การทดสอบสมรรถนะของเครื่องดูดความชื้นอากาศที่ใช้ซิลิกาเจล
Performance Test of a Silica Gel Dehumidifier

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บทคัดย่อ

บทความนี้รายงานผลการทดสอบสมรรถนะของเครื่องดูดความชื้นอากาศที่ใช้ซิลิกาเจลซึ่งออกแบบไว้สำหรับใช้ในพื้นที่ปรับอากาศ โดยได้ทำการแปรค่าความเร็วของอากาศที่ 0.2, 0.4 และ 0.6 m/s (สอดคล้องกับอัตราการไหลของอากาศในช่วง 0.008 ถึง 0.140 m^3/s) แปรค่าปริมาณซิลิกาเจลที่ 10, 15 และ 20 kg และแปรค่าความหนาของชั้นซิลิกาเจลที่ 0.1, 0.2 และ 0.3 m การทดลองทั้งหมดทำในห้องขนาด 8 m x 10 m x 3 m ที่มีการควบคุมอุณหภูมิด้วยเครื่องปรับอากาศไว้ที่ 25°C การทดลองทุกชุดทำในเวลากลางวัน เป็นระยะเวลา 4 ชั่วโมงต่อชุด เพื่อให้แน่ใจว่าสารดูดความชื้นจะอิ่มตัว สมรรถนะของการดูดความชื้นในงานนี้ใช้อัตราการดูดความชื้นเป็นตัวชี้วัด ผลการทดลองแสดงให้เห็นว่าอัตราการดูดความชื้นเพิ่มขึ้น เมื่อความเร็วของอากาศและปริมาณของสารดูดความชื้นเพิ่มขึ้น และจะลดลงเมื่อความหนาของชั้นสารดูดความชื้นลดลง ดังนั้น เครื่องดูดความชื้นควรออกแบบให้ทำงานที่ความเร็วลมและปริมาณสารดูดความชื้นสูง ในขณะที่ความหนาของชั้นสารดูดความชื้นควรจะน้อย ในภาพรวมเครื่องดูดความชื้นนี้ดูดซับความชื้นได้ 0.026×10^{-3} ถึง 0.381×10^{-3} kg_w/s (0.38 ถึง 5.59 $kg_w/4$ h) อัตราการดูดความชื้นเฉลี่ยมีค่าเท่ากับ 0.092×10^{-3} kg_w/s (1.33 $kg_w/4$ h) ส่วนอุณหภูมิ สัดส่วนความชื้น และความชื้นสัมพัทธ์เฉลี่ยของอากาศที่ออกจากเครื่องดูดความชื้นมีค่า 33.09°C, 0.0093 kg_w/kg_{da} และ 30.51% ตามลำดับ

คำสำคัญ : สมรรถนะ; ซิลิกาเจล; เครื่องดูดความชื้น; สารดูดความชื้นชนิดของแข็ง

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Abstract

This article reports the performance test of a silica gel dehumidifier intended to use inside air conditioned spaces. The air velocity was varied at 0.2, 0.4, and 0.6 m/s (corresponding to the air flow rate within a range of 0.008 to 0.140 m^3/s); the amount of the solid desiccant was varied at 10, 15, and 20 kg; and the thickness of the desiccant bed was varied at 0.1, 0.2 and 0.3 m. All experiments were carried out in an 8 m x 10 m x 3 m room where the temperature was controlled at 25°C by an air conditioner. Each set of experiments was run during daytime for a period of 4 hours to ensure that the desiccant was saturated. The moisture adsorption rate was considered as the performance indicator. The results showed that the moisture adsorption rate increased with the air velocity and the desiccant amount while it decreased with the bed thickness. Therefore, the dehumidifier should operate at high desiccant amount and air velocity while the bed thickness should be low. Overall, the dehumidifier adsorbed moisture within a range of 0.026×10^{-3} to 0.381×10^{-3} kg_w/s (0.38 to 5.59 kg_w/4 h). The average moisture adsorption rate was 0.092×10^{-3} kg_w/s (1.33 kg_w/4 h). The average temperature, humidity ratio, and relative humidity of the outlet air were found to be 33.09°C, 0.0093 kg_w/kg_{da} and 30.51%, respectively.

Keywords : Performance; Silica gel; Dehumidifier; Solid desiccant

Introduction

Thailand is in a tropical climate area. The most important task would be to condition the air and create thermal comfort for people inside buildings. In turn, this task contributes a major part of the consumed energy in the world (IEA, 2009; EPPO, 2012). Cooling load of air conditioning systems comprises sensible and latent loads. Conventional air conditioning systems are mostly temperature-controlled by using a thermostat. Once the room temperature is below the setpoint (all sensible load is taken care of), the systems would stop regardless of whether the latent load is totally handled or not. When the air is humid, this might cause stuffy or uncomfortable feelings to the occupants. The method traditionally used to make conventional systems able to control both temperature and humidity level in the room simultaneously is the 'overcool and reheat' scheme. The air will be cooled far below the setpoint to make the moisture in the air condense to reach the desired humidity level and then reheated up to the setpoint temperature. This scheme is obviously not energy efficient.

An alternative method is to handle both loads separately. The sensible load would be handled by a conventional air conditioning system while the latent load would be handled by a desiccant system. Desiccants can be either solid or liquid. Liquid desiccants can normally take up moisture more than solid desiccants (Chirarattananon S., 2005). However, liquid desiccant systems require more equipment, larger area, and thus are not easy to install or relocate later. Their carryover with the dehumidified air might also harm occupants' health and corrode objects inside the room (ASHRAE, 2004). In the light of those reasons, solid desiccants may be more favorable to use in occupied spaces.

There are several types of solid desiccants, e.g., silica gel, zeolite, molecular sieve, activated alumina, carbon, synthetic polymers, etc. Silica gel, molecular sieve, and activated alumina have the highest moisture adsorption capacity among those in the list (Air Res., 1978; ASHRAE, 2005). Molecular sieve needs relatively high regeneration temperature so low quality or waste heat cannot be applied (Harriman L.G., 1994). Compared with activated alumina, silica gel can adsorb moisture 30% higher and needs only around 80°C to regenerate (Katejanekarn T., 2008). Therefore, silica gel was selected to be the desiccant in this study.

It is quite common to dehumidify ventilation air before entering buildings because it is the main source of the latent load (Davanagere B.S et al., 1999). However, ventilation dehumidification systems have a lot of components such as dehumidifiers, heat exchangers, cooling towers, and regenerators (Harriman L.G., 1990; Harriman L.G., 1994; Katejanekarn T., 2008; Alibaba.com, 2013; Deep Clean Expert.com, 2013; Siam Seimitsu, 2013) thus they are normally large and not convenient if humidity control is needed only for a specific area. Small and movable systems should be more appropriate in this case.

This paper reports a performance test of a silica gel dehumidifier which was intended to use in storage rooms (e.g., book archives in libraries, artifact storage rooms in museums) to handle the latent load while the sensible load would be handled by a conventional air conditioning system. The dehumidifier was tested at various air velocities, desiccant amounts, and desiccant bed thicknesses to see their effects on the moisture adsorption capability. The results were also compared with the designed values to observe the validity of the performance calculation model from literature.

Silica Gel Dehumidifier

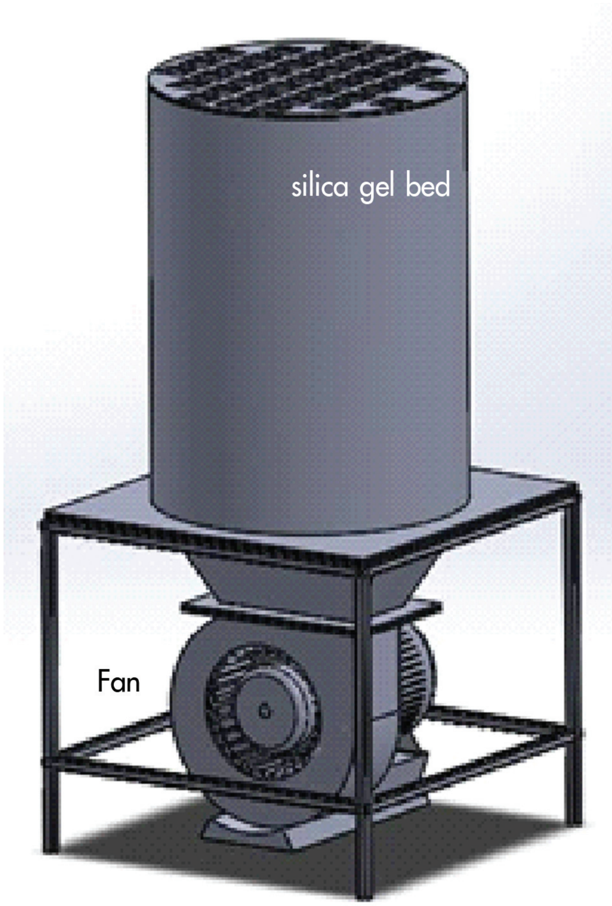

Figure 1 Silica gel dehumidifier

The calculation model from Hamed (Hamed A.M et al., 2013) and the pseudo steady-state concept were used to design the dehumidifier (Hamed A.M et al., 2013). Appropriate size and operating conditions were determined to match an application which was assumed to be a book archive in a library or an artifact storage room in a museum where people would visit only once in a while. From a number of situations, the dehumidifier was designed to have a diameter of 0.52 m and a height of 0.80 m as shown in Figure 1. The fan was driven by a 1.5-kW motor. The static pressure of the fan was 180-1600 Pa. It was also found from the simulations that the silica gel would be saturated within 4 hours of operation.

Methodology

The experiments were designed to study the effects of selected parameters on the performance of the dehumidifier which was considered in terms of moisture adsorption rate (m_{ads}) that can be calculated from the following equation:

$$m_{ads} = m_a(\omega_{a,i} - \omega_{a,o}) \quad (1)$$

Where,

m_{ads} = moisture adsorption rate, kg_w/s

m_a = air flow rate, kg_{da}/s

$\omega_{a,i}\omega_{a,i}$ = humidity ratio of inlet air, kg_w/kg_{da}

$\omega_{a,o}$ = humidity ratio of outlet air, kg_w/kg_{da}

There were 27 cases carried out in the experiments resulted from varying 3 air velocities (0.2, 0.4, and 0.6 m/s corresponding to the air flow rate within a range of 0.008 to 0.140 m^3/s); 3 desiccant amounts (10, 15, and 20 kg); and 3 bed thicknesses (0.1, 0.2, and 0.3 m). Each case was run for 4 hours to ensure the saturation of the desiccant. All experiments were done in an 8 m x 10 m x 3 m room where the temperature was controlled at 25^{o}C by a split-type air conditioner. Outside the room was the actual ambient condition of Nakhon Pathom, Thailand in April 2014. The latent load inside the room was created by boiling water which yielded a vapor production rate of 0.52 kg_w/4 h.

Comparison between the experimental results and the values from the model used in the design step was also carried out. Root mean square error (RMSE) and mean bias difference (MBD) were used as indicators of how accurately the model from the literature could predict the performance (Young H.D., 1962; Taylor J.R., 1997). RMSE gives the sense of magnitude of the difference while MBD shows whether the model overestimates or underestimates the results compared with the actual values. If RMSE and MBD are smaller than the measurement uncertainty of the results, then the model can be said to be accurate and valid. On the other hand, one should be aware when using the model if RMSE and MBD are large. The RMSE and the MBD can be calculated by using Eqs. (2) and (3).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(M_i - E_i)^2}{N}} \tag{2}$$

$$MBD = \frac{1}{N}\sum_{i=1}^{N}(M_i - E_i) \tag{3}$$

Where,

M_i = values from the model

E_i = values from the experiment

N = number of data points.

Results and Discussion

The results are divided into 5 parts. The first 4 parts show the effects on the moisture adsorption capability from the different air flow rates, desiccant amounts, and bed thicknesses as well as the overall performance of the dehumidifier. The last part reports the comparison of the results from the model with the actual experimental results.

Effects of Air Velocity

Table 1 and Figures 2 - 4 show the effects of varying the air velocity on the moisture adsorption rate at various desiccant amounts and bed thicknesses. It can be seen that the adsorption rate increased with the air velocity since the increase in air flow rate means the increase in the amount of moisture entering the system (Tretiak C.S. and Abdallah N.B., 2009). It can also be seen that when the air velocity increased the mass transfer coefficient also increased (Fatouh M. et al., 2009).

Table 1 Moisture adsorption (kg_w) in 4 hours at different air velocities

Desiccant amount (kg)	Bed thickness (m)	Air velocity (m/s)		
		0.2	0.4	0.6
10	0.1	0.654	0.800	2.088
	0.2	0.451	0.729	1.028
	0.3	0.441	0.447	0.507
15	0.1	1.483	1.607	1.828
	0.2	0.730	0.921	0.972
	0.3	0.683	0.902	1.235
20	0.1	2.856	4.542	5.593
	0.2	0.626	1.093	2.251
	0.3	0.380	0.872	0.915

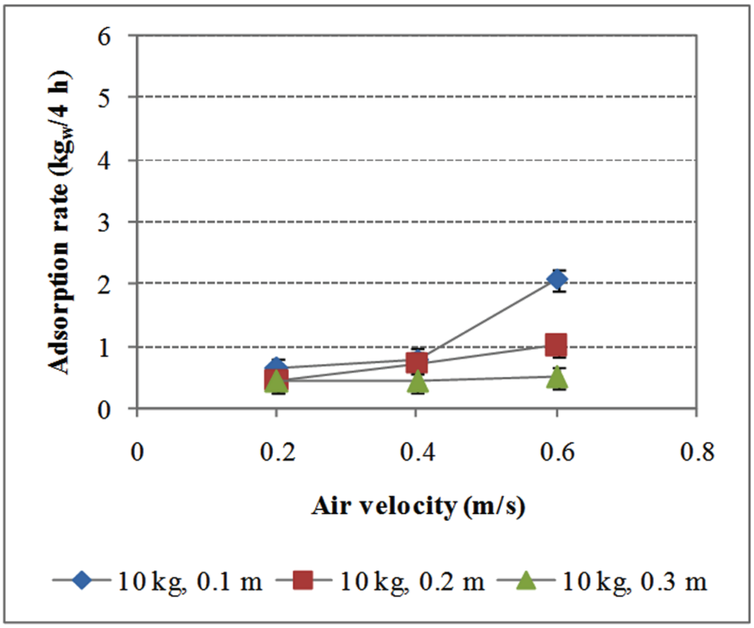

Figure 2 Effects of air velocity on moisture adsorption rate: silica gel = 10 kg, various bed thicknesses

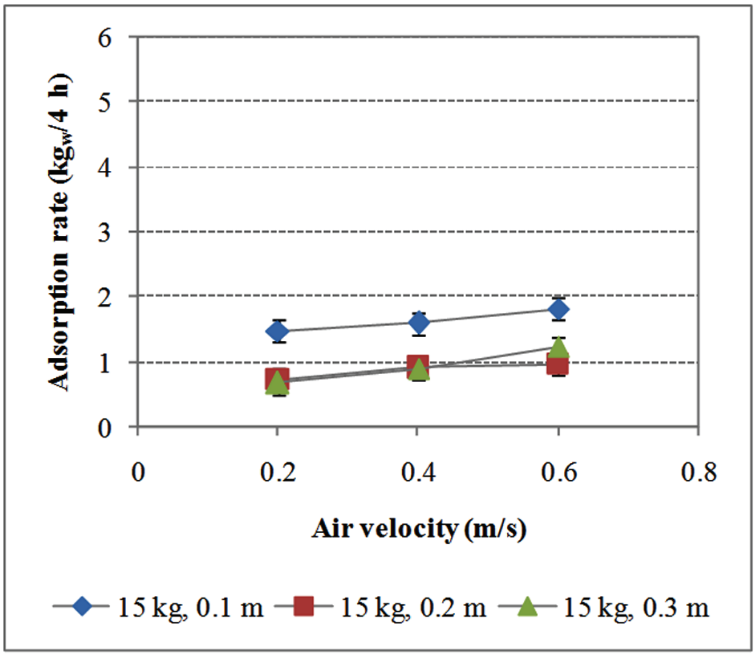

Figure 3 Effects of air velocity on moisture adsorption rate: silica gel = 15 kg, various bed thicknesses

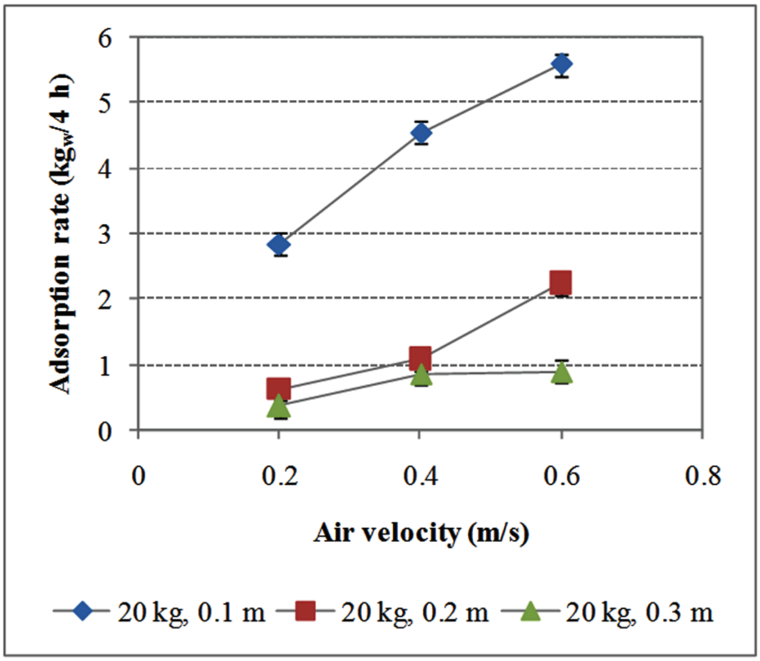

Figure 4 Effects of air velocity on moisture adsorption rate: silica gel = 20 kg, various bed thicknesses

Table 2 Moisture adsorption (kg_w) in 4 hours at different desiccant amounts

Bed thickness (m)	Air velocity (m/s)	Desiccant amount (kg)		
		10	15	20
0.1	0.2	0.654	1.483	2.856
	0.4	0.800	1.607	4.542
	0.6	2.088	1.828	5.593
0.2	0.2	0.451	0.730	0.626
	0.4	0.729	0.921	1.093
	0.6	1.028	0.972	2.251
0.3	0.2	0.441	0.683	0.380
	0.4	0.447	0.902	0.872
	0.6	0.507	1.235	0.915

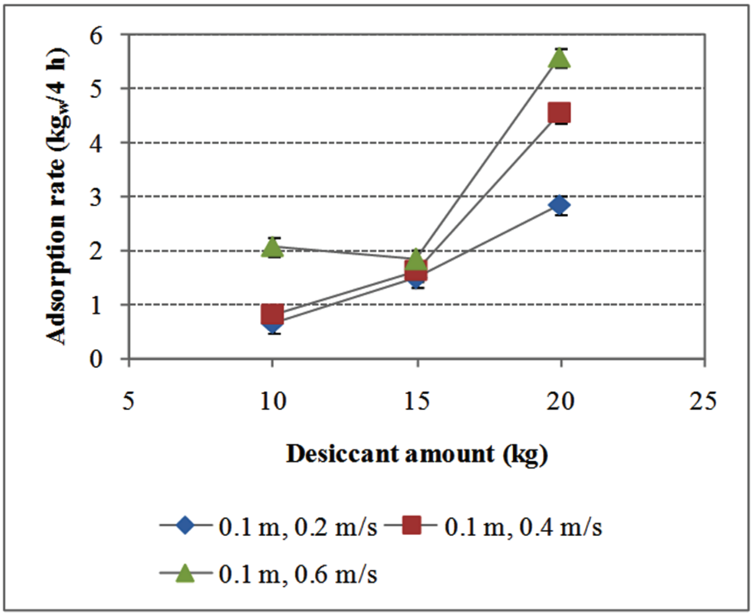

Figure 5 Effects of desiccant amount on moisture adsorption rate: bed thickness = 0.1 m, various air velocities

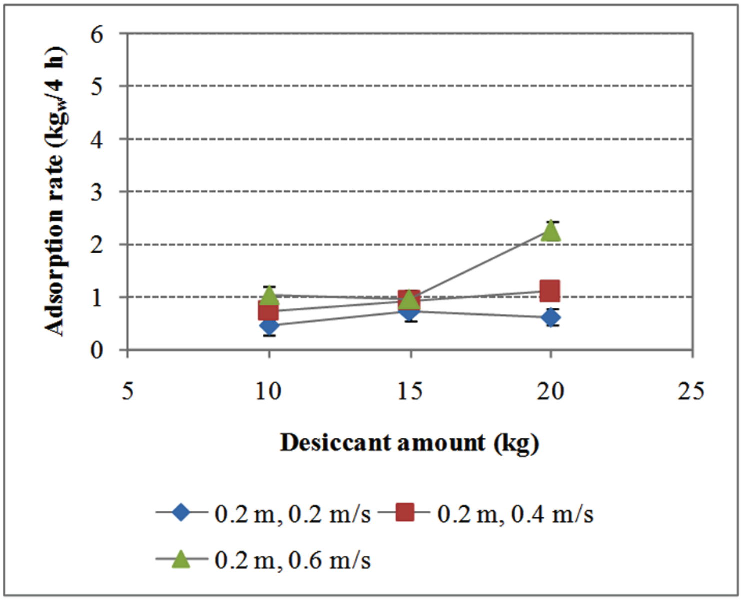

Figure 6 Effects of desiccant amount on moisture adsorption rate: bed thickness = 0.2 m, various air velocities

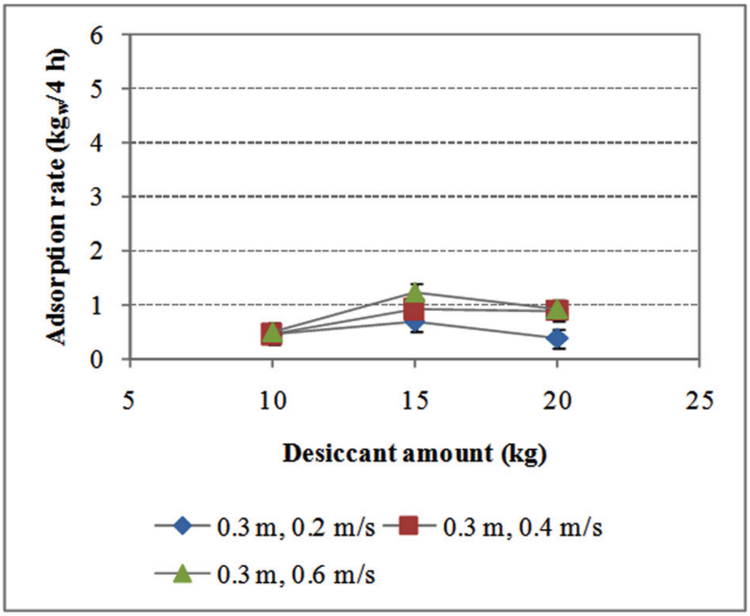

Figure 7 Effects of desiccant amount on moisture adsorption rate: bed thickness = 0.3 m, various air velocities

Effects of Desiccant Amount

Table 2 and Figures 5 – 7 show the effects of varying the desiccant amount on the moisture adsorption rate at various air velocities and bed thicknesses. It was found that the moisture adsorption rate increased with the desiccant amount because of the increase in adsorption capacity (Fatouh M. et al., 2009).

Effects of Bed Thickness

Table 3 and Figures 8 – 10 show the effects of varying the bed thickness on the moisture adsorption rate at various desiccant amounts and air velocities. It can be seen that the moisture adsorption rate decreased with the increase of the bed thickness. This might be explained that when the moist air enters the bed it has the highest humidity level. As it is passing through the bed the air is getting drier thus the moisture transfer is reducing. Therefore, if the bed is thicker the total moisture adsorption would decrease. It can also be viewed that when the bed is thicker the pressure drop would increase and hamper the moisture transfer since the air flows through the bed with more difficulty (Kabeel A.E., 2009).

Table 3 Moisture adsorption (kg_w) in 4 hours at different bed thicknesses

Desiccant amount (kg)	Air velocity (m/s)	Bed thickness (m)		
		0.1	0.2	0.3
10	0.2	0.654	0.451	0.441
	0.4	0.800	0.729	0.447
	0.6	2.088	1.028	0.507
15	0.2	1.483	0.730	0.683
	0.4	1.607	0.921	0.902
	0.6	1.828	0.972	1.235
20	0.2	2.856	0.626	0.380
	0.4	4.542	1.093	0.872
	0.6	5.593	2.251	0.915

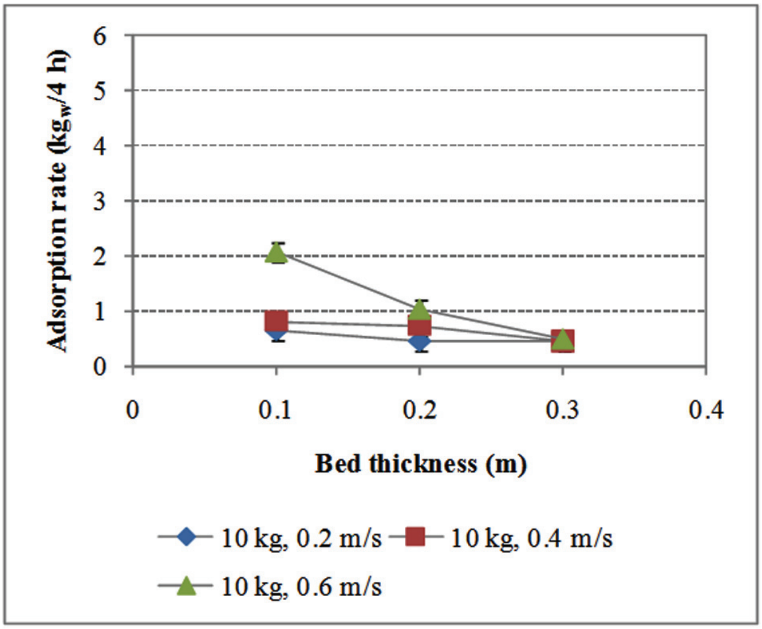

Figure 8 Effects of bed thickness on moisture adsorption rate: desiccant amount = 10 kg, various air velocities

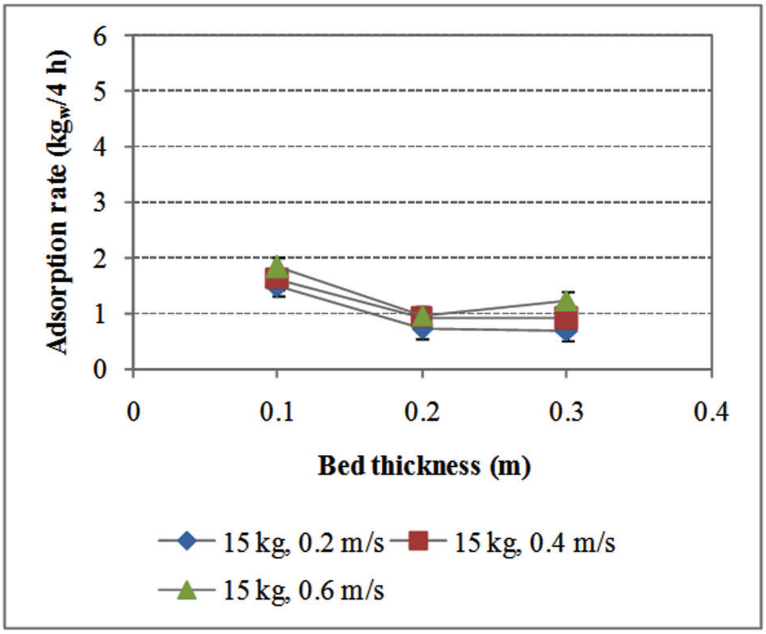

Figure 9 Effects of bed thickness on moisture adsorption rate: desiccant amount = 15 kg, various air velocities

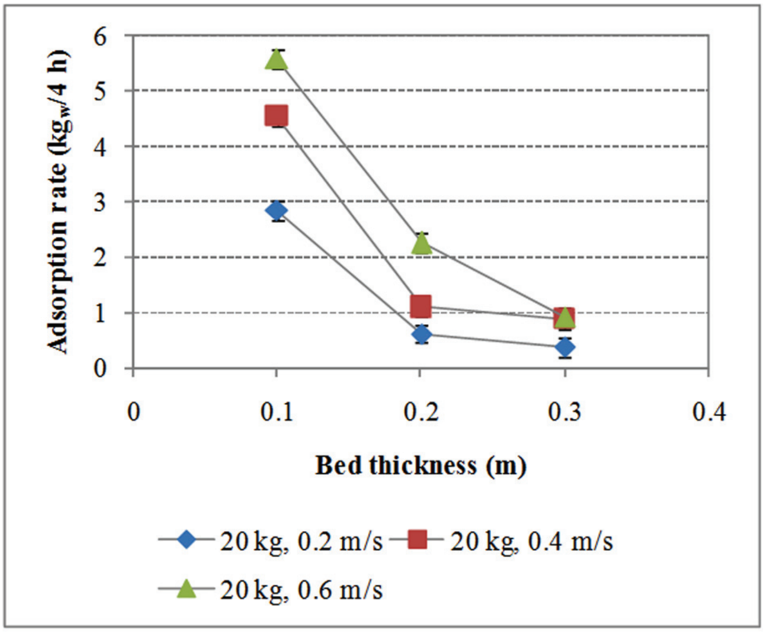

Figure 10 Effects of bed thickness on moisture adsorption rate: desiccant amount = 20 kg, various air velocities

Overall Performance

From the previous 3 sections, it is suggested that the dehumidifier should operate at high desiccant amount and air velocity while the bed thickness should be low. From all experimental cases, the dehumidifier could adsorb moisture within a range of 0.026×10^{-3} to 0.381×10^{-3} kg_w/s (0.38 to 5.59 kg_w/4 h). The average moisture adsorption rate was 0.092×10^{-3} kg_w/s (1.33 kg_w/4 h). The average temperature, humidity ratio, and relative humidity of the outlet air were found to be 33.09°C, 0.0093 kg_w/kg_{da} and 30.51%, respectively.

Comparison of the Results from the Experiments and the Model

Table 4 Comparison of moisture adsorption (kg_w) from the experiments and the model

No.	Case	Model (M_i)	Exp. (E_i)
1	10 kg, 0.1 m, 0.2 m/s	0.784	0.654
2	10 kg, 0.1 m, 0.4 m/s	0.867	0.800
3	10 kg, 0.1 m, 0.6 m/s	0.902	2.088
4	10 kg, 0.2 m, 0.2 m/s	0.723	0.451
5	10 kg, 0.2 m, 0.4 m/s	0.814	0.729
6	10 kg, 0.2 m, 0.6 m/s	0.858	1.028
7	10 kg, 0.3 m, 0.2 m/s	0.677	0.441
8	10 kg, 0.3 m, 0.4 m/s	0.777	0.447
9	10 kg, 0.3 m, 0.6 m/s	0.824	0.507
10	15 kg, 0.1 m, 0.2 m/s	0.960	1.483
11	15 kg, 0.1 m, 0.4 m/s	1.013	1.607
12	15 kg, 0.1 m, 0.6 m/s	1.032	1.828
13	15 kg, 0.2 m, 0.2 m/s	0.914	0.730
14	15 kg, 0.2 m, 0.4 m/s	0.984	0.921
15	15 kg, 0.2 m, 0.6 m/s	1.012	0.972
16	15 kg, 0.3 m, 0.2 m/s	0.875	0.683
17	15 kg, 0.3 m, 0.4 m/s	0.957	0.902
18	15 kg, 0.3 m, 0.6 m/s	0.991	1.235
19	20 kg, 0.1 m, 0.2 m/s	1.091	2.856
20	20 kg, 0.1 m, 0.4 m/s	1.132	4.542
21	20 kg, 0.1 m, 0.6 m/s	1.147	5.593
22	20 kg, 0.2 m, 0.2 m/s	1.053	0.626
23	20 kg, 0.2 m, 0.4 m/s	1.110	1.093
24	20 kg, 0.2 m, 0.6 m/s	1.132	2.251
25	20 kg, 0.3 m, 0.2 m/s	1.020	0.380
26	20 kg, 0.3 m, 0.4 m/s	1.090	0.872
27	20 kg, 0.3 m, 0.6 m/s	1.117	0.915
		RMSE	1.21
		MBD	-0.40

Table 4 shows the comparison of the moisture adsorption from the actual experiments and that from the model used in the design step. The RMSE and the MBD values were found to be 1.21 kg_w and -0.40 kg_w, respectively. This means that the moisture adsorption values calculated from the model and the actual values from the experiments would differ by around 1.21 kg_w on average. Also, the model tends to underestimate the actual values. By propagating errors from the measurements of the input parameters (i.e., air velocity, desiccant amount, and bed thickness), it was found that the total uncertainty of the moisture adsorption was 0.17 kg_w. This implies that the model still predicts the results relatively far away from the actual values especially for the cases that use the silica gel of 20 kg. A reason is that the total bed height has to be divided into layers with a thickness of less than 0.10 to 0.15 m in the model (Kabeel A.E., 2009). Therefore, when more amount of silica gel is used, more layers are required in the calculation and could lead to less accuracy.

Conclusion

From the performance test of a silica gel dehumidifier where the air velocity, the desiccant amount, and the bed thickness were varied for 3 values, it was found that the moisture adsorption rate increased with the air velocity and the desiccant amount whereas it decreased with the increase of the bed thickness. This suggests that the dehumidifier should operate at high desiccant amount and air velocity while the bed thickness should be low. It was also found that the results from the model used in the design step differed from the actual experimental results by a relatively high magnitude. Overall, the dehumidifier could adsorb moisture within a range of 0.026×10^{-3} to 0.381×10^{-3} kg_w/s (0.38 to 5.59 $kg_w/4$ h). The average moisture removal rate was 0.092×10^{-3} kg_w/s (1.33 $kg_w/4$ h). The average temperature, humidity ratio, and relative humidity of the outlet air were found to be 33.09°C, 0.0093 kg_w/kg_{da}, and 30.51%, respectively.

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