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Performance Analysis of a Solid Desiccant Air Dehumidifier

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Abstract –*A desiccant air dehumidification system is widely used in many applications such as refrigeration, crops drying, food industries, pharmaceutical and air-conditioning. The thermal effectiveness is often used to represent the performance of the system. Its value depends on the psychrometric properties of the incoming air and several other parameters. This article presents an experimental study to determine the thermal performance of a compact solid desiccant air dehumidifier. The effects of percent opening combination of the control valve for the process and regeneration air ducting on the thermal performances of the dehumidifier was investigated. An experimental rig was fabricated for these purposes. It consists of a solid desiccant air dehumidifier, process and regeneration air ducts, instrumentation and data acquisition system. Experimental data were acquired under a steady-state operating condition, for three cases of control valve opening combinations. It was found that the thermal effectiveness of the air dehumidifier decreases with increasing flow velocity of the process air. At a given process air flow velocity, the thermal effectiveness for case 1 is higher than that for case 3. The difference in the thermal effectiveness between the two cases becomes smaller as the process air flow velocity increases.*

Keywords: Air dehumidifier, Solid Desiccant System, Thermal Performance

1.0 INTRODUCTION

Solid desiccant air dehumidification system is widely used in many applications such as refrigeration, crops drying, food industries, pharmaceutical and air-conditioning. There are several advantages of using this system, which includes continuous operation even during off-sunshine hours that would reduce drying time due to hot and dry air [1], environmental-conscious operation, separate control of sensible and latent loads which lead to comfortable indoor air quality. In addition, the system is a heat-driven cycle, thus it has the promise of being able to use low density energy such as natural gas, waste heat and solar energy [2]. The performance of the system depends on several operating parameters, such as desiccant wheel speed, regeneration temperature, air-flow rate, wheel thickness, sector angle and desiccant loading. This article presents an experimental study to determine the thermal performance of a compact solid desiccant air dehumidifier. The effects of percent opening combination of the control valve for the process and regeneration air ducting on the thermal performances of the dehumidifier was investigated.

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2.0 EXPERIMENTAL SETUP AND PROCEDURE

2.1 Description of the Experimental Apparatus

The air dehumidification system experimental apparatus consists of three main sections: (1) a solid desiccant air dehumidifier unit, (2) an open-loop regeneration air duct work, and (3) an open-loop process air duct work. These are illustrated in Figure 1.

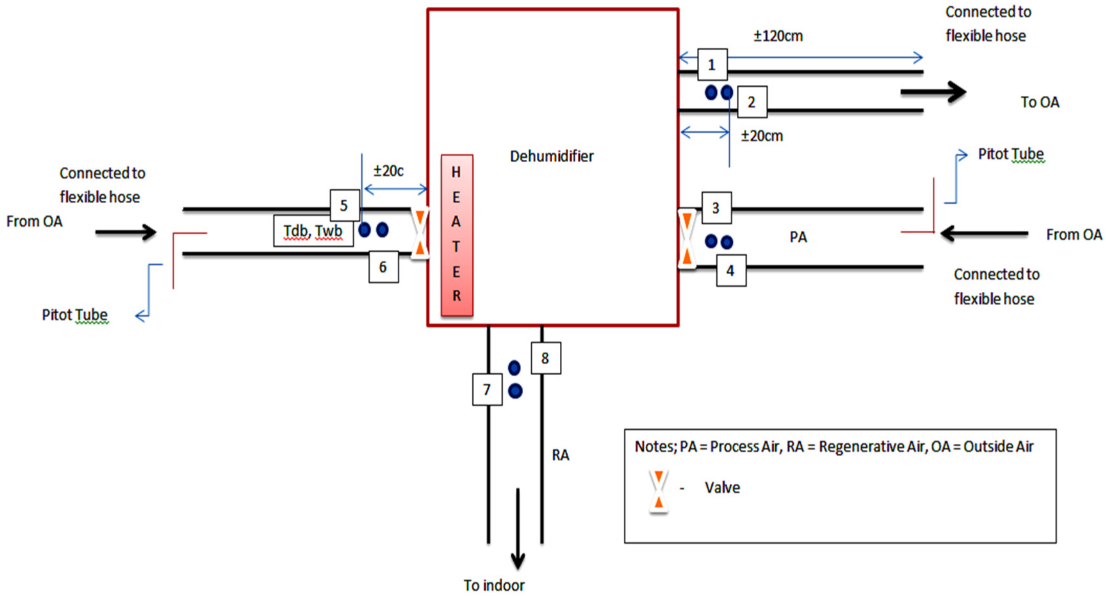

Figure 1: Schematic diagram of an air dehumidifier experimental apparatus.

The air dehumidifier unit is a Bry-Air Fluted Flat Bed (FFB) Series Compact Desiccant Dehumidifier type. The schematic diagram of the air dehumidifier unit is shown in Figure 2. It consists of a solid desiccant rotor, process air inlet and outlet, regeneration air inlet and outlet, an electrical heater and a control unit.

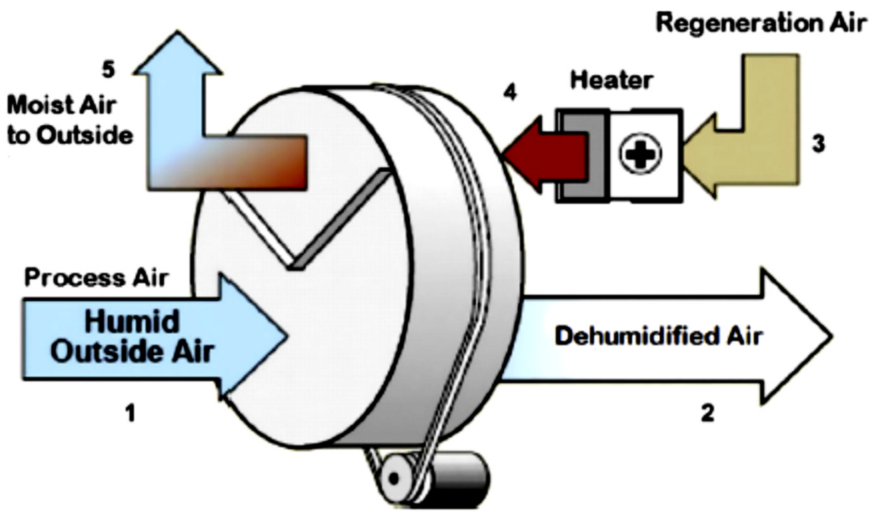

Figure 2: Schematic diagram of the dehumidifier unit [1].

The open-loop regeneration air and process air ducts were made of a 100-mm diameter PVC material. Type-K thermocouples were used to measure the dry- and wet-bulb temperatures of the air at the process air inlet and outlet ducts and also at the regeneration air inlet and outlet ducts. The thermocouples have an accuracy of ±0.3°C they were calibrated by comparing their temperature readings with temperature readings from a standard mercury-in-glass thermometer having an accuracy of ±0.2°C. A Pitot tube anemometer sensor with an accuracy of ±0.5% was placed at the process air inlet ducting to measure the air velocity. All sensors were connected to a data logger furnished with PicoLog software.

2.2 Description of the Test Procedures

The experiments were conducted in a room temperature environment and all data were recorded at steady-state conditions. The experiments were carried out at different combinations of control valve opening for the process and regeneration air ducts. In this study, three cases of valve opening combination were considered. In the first case, the control valves for both process and regeneration air ducts were increased in the same amount, namely from 25% to 100%, with a 25% increment. In the second case, the control valve for the process air duct was kept at 100% opening while the valve opening for the regeneration air duct was increased from 25% to 100%, with a 25% increment. In the third case, the control valve for the regeneration air duct was kept at 100% opening while the valve opening for the process air duct was increased from 25% to 100%, with a 25% increment. In each case, the dry- and wet-bulb temperatures for both the process and regeneration air were recorded. The air flow velocity for both process and regeneration air were also recorded. All readings were acquired at a steady-state operating condition. To stabilize the air dehumidifier unit and to ensure that a steady-state condition was attained, the dehumidifier unit was turned-on for a period of 30 minutes prior to each data gathering.

3.0 PERFORMANCE ANALYSIS

3.1 Performance Parameters

Common parameter used to assess the performance of a solid desiccant air dehumidifier is thermal effectiveness [3 & 4]. It is defined as the ratio between the thermal energy transferred to the process air and the thermal energy supplied by the regeneration air. Assuming that the specific heat capacity, c_p of both the process and generation air is the same, the thermal effectiveness of the air dehumidifier can then be expressed as,

$$\eta_T = \frac{T_2 - T_1}{T_4 - T_3} \qquad (1)$$

where T_1 is the dry-bulb temperature of the process entering the air dehumidifier unit, T_2 is temperature of the process air leaving the dehumidifier, T_3 is temperature of regeneration air leaving the heater and supplied to the desiccant wheel, and finally T_4 is the temperature of the regeneration air leaving the air dehumidifier unit.

3.2 Experimental Data

The experimental data are tabulated in Table 1 through Table 3, as given below. The data in Table 1 were obtained when the percent opening of the control valve for both process and

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regeneration air ducting was set at the same value, from 25% up to 100%. At each valve opening, the dry-bulb temperatures of the inlet and outlet process and regeneration air were recorded at steady-state condition. The air flow velocity was also obtained for each valve opening, using a Pitot tube apparatus. The data shown in Table 2 were obtained when the valve opening for the process air was set and maintained at 100% while the valve opening for the regeneration air was varied from 25% to 100%. Finally, the data shown in Table 3 were obtained when the control valve opening for the process air was varied from 25% to 100% while the valve opening for the regeneration air was set and maintained at 100%.

Table 1: Data for similar percent opening of valve for the process and regeneration air ducts.

Control Valve Opening (%)		Dry-bulb temperature (°C)				Air Flow Velocity (m/s)	
Process Air	Regen. Air	Process Inlet	Process Outlet	Regen. Inlet	Regen. Outlet	Process Inlet	Regen. Inlet
25	25	32.6	47.5	62.0	46.9	6.8	5.3
50	50	33.1	47.0	61.5	47.0	7.9	5.6
75	75	33.6	46.6	60.5	46.5	8.6	5.8
100	100	30.7	45.0	61.0	45.0	9.5	6.1

Table 2: Data for 100% valve opening for the process air duct and varying percent opening for the regeneration air duct.

Control Valve Opening (%)		Dry-bulb temperature (°C)				Air Flow Velocity (m/s)	
Process Air	Regen. Air	Process Inlet	Process Outlet	Regen. Inlet	Regen. Outlet	Process Inlet	Regen. Inlet
100	25	30.8	49.5	61.7	42.5	9.8	4.9
100	50	31.0	48.9	61.6	43.0	9.8	5.6
100	75	30.9	47.2	61.6	44.0	9.6	6.2
100	100	30.7	45.0	61.0	45.0	9.5	6.1

Table 3: Data for varying percent opening of valve for the process air duct and 100% valve opening for the regeneration air duct.

Control Valve Opening (%)		Dry-bulb temperature (°C)				Air Flow Velocity (m/s)	
Process Air	Regen. Air	Process Inlet	Process Outlet	Regen. Inlet	Regen. Outlet	Process Inlet	Regen. Inlet
25	100	33	47.2	61.6	47	7.0	6.5
50	100	32.5	46.8	61.5	46.3	8.1	6.3
75	100	32.2	45.5	61.2	46.5	9.1	6.4
100	100	30.7	45.0	61.0	45.0	9.5	6.1

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It can be observed that varying the percent opening of control valve for the process air duct directly varies the air flow velocity of the process air. Increasing the percent valve opening thus causes higher air flow velocity.

4.0 RESULTS AND DISCUSSION

The thermal effectiveness of the solid desiccant air dehumidifier unit for all cases considered in this study, are shown in Table 4 through Table 6 below.

Table 4: Results for similar percent opening of control valve for the process and regeneration air ducts.

Control Valve Opening (%)		**Air Flow Velocity (m/s)**	**Thermal Effectiveness (%)**
Process Air	Regen. Air	Process Air	
25	25	6.8	98.7
50	50	7.9	95.9
75	75	8.6	92.9
100	100	9.5	89.4

Table 5: Results for 100% control valve opening for the process air and varying percent opening for the regeneration air duct.

Control Valve Opening (%)		**Air Flow Velocity (m/s)**	**Thermal Effectiveness (%)**
Process Air	Regen. Air	Process Air	
100	25	9.8	97.4
100	50	9.8	96.2
100	75	9.6	92.6
100	100	9.5	89.4

Table 6: Results for varying percent opening of control valve for the process air and 100% opening for the regeneration air duct.

Control Valve Opening (%)		**Air Flow Velocity (m/s)**	**Thermal Effectiveness (%)**
Process Air	Regen. Air	Process Air	
25	100	7.0	97.3
50	100	8.1	94.1
75	100	9.1	90.5
100	100	9.5	89.4

The effects of flow velocity of the process air on the thermal effectiveness of the solid desiccant air dehumidifier unit (for case 1 and case 3) are illustrated in Figure 3.

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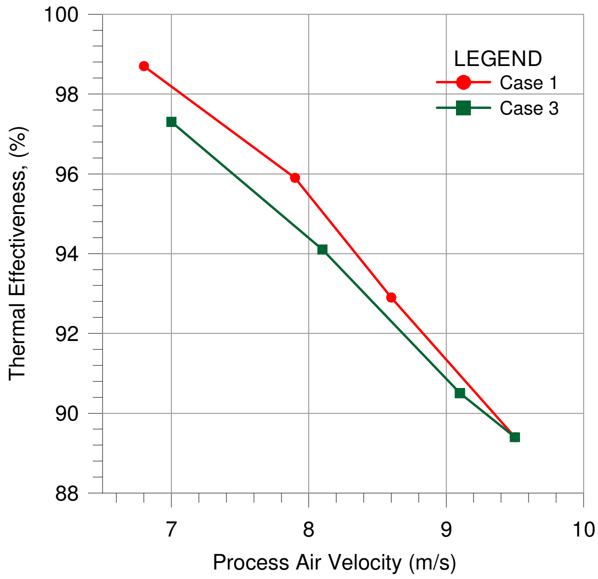

Figure 3: Effects of flow velocity of process air on thermal effectiveness.

It can be seen that the thermal effectiveness of the air dehumidifier decreases with increasing air flow velocity of the process air. This is true for both case 1 and case 3. Also, at any given process air flow velocity, the thermal effectiveness for case 1 is higher than that for case 3. The difference in the thermal effectiveness between the two cases becomes smaller as the process air flow velocity increases.

5.0 CONCLUSION

An experimental study to determine thermal effectiveness of a solid desiccant air dehumidifier unit was presented. Data were acquired at various combinations of control valve opening for the process and regeneration air. The effects of process air inlet velocity on the thermal effectiveness were examined. It was found that the thermal effectiveness of the air dehumidifier decreases with increasing air flow velocity of the process air. At any given process air flow velocity, the thermal effectiveness for case 1 is higher than that for case 3. The difference in the thermal effectiveness between the two cases becomes smaller as the process air flow velocity increases.

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