

# Performance Test of Solar Assisted Solid Desiccant Dryer

S. MISHA<sup>1,2,\*</sup>, S. MAT<sup>1</sup>, M. H. RUSLAN<sup>1</sup>,  
K. SOPIAN<sup>1</sup>, E. SALLEH<sup>1</sup>, M. A. M. ROSLI<sup>1</sup>

<sup>1</sup> Solar Energy Research Institute, Universiti Kebangsaan Malaysia,  
43600 Bangi, Selangor, Malaysia

<sup>2</sup> Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka,  
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

\*suhaimimisha@utem.edu.my

**Abstract:** - The solar assisted solid desiccant dryer was designed and developed to dry agricultural product. The experiment was carried out to study the performance of the component in the dryer system and drying air condition without load. The system can produce drying air at average temperature 52°C under average solar radiation of 797 W/m<sup>2</sup> which is suitable for heat sensitive product to maintain the fresh color, taste and nutrient content. The collector efficiency, heat exchanger effectiveness 1 and 2 was 70%, 77% and 67%, respectively. The thermal, regeneration and dehumidification effectiveness was 48%, 29% and 6%, respectively. The poor performance of desiccant wheel may be improved by increasing the regeneration temperature above 65°C. Some improvements are still required to improve the overall performance of the system such as decrease the regeneration air flow rate, increase electrical heater power and using direct connection from the solar collector to the dryer system.

**Key-Words:** - Solar drying; desiccant drying; desiccant wheel

## 1 Introduction

Depletion of fossil fuel and gas reserves, has encourages industries to find others alternative energy sources to cater the current demands. An alternative energy resource especially solar energy becomes more attractive because it available in abundant. Solar energy is a free energy and environmental friendly source of renewable energy. Some of the solar applications are drying of agricultural products, space heating, solar desalination, etc. In drying application generally, up to 70% of the life cycle cost of a convective dryer is due to energy used. Therefore, the use of an energy-efficient drying process is important even at a higher initial cost. Various types of solar drying systems for agricultural and marine products have been reviewed [1]. Solar drying system is one of the most attractive and promising applications of solar energy systems in tropical and subtropical countries.

Drying process plays an important role in the preservation of agricultural products. The drying air heats the product and carries the water in the form of vapor away from the product being dried. The lower the humidity of hot air supplied to the drying chamber is, the better the drying rate, as the dry air can carry more moisture from the product surface. These parameters (i.e., heat, velocity, and humidity) must be addressed in designing a dryer system.

Generally, increasing the temperature and velocity improves the drying performance. However, for heat-sensitive products, such as pharmaceutical and food products, high temperature decreases product quality. Therefore, drying at low temperature and humidity is required to maintain the fresh color of the product using the desiccant system [2]–[4]. Several advantages of using desiccant material in drying application have been discussed in detail by Misha et al. [5].

Desiccant materials work based on the principle of moisture transfer due to the difference of vapor pressure between the air and the desiccant [6]. The desiccant with low moisture content will adsorb moisture from air until its vapor pressure is in equilibrium with the air. The saturated desiccant must be heated to enable the desiccant to remove the moisture. Generally, using solid desiccant in the construction of a dryer is simpler than using liquid desiccant because handling solid desiccant is easier [5]. Solid desiccant systems are widely used in the form of rotary wheel beds for packing the desiccant materials.

Narayanan et al [7] studied on the performance of three different designs of desiccant wheel. Results shows that the counter flow desiccant wheel (Fig. 1) has better dehumidification performance than parallel flow. Addition of axial cooling section can improve dehumidification performance further.

Nomenclature		
$h$	Specific enthalpy of moist air (kJ/kg dry air)	$\varepsilon$ Effectiveness
$h_{fg}$	Latent heat of vaporization (kJ/kg dry air)	Subscripts
$T$	Temperature (°C)	1-5 States point of air in Fig. 1
$w$	Absolute humidity of air (kg water/kg dry air)	Dw Desiccant wheel

Effectiveness is the best way to compare the performance of desiccant wheel. Air stream dehumidification occurring in desiccant wheel involves combination of heat and mass transfer. The common efficiencies of desiccant wheel has been reported are thermal effectiveness and regeneration effectiveness [8], [9]. Another expression of desiccant wheel effectiveness considering the mass transfer during dehumidification process is known as dehumidification effectiveness.

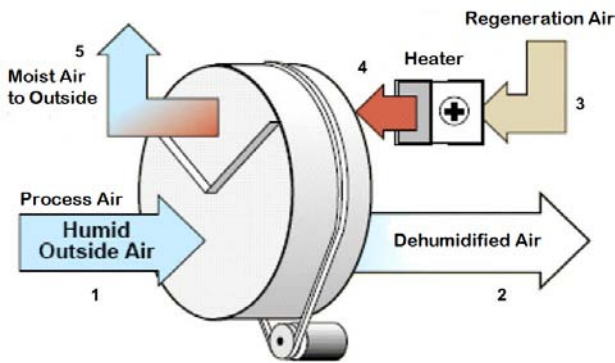


Fig. 1 Schematic diagram of the counter flow desiccant wheel

The expression of desiccant wheel's effectiveness is given in Eq. (1) to (3)

Thermal effectiveness,

$$\varepsilon_{Dw,1} = \frac{T_2 - T_1}{T_4 - T_1} \quad (1)$$

Regeneration effectiveness,

$$\varepsilon_{Dw,2} = \frac{(w_1 - w_2) h_{fg}}{h_4 - h_3} \quad (2)$$

Dehumidification effectiveness,

$$\varepsilon_{Dw,3} = \frac{w_1 - w_2}{w_1 - w_{2,ideal}} \quad (3)$$

Where  $w_{2, ideal}$  is the ideal specific of the air stream at outlet of desiccant wheel. Ideally, the air is completely dehumidified where the value is equal to zero. In the optimization of desiccant wheel, dehumidification effectiveness is the most important and usually assumed as objective function [10], [11].

## 2 Experimental setup

### 2.1 Dryer system

The industrial scale of solar assisted solid desiccant dryer was designed and developed to investigate system performance. The diameter of desiccant wheel is 550 cm with 20 cm thickness. Silica gel is used as an absorbent material. The silica gel can be regenerated up to temperature of 175°C. Fig. 2 shows a schematic of the experimental apparatus, which includes the following: an evacuated tube solar collector, a primary circulation pump, a storage tank with an electric heater, a secondary circulation pump, a desiccant dryer system, and a drying chamber. The diagram also indicates the sensor positions for air (A1 to A9) and water (W1 to W8). The types of sensor were used at each position are shown in Tables 1. All sensors were connected to the computer and the data were recorded for each time interval. The hot water system is divided into primary and secondary circuits. The hot water in the primary circuit is generated by 300 tubes of evacuated tube solar collector. The single tube had an absorber surface of 0.105 m<sup>2</sup>.

The hot water in the primary circuit will pass through the copper coil in the tank to heat the water in the secondary circuit (storage tank). The storage tank capacity is 200 liters each, insulated by a 50 mm polyethene layer to maintain thermal energy in the tank with minimum loss. The tank has one heating coil with a surface area of 0.9 m<sup>2</sup>. Each storage tank is used for different applications. In this case, only one tank is used and the hot water is not

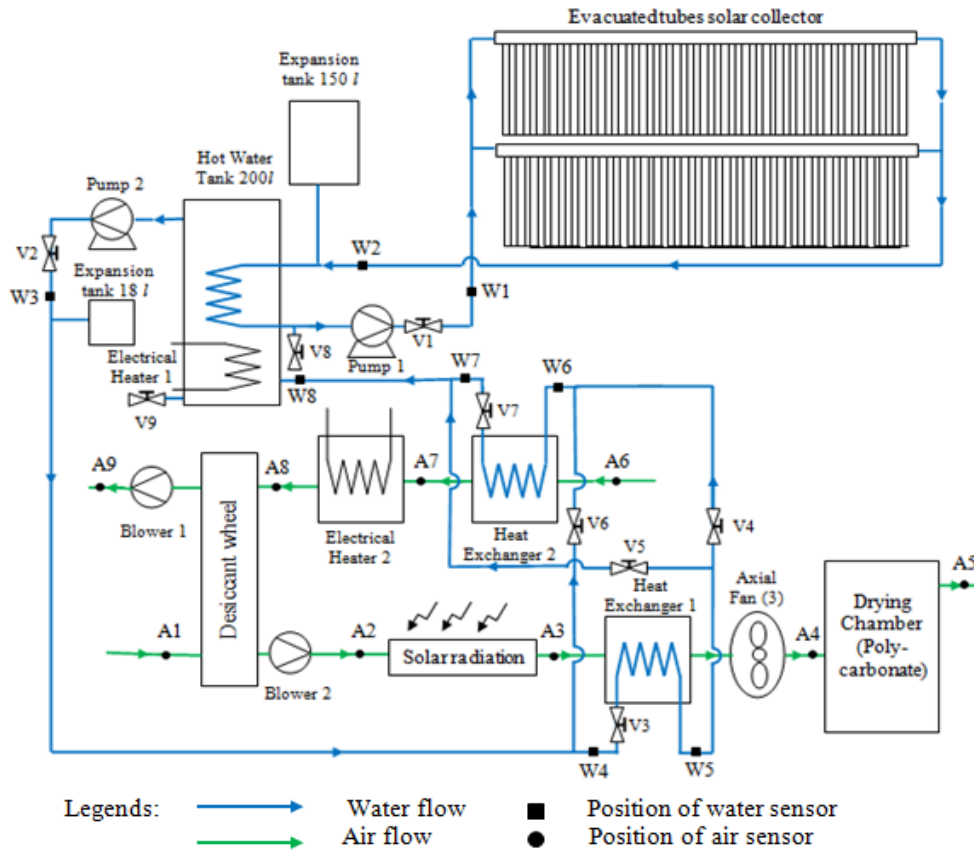


Fig. 2 Schematic diagram of the experiment

allowed to flow to another heating coil by closing the valves. Heat exchanger 1 is used to increase air temperature after dehumidification, and heat exchanger 2 is used to regenerate the desiccant wheel. After dehumidification, the air passes through the top of the drying chamber and heated by solar radiation before passing through the heat exchanger 1. The illustration of the experimental set up is shown in Fig. 3. In this experiment, the connection of the heat exchanger 1 and 2 was parallel by closing valve V4.

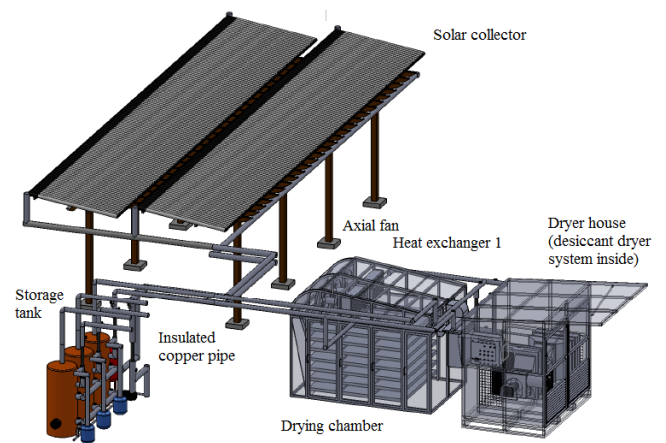


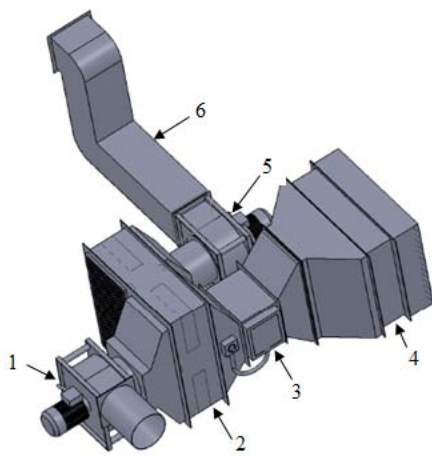
Fig. 3 Illustration of experimental setup

Table 1 Position of sensors

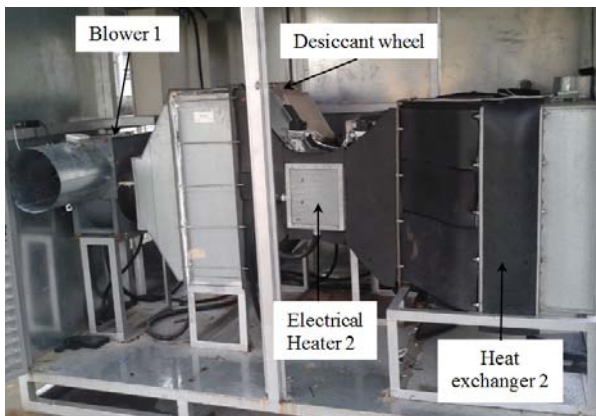
No.	Type of sensors	Sensors position
1	Air temperature and humidity	A1, A3, A6, A7, A8
2	Air temperature, humidity and velocity	A2, A4, A5, A9
3	Water temperature and flow rate (flow meter)	W1, W3, W7
4	Water temperature	W2, W4, W5, W6, W8

The system was equipped with electrical heater to maintain the temperature of water or air if the solar radiation is low. The power of electrical heaters 1 and 2 are 4.5 kW and 2.5 kW, respectively. Blowers 1 and 2 are centrifugal fan-types with 3 kW each. The detailed illustration and actual picture of the desiccant dryer system are shown in Fig. 4. Three pieces of axial fan were used to increase the velocity of drying air that enters the drying chamber. The

power of each axial fan is 0.55 kW. The power of the centrifugal pumps 1, 2 and the desiccant wheel motor are 0.75 kW, 0.25 kW and 1/80 hp, respectively.



(a) 3D drawing



(b) Actual picture

Fig. 4 Solar assisted solid desiccant dryer system  
1-Blower 1: 2-Desiccant wheel: 3-Electrical heater:  
4- Heat exchanger 2: 5-Blower 2: 6-Ducting to heat exchanger 1

## 2.2 Drying Chamber

The design of the drying chamber is shown in Fig. 5, and includes seven layers of trays. The drying chamber is designed symmetrically from above. The sensors are installed only at the right side, assuming that values from the left side are the same, owing to this symmetry. The volume of the drying chamber is 1.7 m x 2 m x 3 m. The wall of the dryer system was constructed using 6-cm thick hollow polycarbonate with a hollow space in the middle, 4 cm deep. The top roof is made of glass. The velocity, temperature and humidity sensors were installed at the inlet (A4) and outlet (A5) of the drying chamber. The trays are made from teflon to avoid the heat being absorbed by the tray material. Only the frame is made from

aluminum. Fig. 6 shows the actual picture of the drying chamber and the dryer system.

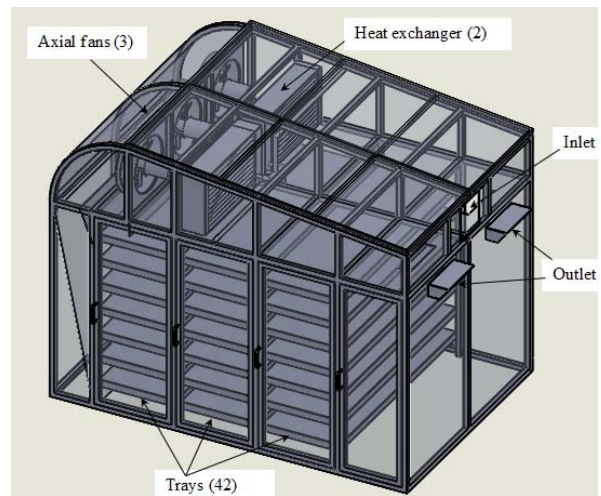


Fig. 5 Drying chamber



Fig. 6 Drying chamber and dryer system

## 2.3 Test overview

The focus of this work is to study the drying air condition that will be supplied to the drying chamber and the effectiveness of the desiccant wheel. Therefore the experiment is performed on an empty dryer (no-load). The hot water flow rate in the heat exchanger 1 and 2 are 150 and 450 l/h, respectively. The selected value is based on the previous study to obtain the optimum performance of heat exchanger by varies the water flow rate. The experiment was conducted start at 12.30 pm to 4.45 pm. However the electrical heater was on 30 minutes earlier to heat the water in the tank. The electrical heater 1 will deactivate if the water temperature at point W3 achieved 80°C and the electrical heater 2 will deactivate if the air temperature at point A8 achieved 65°C. The sensor readings were recorded at time interval every 15

minutes. The flow rate of primary hot water circuit was 1500 litres/hour.

### 3 Result and Discussion

The performance of collector, heat exchanger 1, heat exchanger 2 and desiccant wheel are shown in Table 1. Generally, the performance of desiccant wheel considered low because of the low regeneration temperature. According to the manufacturer, the minimum regeneration temperature should be above 65°C to obtain high performance of desiccant wheel. The flow rate of regeneration air is approximately 1.4 kg/s. The higher temperature of regeneration air can be obtained by decreasing the air flow rate. However the speed controller is not installed in the system, thus the flow rate is constant.

The performance of other components also was influenced by water and air flow rate. Therefore the optimum performance can be achieved by varies the water and air flow rate. Low solar radiation at 2.15 pm until 3.00 pm and after 3.20 pm (Fig. 7) contributes to the low performance of the system. The average solar radiation is 797 W/m<sup>2</sup>. In drying process the drying air condition is very important to determine the drying rate. The process air starts from the ambient (Ta1), then it pass through the desiccant wheel for dehumidification (Ta2). The air temperature at this stage is not enough for drying application, thus the air goes to the top space of the drying chamber (Ta3) and was heated by solar radiation through the glass. The air temperature was increased further by force the air through the heat exchanger 1 (Ta4). The average air temperature at position Ta1, Ta2, Ta3 and Ta4 were 35°C, 44°C, 46°C and 52°C respectively. The air temperatures at those positions are shown in Fig. 7.

Table 1. Performance of the system

No.	Performance criteria	Value
1	Collector efficiency	70%
2	Heat exchanger 1 effectiveness	77%
3	Heat exchanger 2 effectiveness	67%
4	Thermal effectiveness, desiccant wheel	48%
5	Regeneration effectiveness, desiccant wheel	29%
6	Dehumidification effectiveness, desiccant wheel	6%

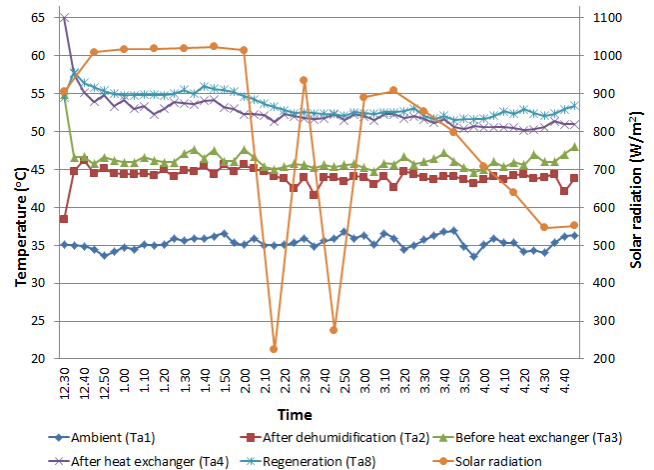


Fig.7 Temperature of process air and regeneration

It was found that the temperature is increasing at each stage from Ta1 to Ta4. Finally, the average temperature of air inlet to the drying chamber is 52°C. This temperature is suitable for most of the food and agricultural product. Some products like food, pharmaceutical products, and others heat-sensitive products are not suitable for drying at high temperature because product quality may be degraded or damaged. Normally drying at high temperature will change the original color and damage the nutrient content of the product. The lower humidity of drying air is better since it can carry more moisture from the product. The relative humidity of process air is shown in Fig. 8.

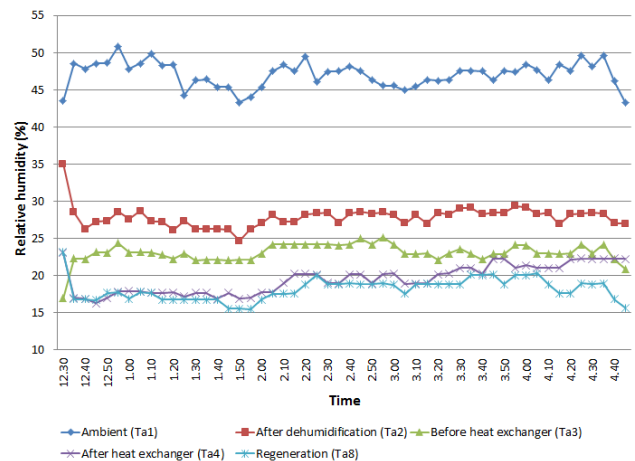


Fig. 8 Relative humidity of process air and regeneration

The temperature profile for hot water and cold air of heat exchanger 1 and 2 are shown in Fig. 9 and 10, respectively. The performance of both heat exchangers was 77% and 67%, respectively. The heat exchanger 1 and 2 was connected in parallel so that the hot water enters to each heat exchanger at

the same temperature. The series connection will cause the heat exchanger 2 receive hot water at lower temperature than heat exchanger 1. Series configuration is possible if the hot water temperature from the storage tank is very high.

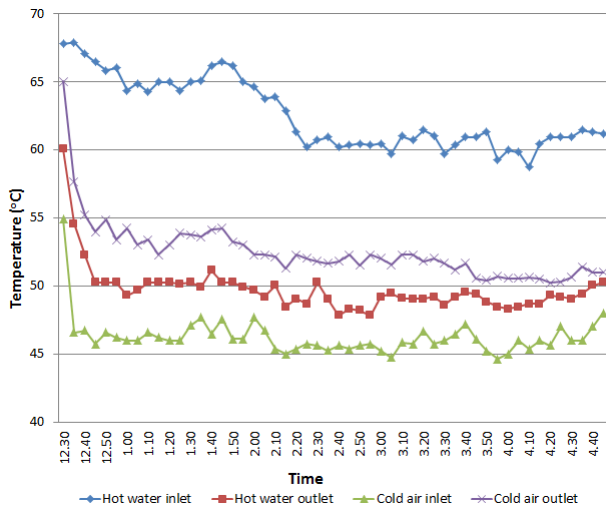


Fig. 9 Temperature of heat exchanger 1

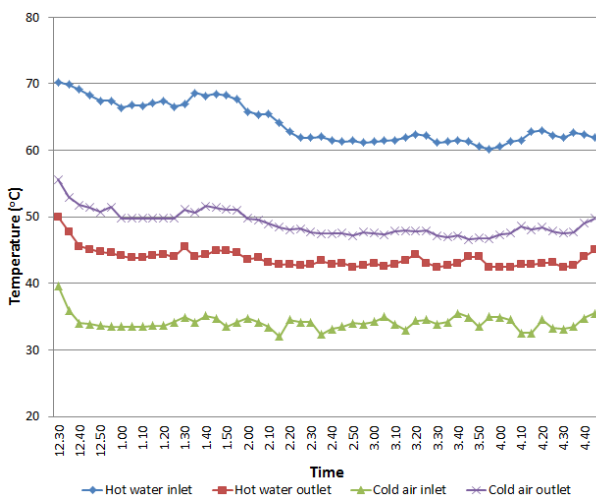


Fig. 10 Temperature of heat exchanger 2

The heat transfer through the copper coil between the hot water from the solar collector and water in the storage tank is poor. The average temperature of the hot water return from solar collector is approximately 84°C, but the temperature of water in the tank is approximately 65°C. The water in the tank is not only heated by copper coil from the primary circuit but it also assist by 4.5 kW electrical heater. The effectiveness of heating coil is only approximately 27% after considered the electrical heater energy consumption. The heat transfer was limited by the surface area of the heating coil which is 0.9 m<sup>2</sup>.

The higher temperature of hot water supply to the dryer system may be obtained by using direct connection from the solar collector to the dryer system without using water from the storage tank. The water in the storage tank was also heated by 4.5 kW electrical heater to increase the water temperature. In regeneration air, 2.5 kW electrical heater was used to increase the air temperature. The electrical heater was increase the average temperature of air from 49°C to 54°C for regeneration. Both electrical heater was consistently on during this experiment to maintain the high temperature. The speed of blower 1 and 2 for regeneration and dehumidification, respectively is a constant. However the speed of axial fan at the top of drying chamber is adjustable. In this experiment the speed of each axial fan is set at maximum value with the average value of 3 m/s because the high velocity will also improve the drying kinetic of the product.

## 4 Conclusion

The designed and developed solar assisted solid desiccant dryer can produce drying air at average temperature 52°C under average solar radiation of 797 W/m<sup>2</sup>. This drying temperature is suitable for heat sensitive product such as food and pharmaceutical product to maintain the fresh color, taste and nutrient content. The collector efficiency, heat exchanger effectiveness 1 and 2 was 70%, 77% and 67%, respectively. The thermal, regeneration and dehumidification effectiveness was 48%, 29% and 6%, respectively. Poor performance of desiccant wheel is due to the low regeneration temperature. The performance may be improved by increasing the regeneration temperature above 65°C. The higher temperature of regeneration air may be obtained by decreasing the air flow rate and increase electrical heater power. The overall performance of the dryer system also may be improved by using direct connection from the solar collector to the dryer system to obtain higher temperature of hot water.

## Acknowledgement

The authors would like to thank the Solar Energy Research Institute, Universiti Kebangsaan Malaysia, as well as Universiti Teknikal Malaysia Melaka and Kementerian Pendidikan Malaysia for sponsoring this work under Grant PRGS/1/12/TK07/UKM/02/2

## References:

- [1] A. Fudholi, K. Sopian, M. H. Ruslan, M. A. Alghoul, and M. Y. Sulaiman, Review of solar dryers for agricultural and marine products, *Renewable and Sustainable Energy Reviews*, Vol. 14, 2010, pp. 1–30.
- [2] K. Sato, M. Katahira, and E. Toji, Drying characteristics of raw bulb and dehumidified air and moisture content distribution of different bulb parts, *Journal of Japanese Society of Agricultural Machinery, Tohoku Branch*, Vol. 44, 1997, pp. 43–46.
- [3] W. Miller, Energy storage via desiccant for food agricultural applications, *Energy in Agriculture*, Vol. 2, 1983, pp. 341–354.
- [4] H. Okano, Honeycomb rotor type dehumidifiers: comparison between honeycomb rotor type dehumidifiers and various dehumidifying systems and explanation on their outlines, *Clean Technology*, Vol. 3, 1998, pp. 33–37.
- [5] S. Misha, S. Mat, M. . Ruslan, and K. Sopian, Review of solid/liquid desiccant in the drying applications and its regeneration methods, *Renewable and Sustainable Energy Reviews*, Vol. 16, No. 7, 2012, pp. 4686–4707.
- [6] S. Neti and E. I. Wolfe, Measurements of effectiveness in a silica gel rotary exchanger, *Applied Surface Science*, Vol. 20, 2000, pp. 309–322.
- [7] R. Narayanan, W. Y. Saman, S. D. White, M. Goldsworthy, Comparative study of different desiccant wheel designs, *Applied Thermal Engineering*, Vol. 31, No. 10, 2011, pp. 1613–1620.
- [8] K. Daou, R. Wang, Z. Xia, Desiccant cooling air conditioning: a review, *Renewable and Sustainable Energy Reviews*, Vol. 10, No. 2, 2006, pp. 55–77.
- [9] M. Kanoğlu, M. Özdiñ Çarpınlioğlu, M. Yıldırım, Energy and exergy analyses of an experimental open-cycle desiccant cooling system, *Applied Thermal Engineering*, Vol. 24, No. 5–6, 2004, pp. 919–932.
- [10] M. N. Golubovic, H. D. M. Hettiarachchi, W. M. Worek, Sorption properties for different types of molecular sieve and their influence on optimum dehumidification performance of desiccant wheels, *International Communications in Heat and Mass Transfer*, Vol. 49, 2006, pp. 2802–2809.
- [11] F. E. Nia, D. van Paassen, M. H. Saidi, Modeling and simulation of desiccant wheel for air conditioning, *Energy and Buildings*, Vol. 38, No. 10, 2006, pp. 1230–1239.