วารสารสมาคมวิศวกรรมเกษตรแห่งประเทศไทย ปีที่ 24 ฉบับที่ 1 (2561), 6-12

วารสารสมาคมวิศวกรรมเกษตรแห่งประเทศไทย
ปีที่ 24 ฉบับที่ 1 (2561) 6-12
Available online at www.tci-thaijo.org /index.php/TSAEJ

บทความวิจัย

ISSN 1685-408X

Study on psychrometric properties of air in a hot air drying system combined with a desiccant wheel

Palida Suvanvisan[1], Ekkapong Cheevitsopon[2], Jiraporn Sripinyowanich Jongyingcharoen[1]*

[1]Curriculum of Agricultural Engineering, Department of Mechanical Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand

[2]Department of Food Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand

*Corresponding author: Tel: +66-2329-8337, Fax: +66-2329-8336, E-mail: jiraporn.jo@kmitl.ac.th

Abstract

A hot air drying system combined with a desiccant wheel (HA-DW) was developed in this study to provide dehumidified air in the system. The rotary desiccant wheel (DW) with silica gel could reduce humidity of fresh air as shown by its lower relatively humidity (RH) and humidity ratio of 33.9% and 16 g water/kg dry air, respectively. The RH and humidity ratio of regenerative air at the temperature of 60°C exiting the DW were increased from 15.5% to 42.6% and from 19 g water/kg dry air to 26 g water/kg dry air, respectively. In the HA-DW system with a given drying temperature of 90°C, the RH of 42.6% (17.5 g water/kg dry air) at the inlet decreased to 9% (7.5 g water/kg dry air) at the outlet of the DW during dehumidification. In the section of DW regeneration, the RH increased by 13.8% (7.5 g water/kg dry air added) after passing through the DW. The HA-DW system was proved to provide this drying system with lower humidity following the theoretical dehumidification and regeneration process in a psychrometric chart.

Keywords: Desiccant wheel, Hot air drying, Desiccant, Silica gel, Psychrometric properties

1 Introduction

Using a dehumidification process in hot air drying is advantageous for improvement of drying characteristics and dried product quality. Low RH which promotes the efficient water removal could be observed in this drying system. Naidu et al. (2016) has shown that lightness, greenness, and yellowness of dill greens dried by low humidity hot air were higher than those of the samples dried by hot air. The low humidity air drying of dill greens (50°C, 28-30%RH) also contributed to its higher anti-oxidant activity as compared to conventional hot air drying at the same temperature (50°C, 58-63%RH).

A rotary DW is one of the most promising dehumidification of air conditioning system. It could be incorporated into a hot air drying system as an alternative way of drying. Regarding to process development, desiccant dehumidification system may offer several advantages such as low initial costs, environmental friendliness, and energy saving (Madhiyanon et al, 2007).

Therefore, this study was focused on development of a HA-DW system and determination of psychrometric properties of air in the system.

2 Materials and Methods

2.1 A hot air drying system with a DW

Figure 1 shows the experimental set-up of the HA-DW system. This system is composed of three main components including a rotary DW, a dryer, and an air-to-air heat exchanger.

The rotary DW with silica gel (desiccant material) was equipped with a hot air drying system. The stainless steel DW was 700 mm diameter × 50 mm thickness. It was divided into two equal sections, i.e. adsorption and regeneration sections. These sections were run simultaneously by means of continuous rotaion between the ambient humid air through the adsorption section and the heated regenerative air through the regeneration section. It was driven by a motor (RS Motor Industry, Taiwan) at 0.5 rpm.

The cylindrical drying chamber was 200 mm inner diameter x 300 mm length. The blowers (1 HP, MA40B, EuroVent, Thailand) were used to supply air for drying and regeneration, respectively. The air was heated to required temperatures by 3.74-kW electrical heaters (Technology Instruments, Thailand).

The heat exchanger was made of aluminium with a heat exchanging area of 50 m^2. It was designed to transfer receive the inlet heated air from the drying unit and exchange the heat to the inlet ambient air for regenerating the DW.

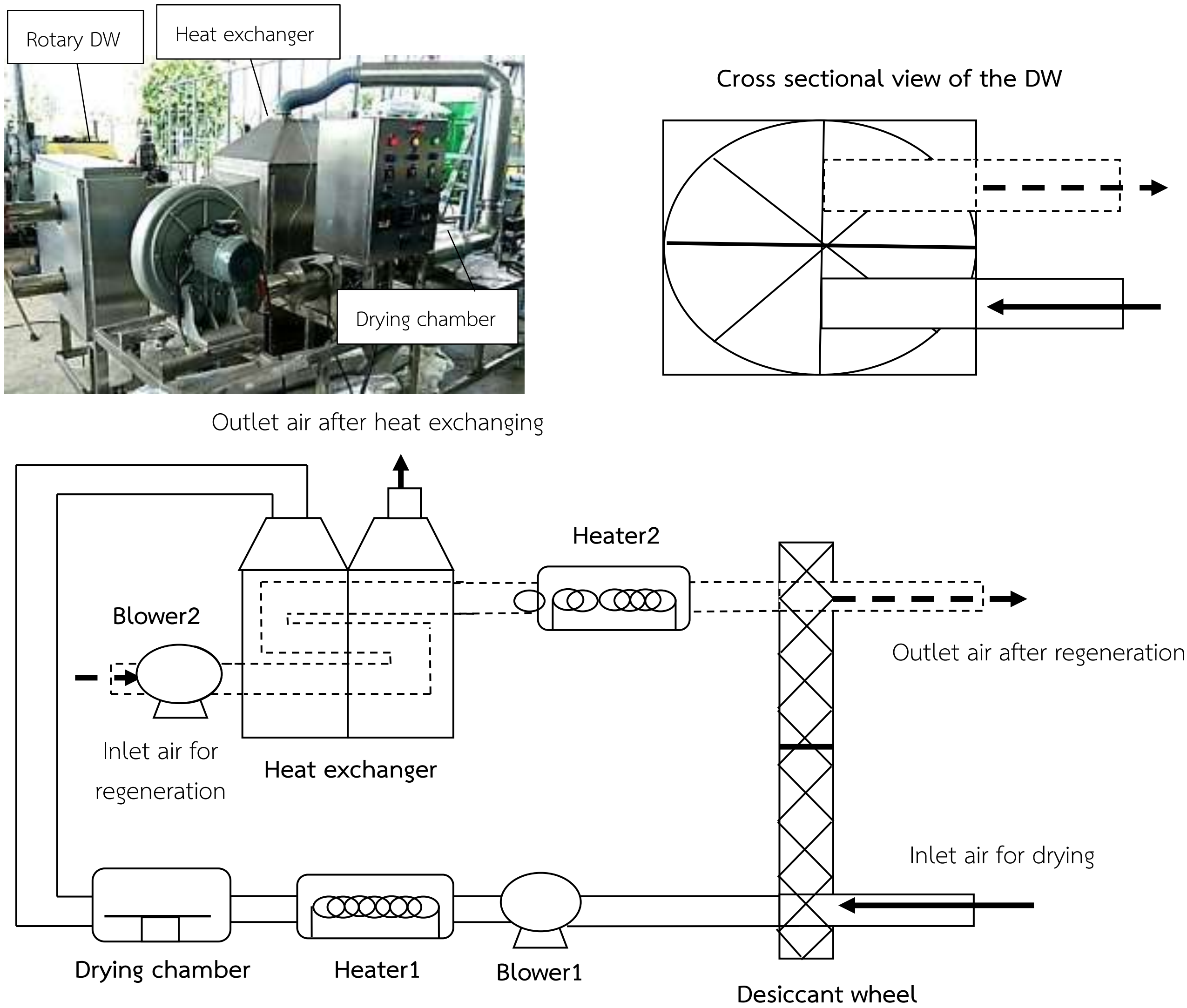

Figure 1 A schematic diagram of a HA-DW system.

2.2 Performance of a DW dehumidification system

2.2.1 Dehumidification process

Figure 2 shows the schematic diagram of the dehumidification process unit. The DW contained 3-kg fresh silica gel with the thickness of 1 cm. The ambient humid air (daytime, 35.9˚C, 50.2%RH and 19 g water/kg dry air) passed through the DW at the flow rate of 0.04 m^3/s (0.044 kg dry air/s). During the process, a temperature/ hygrometer (KT320, Kimo, France) was used to measure RH and temperature of the processed air. The experiment was conducted for 30 min with the measuring intervals of every 1 min for the first 10 min and every 5 min for the last 20 min.

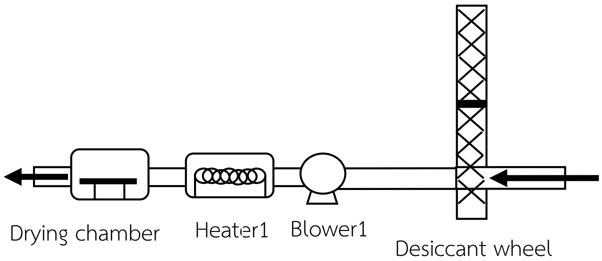

Figure 2 A schematic diagram of the dehumidification process unit.

2.2.2 Regeneration process

Figure 3 shows the schematic diagram of the regeneration process unit. The silica gel inside the DW was allowed to absorb moisture at the ambient condition for 5 hrs until it became pink prior to experiment. The heated air with the temperatures of 60°C and the flow rate of 0.04 m^3/s (0.041 kg dry air/s) was used to regenerate the silica gel. The air supplied in this process was heated up by a supplement heater 2. The RH and temperature of this process were measured at the same intervals as stated in 2.2.1

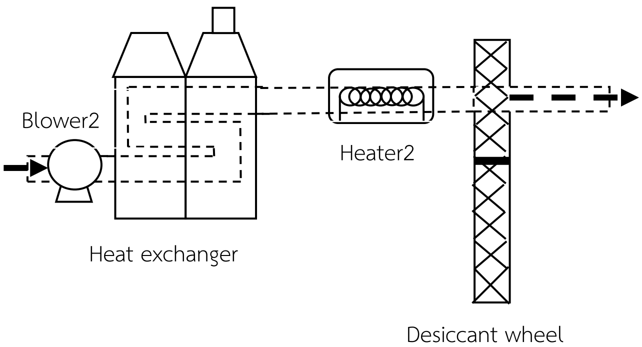

Figure 3 A schematic diagram of the regeneration process unit.

2.3 Psychrometric properties of air in a hot air drying system with a DW

Figure 4 shows the schematic diagram of a HA-DW system. There are two simultaneous process including the dehumidification process (line A) and the regeneration process (line B). In the dehumidification process, the ambient air was introduced to the process at A1, reduced its moisture by the DW, heated by the heater, used for drying, and then passed through the heat exchanger for exhanging its heat with the ambient air from line B. In the regeneration process, the ambient air was inletted at B1, incresed it temperature using the heat exchanger and passed through the DW for regenerating the silica gel. The heater 2 was closed during this experiment. The experiment was conducted at the temperature in a drying chamber of 90°C and the flow rate of 0.04 m^3/s for both lines (0.044 kg dry air/s for line A and 0.040 kg dry air/s for line B). During the process, the RH and temperature of this process were measured at every 5 min for 30 min.

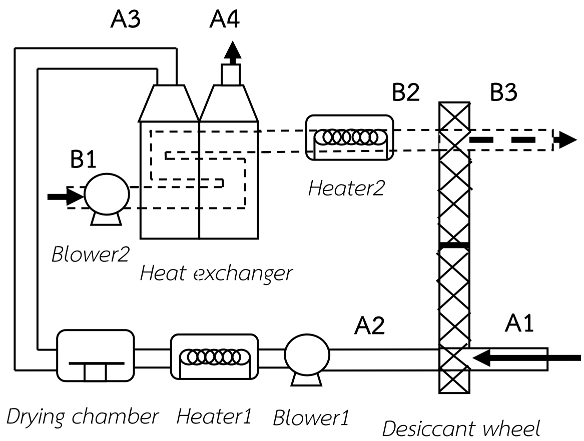

Figure 4 A schematic diagram of a HA-DW system with points of air condition assessment.

2.4 Desiccant wheel effectiveness

Effectiveness of the DW was determined using four equations, which were introduced by Mandegari and Pahlavanzadeh (2009). The DW effectiveness could be defined in terms of heat and mass transfer processes. The first equation is considered as thermal effectiveness as follows:

$$\varepsilon = \frac{T_{A2}-T_{A1}}{T_{B2}-T_{A1}} \quad (1)$$

where T_{A1}, T_{A2} and T_{B2} are inlet and outlet dehumidification process air and inlet regenerative air temperature, respectively.

Assuming DW as a heat exchanger, the DW effectiveness could be derived from the heat exchanger effectiveness as given by Eq. (2):

$$\varepsilon = \frac{(w_{A1}-w_{A2})\, h_{fg}}{h_{B2}-h_{B1}} \qquad (2)$$

where w and h are the specific humidity and the vaporization latent heat of water, respectively.

Based on the ideal dehumidification of DW in which the air is completely dehumidified and the humidity ratio of the outlet air of DW ($w_{A2,ideal}$) is zero, the expression of DW effectiveness could be:

$$\varepsilon = \frac{w_{A1}-w_{A2}}{w_{A1}-w_{A2,ideal}} \qquad (3)$$

where w_{A1} and w_{A2} was the specific humidity of the inlet and outlet air of DW.

As the theoretical operation of DW would be adiabatic, the following equation expresses the DW effectiveness with respect to the enthalpy deviation from the adiabatic condition, in which the effectiveness value reaches to 100% (Figure 5).

$$\varepsilon = 1-\frac{(h_{A2} - h_{A1})}{h_{A1}} \qquad (4)$$

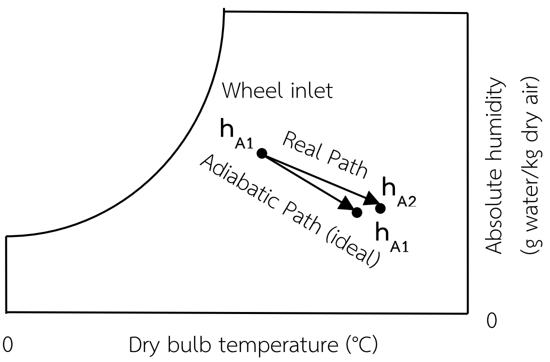

Figure 5 Adiabatic and real DW processes on psychrometric chart. (Modified from Mandegari and Pahlavanzadeh, 2009).

3 Results and discussion

3.1 Performance of a DW dehumidification system

3.1.1 Dehumidification process

During the dehumidification process, DW could reduce RH and humidity ratio from 50.2% and 19 g water/kg dry air to 33.9% and 16 g water/kg dry air after running the process for 1 min, respectively. The temperature dramatically rised about 5% from 35.9°C to 41.1°C for the first 1-min process as well. As can be seen in Figure 6, the experimental dehumidification process aligned well with the theoretical adiabatic dehumidification process.

Figure 7 shows the relationship of RH and temperature of DW outlet air with dehumidification time. It was found that the RH tended to reduce throughout the process. The RH was decreased by 16% approximately after running the process for only first min, which was correspondent to the reduction of humidity ratio by 3 g water/kg dry air. The RH was slightly increased and its value was 37.9% at 30 min, which was reduced by about 12% from the ambient RH of 50.2%. It is obvious that the DW successfully dehumidified air condition in the system. These results were agreed with Dina et al. (2015). They reported that solar drying with desiccant thermal energy storage, which provided lower humidity inside the drying chamber and hence contributed to decrease in drying time. However, the temperature tended to be stable for the whole process operation. After 30 min, the temperature was 40.3°C, which was increased by about 4.4% from the ambient temperature.

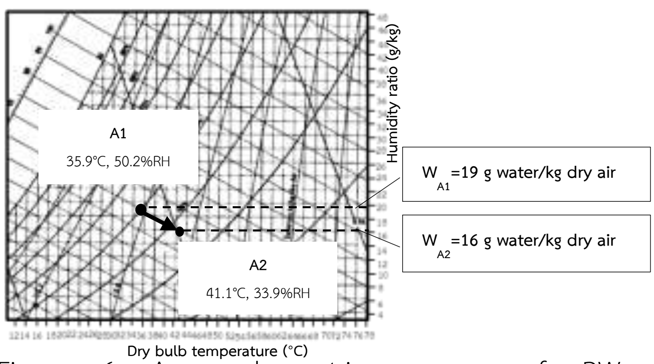

Figure 6 A psychrometric process of DW dehumidification.

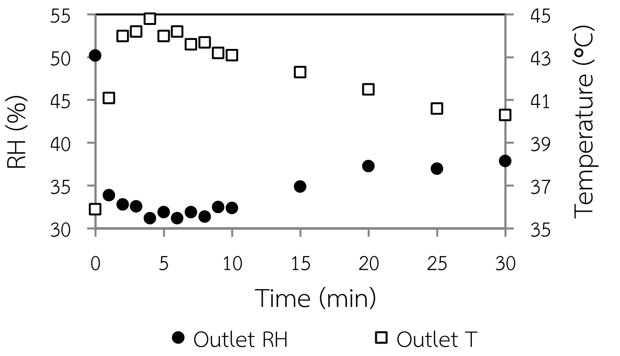

Figure 7 Relationship of RH and temperature at the outlet of the DW with adsorption time

3.1.2 Regeneration process

The psychrometric process of DW regeneration is shown in Figure 8. The changes of RH and temperature of DW outlet air during the regeneration process at 60°C are presented in Figure 9. An increase in RH of about 27% was observed when regenerating the silica gel for first 1 min from hot air of 60°C (15.5% and 19 g water/kg dry air). At this time, the corresponding humidity ratio was 7 g water/kg dry air for exiting DW of 42.6% (26 g water/kg dry air). After 30-min operation, the RH was 19%, which was increased by about 3.5% from the ambient RH (51.7%). It is obvious that the DW could be regenerated under this regeneration condition.

As expected, the temperature decreased by about 15% from 60°C to 44.8°C after regeneration the DW for first 1 min. After 30 min, the temperature of the outlet air was almost equal to that of the heated air supplied to the DW.

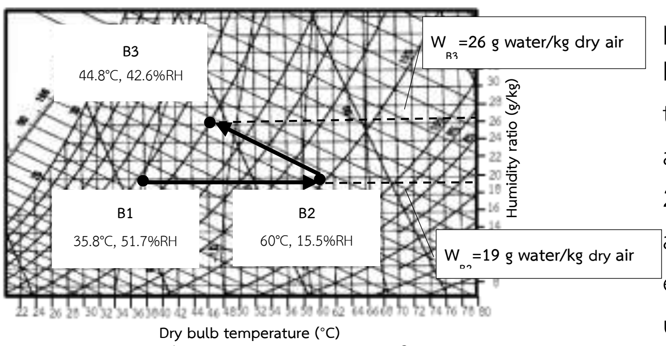

Figure 8 A psychrometric process of DW regeneration.

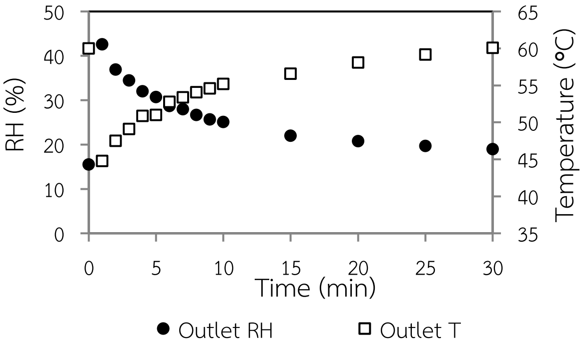

Figure 9 Relationship of RH and temperature at the outlet of the DW with desorption time at the regeneration temperature of 60°C.

3.2 Psychrometric properties of air in a hot air drying system with a DW

Figure 10 shows the relationship of RH and temperature of outlet air of the DW at the fixed drying temperature of 90°C. Similarly, dramatic decrease in RH was obtained at the five minute dehumidification. It is interesting that the desirable low RH was constantly observed for the whole period of dehumidification. The corresponding humidity ratios were in the range of 9 and 10 g water/kg dry air, which was reduced by about 7.5 g water/kg dry air from the ambient humid air. The RH changes during the regeneration process was obvious at the first five minutes as well. Dramatic increase and decrease in temperature of the outlet air were also observed at the first five minutes for the dehumidification and regeneration process.

The air condition at each point in the HA-DW system is shown in Figure 11. Humidity of air was reduced after passing through the DW from A1 to A2. The air was then heated to the temperature of 90°C and introduced to the heat exchanger at A3. After exchanging its heat, the air condition was determined at A4 to be 53.7°C and 27%RH. For the regeneration process, the inlet ambient air was supplied to B1, passed through the heat exchanger at B2 to increase its temperature, and then used to remove moisture from silica gel in the DW. It was observed that the outlet air condition of this process (B3) was 56.5°C and 22.9%RH.

The air properties observed in Figure 11 could be plotted in the psychrometric chart. The psychrometric process of air passing through the DW for both dehumidification and regeneration sides followed typical adiabatic process. The heater is used to regenerate the DW and to control the process of air conditioning. The adiabatic efficiency will have an optimum value that depends on dehumidification and regeneration efficiency (Misha et al. 2012).

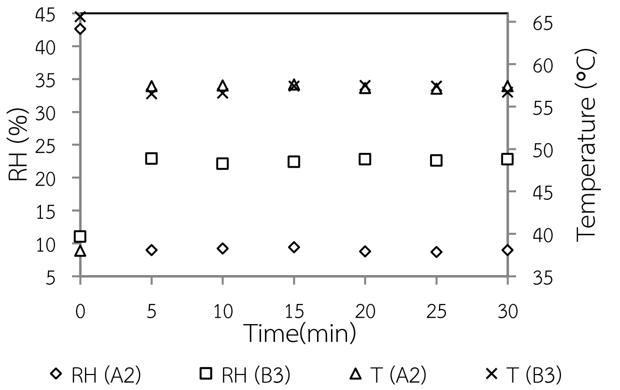

Figure 10 Relationship of RH and temperature at the outlet of DW during dehumification (A2) and regeneration (B3) with processing time at the drying temperature of 90°C.

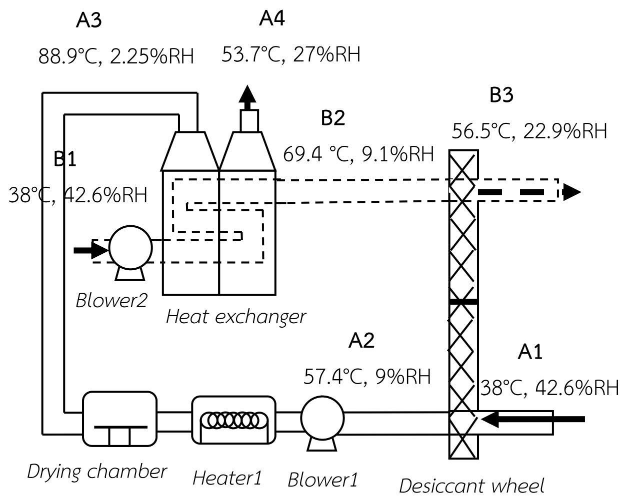

Figure 11 Schematic diagram of a HA-DW system with the air condition at each point after running the process for 30 min.

3.3 Desiccant wheel effectiveness

DW's effectiveness are shown in Table3. The properties of air in a hot air drying used in this study at 90°C. The effectiveness results showed that thermal, regeneration, dehumidification and adiabatic DW's would be gained by an optimum value operation which provided completely lower humidity inside the drying chamber.The specific absorption of silica gel for dehumidification process was 2.64 g water/kg dry air· kg silica gel·min

Table 1 Effectiveness of DW.

Effectiveness	Percentage (%)
Thermal effectiveness	69.28
Regeneration effectiveness	61.42
Dehumidification effectiveness	44.39
Adiabatic DW's effectiveness	98.49

4 Conclusions

The RH and humidity ratio decreased from 50.2 to 33.9% and from 19 to 16 g water/kg dry air during moisture adsorption by the DW, respectively. The temperature increased from 35.9 to 40.3°C

In the regeneration process at 60°C, the RH and humidity ratio increased from 15.5 to 42.6% and from 19 to 26 g water/kg dry air, respectively. The temperature decreased in the first period to 50°C and kept constant at 60°C in the last period.

In the HA-DW system, the RH and humidity ratio of the dehumidification process decreased from 42.6 to 9% and from 17.5 to 10 g water/kg dry air, respectively. The RH and humidity ratio of the regeneration process increased from 11 to 22.9% and from 17.5 to 25 g water/kg dry air, respectively.

The performance of the HA-DW system that thermal, regeneration, dehumidification and adiabatic desiccant wheel's effectiveness were 69.28, 61.42, 44.39 and 98.49%, respectively.

5 Acknowledgements

This research project was supported by the National Research Council of Thailand, fiscal year of 2016.

6 References

Dina, S.F., Ambarita, H., H. Napitupulu, F.H., Kawai, H. 2015. Study on effectiveness of continuous solar dryer integrated with desiccant thermal storage for drying cocoa beans. Case Studies in Thermal Engineering 5, 32–40.

Madhiyanon, T., Adirekrut, S., Sathitruangsak, P., Soponronnarit, S. 2007. Integration of a rotary desiccant wheel into a hot-air drying system: Drying performance and product quality studies. Journal of Chemical Engineering and Processing 46, 282–290.

Mandegari, M.A., Pahlavanzadeh, H. 2009. Introduction of a new definition for effectiveness of desiccant wheels. Journal of Chemical Engineering 34, 797–803.

Misha, S., Mat, S., Ruslan, M.H., Sopian, K. 2012. Review of solid/liquid desiccant in the drying application and its regeneration methods. Journal of renewable and Sustainable Energy Reviews 16, 4686–4707.

Naidu, M.M., Vedashree, M., Satapathy, P., Khanum, H., Ramsamy, R., Hebbar, H.U. 2016. Effect of drying methods on the quality characteristics of dill (Anethumgraveolens) greens. Journal of Food Chemistry 192, 849–856.