (1) and Eq. (2). Figure 4 shows plots of both the efficiencies against the regeneration air temperature. As seen from this figure, in general, both efficiencies decrease with as the regeneration air temperature is increased. The thermal efficiency of the dehumidifier represents the amount of sensible heat is absorbed by the process air. Thus the higher the thermal efficiency, the higher the amount of sensible heat absorbed by the air during its dehumidification process. If the process outlet air is to be used in air cooling system, higher values of thermal efficiency would result in the increase in sensible load of the cooling system. The dehumidification efficiency represents how well the desiccant material removes the moisture, thus the latent heat, from the process air flowing through it. Hence the higher the dehumidification efficiency, the higher the the amount of latent heat removed from the process air. If the outlet process air is to be utilized in the air cooling system, a dehumidifier with higher dehumidification efficiency should be preferred.

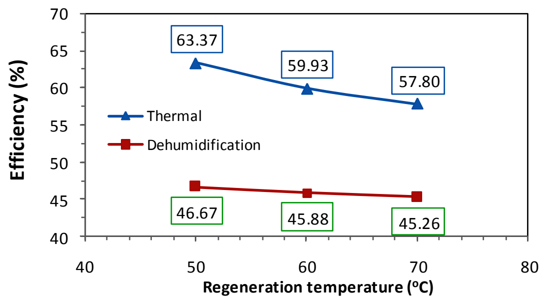

Figure 4: Effects of regeneration air temperature on thermal and dehumidification efficiencies

Eq. (3) was used to calculate the rate of moisture reduction or dehumidification rate by the solid desiccant dehumidifier. Fig. 5 shows a plot of the dehumidification rate versus regeneration air temperature. It can be observed that the rate of dehumidification increases when the temperature of regeneration air is raised. This means that the solid desiccant dehumidifier works more efficiently at higher regeneration air temperature. A comparison between the experimental results and results obtained by Ali et al. [5] using a Dynamic Modeling Laboratory (Dymola) is also shown in Figure 5. It can clearly be seen that there is a similarity in the general trend of both results. However, for a given regeneration air temperature, the experimental results are slightly higher than that of Dymola model. This indicates that the dehumidification performance of the solid desiccant dehumidifier used in this study is better than the results predicted by the Dymola model.

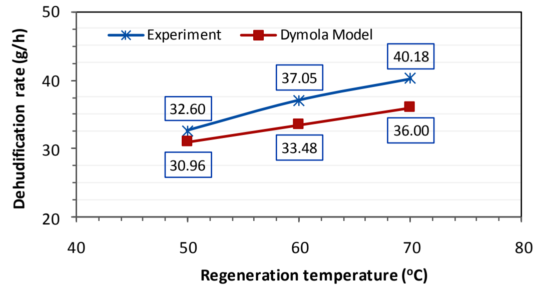

Figure 5: Effects of regeneration air temperature on dehumidification rate

5. CONCLUSIONS

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 the temperature of the regeneration air on the performance of the unit. It was found that increasing the regeneration air temperature increases the sensible heat but reducing the latent heat of the process air leaving the dehumidifier. Both thermal and dehumidification efficiency are reduced as the regeneration air temperature is raised. The rate of decrease of the thermal efficiency is greater than that of the humidification efficiency. The dehumidification rate increases as the regeneration air temperature is raised and the trend agrees well with the data obtained from the Dymola model.

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