Theoretical and Experimental Analysis of Desiccant Wheel Performance for Low Humidity Drying System

TRI SUYONO, SOHIF MAT, MUHAMMAD YAHYA, MUHD. HAFIZ RUSLAN, AZAMI ZAHARIM & KAMARUZZAMAN SOPIAN
Solar Energy Research Institute
Universiti Kebangsaan Malaysia
43600 UKM Bangi, Selangor
MALAYSIA
Email: Tri_suyono78@yahoo.com, azami.zaharim@gmail.com, ksopian@eng.ukm.my

Abstract: The drying process is influenced by three main factors temperature, flow rate and humidity, resulting in the drying process of hot air required in accordance with the character of materials with low humidity, so it can speed up the drying process. Malaysia is located south East Asia region that has a sufficiently high temperature and humidity, so it requires a process to reduce moisture in the air. The system is integrated solar dryer with a desiccant wheel is designed to produce dry air. The system consists of evacuated tube collector (solar water heater collector), heat exchanger, desiccant wheel, blower, hot water pumps and hot water tank. The system produces air with a temperature of absolute humidity 58.02°C with kg H₂O/kg dry air 0.0167. This system is capable of evaporating water 10.8kg H₂O/hr. With temperatures and humidity are controlled then the system can perform sensitive drying material to heat, but also with a low humidity can reduce the drying time.

Key-Words: desiccant wheel, temperature and humidity, water evaporation.

1 Introduction
Drying process in principle is to vaporize the water in the dried material. This process is influenced by temperature, humidity and air velocity dryer. In the process of drying air required to heat and dry so that drying time can be shortened, but the air temperature must be adjusted to the properties of dried material [1]. Desiccant wheel is widely used to lower the humidity of air in the cooling system [2], desiccant wheel has a good ability to absorb water in air [3]. In the process of air through two desiccant wheel that is latent and sensible state, where in addition to the air becomes dry, the air will also experience an increase in temperature [40-10].

Noting that the use of desiccant wheel in the process of drying is considered appropriate. Low temperature and dry air are good for drying foodstuffs [11]. System using desiccant wheel dryer for drying sensitive materials such as products, vegetables and herbs, with temperature and humidity are low / controlled the drying of products such as vegetables to maintain color, texture, aroma and nutrients of dried material [12].

2 Drying System
The system is designed for drying in a commercial scale. The system consists of solar collector (evacuated tube) with a 13:32 wide m², 0.62 m² area heat exchanger 0.15m thick, desiccant wheel maximum 1.500 cfm flow rate and 2 blowers with a maximum flow rate of 1.500 cfm. To operate the tool at night or when there is no sun used electrical air heater for heating regeneration process.

Dryer system uses a heat source of the evacuated tube collector in the form of hot water, then poured into hot water heat exchanger to heat the air.

Flow rate in this experiment was made at the 929.6 cfm / 1,579.5 m³ h for both processes (regeneration and dehumidification), mean ratio between the regeneration of the desiccant wheel and dehumidification 1:1.

Fig.1 Schematic Diagram of Solar Desiccant Drying System.
3 Analytical Method

This system uses solar energy as heat sources, heat energy from the sun transferred to the water through the heat pipe evacuated tube. Hot water flowed into the heat exchanger to heat air and water that has passed through a heat exchanger and the heat flow is reduced to the hot water tank and then flowed back to the collector with hot water pump, so this process takes place continuously throughout the process. Hot air generated by the heat exchanger is used for the regeneration desiccant wheel. This paper will only discuss the performance of desiccant wheel and the estimated drying process, while the collector performance, heat exchangers and other components not discussed.

Desiccant wheel operating system there are two processes, namely the process of regeneration and dehumidification [10]. This process is called regeneration or recovery process is the process of drying in silica gel desiccant that has been wet while due process of dehumidification. While the dehumidification process is the process of water absorption in the air so the air will become drier and the temperature is increased [12].

To determine the desiccant wheel performance will be evaluated effectiveness dehumidification and regeneration process (Sensible and latten), and the adiabatic effectiveness [4].

3.1 Dehumidification process

Sensible/thermal Effectiveness
\[ \varepsilon_{dh.sbl} = \frac{m_{dh}}{m_{min}} \frac{T_1 - T_2}{T_1 - T_7} \]  
Latten Effectiveness
\[ \varepsilon_{dh.ltn} = \frac{m_{dh}}{m_{min}} \frac{h_1 - h_2}{h_1 - h_7} \]

From the equation above, the temperature and absolute humidity of air which has passed the dehumidification process can be calculated by the following equation:
\[ T_2 = \frac{m_{min}}{m_{dh}} \varepsilon_{dh.sbl} (T_2 - T_1) + T_1 \]
\[ h_2 = \frac{m_{min}}{m_{dh}} \varepsilon_{dh.ltn} (h_1 - h_2) + h_1 \]

3.2 Regeneration Process

Equation for the process of regeneration can be written as follows:

Sensible / thermal Effectiveness
\[ \varepsilon_{reg.sbl} = \frac{\dot{m}_{reg}}{\dot{m}_{min}} \frac{T_8 - T_7}{T_1 - T_7} \]  
Latten Effectiveness
\[ \varepsilon_{reg.ltn} = \frac{\dot{m}_{dh}}{\dot{m}_{min}} \frac{h_8 - h_7}{h_1 - h_7} \]

Thus the temperature and absolute humidity of air that has passed through the process of regeneration can be written with the following equation:
\[ T_{reg.out} = \frac{\dot{m}_{min}}{\dot{m}_{dh}} \varepsilon_{reg.sbl} (T_1 - T_7) + T_7 \]
\[ h_{reg.out} = \frac{\dot{m}_{min}}{\dot{m}_{dh}} \varepsilon_{reg.ltn} (h_1 - h_7) + h_7 \]

Adiabatic efficiency can be calculated by the following equation:
\[ \varepsilon_{adiabatic} = 1 - \frac{(h_2 - h_1)}{h_1} = \frac{(2h_1 - h_2)}{h_1} \]

3.3. Drying estimate

In the analysis of the drying time will be calculated theoretically with the assumption that ideal drying process, and not discuss the nature of the material in the drying process. Decrease in water content in the dried material was calculated in each 30-minute intervals until the material is dried achieve the desired water content. In this analysis, will look for reduction in water content in the dried material using pick-up efficiency equation [13].
\[ \eta_p = \frac{h_{out} - h_{in}}{h_{as} - h_{in}} = \frac{W}{\rho v t (h_{as} - h_{in})} \]  
If, \( W = m_o - m_i \) then,
\[ \eta_p = \frac{m_o - m_i}{\rho v t (h_{as} - h_{in})} \]
\[ m_i = m_o - (\rho v t (h_{as} - h_{in}) \eta_p) \]
The decrease in the per time period

\[ m_{t,n+1} = m_{o,n+1} - (\rho \nu (h_{air} - h_m) \eta_p)_{n+1} \]  

(13)

\[ G_a = \frac{\dot{m} C_p}{(h_{in} + 1)} \frac{\nu}{(h_{in} + 1)} \]  

(14)

### 4 Result and Discussion

Overall performance of desiccant wheel is strongly influenced by the air used in the process of regeneration and the air that goes into the process of dehumidification. The more hot and dry air that is used in the process and entering the dehumidification process, the air generated in the dehumidification process will be more hot and dry because the desiccant wheel operation occurs Sensible and latten. Sensible process occurs because the process is valid isotermit process.

#### 4.1 Dehumidification Process

Dehumidification process on this system produces the appropriate temperature and humidity for the drying process. In theoretic temperature dehumidification process incoming average 33.9°C with inlet air temperature 67°C regeneration process will result in air temperature 58.8°C, this process can be seen in figure 2. Experiment results show that the dehumidification process in the same conditions produce 58.02°C air temperature, this indicates that the results approached theoric experiment, the results can be seen in Figure 3. Sensible effectiveness of this system an average of 0.73 is shown in Figure 4.

In theoretic absolute humidity at the inlet air regeneration process and the absolute humidity 0.0148 kg H2O/kg dry air air dehumidification process kg H2O/kg dry air 0024 kg H2O/kg dry air will result in air by absolute humidity of the air 0017 kg H2O/kg dry air while the experiment is 0.0167 kg H2O/kg dry air.

From the results of these experiments is known latten effectiveness in this system an average of 0793. This process can be seen in Figure 5 and 6.
4.2 Regeneration Process
Regeneration process aims to dry the silica gel desiccant wheel in order to function again as a dehumidifier. Regeneration process the incoming air is hot and dry air, and air that has been used for the regeneration temperature becomes lower and wetter. In this system theoretic regeneration process will produce air with an average temperature of 42°C and experiment results show that air temperature 39.8°C, absolute humidity of air which has been used for the regeneration process will also increase, the theoretic average 0.022 kg\text{H}_2\text{O}/kg\text{dry.air}, and experiment results 0.0218 kg\text{H}_2\text{O}/kg\text{dry.air}, it can be seen in Figure 7 and 8. Sensible effectiveness Regeneration average of 0.82, while the regeneration latten effectiveness in this system 0.789, can be seen in Figure 9 and 10. Several process conditions on the desiccant wheel Sensible depicted in Figure 11, while the adiabatic effectiveness desiccant wheel can be seen in Figure 12 is an average of 0.93.
4.3 Drying Estimate

The results of experiments on this system indicates dry air flow rate 1,684.6 kg\textsubscript{dry,air}/hr, inlet air absolute humidity drying chamber average of 0.0167 kg\textsubscript{H2O}/kg\textsubscript{dry,air}, assuming a 55% drying efficiency of the system is capable to evaporate of water in the dried material 10.8 kg\textsubscript{H2O}/jam. If it is assumed that the material is dried weighing 100 kg which has a moisture content of 80% initial and final moisture content of 3% or the final weight of 10.3 kg of material. Thus this system should to evaporate water in the dried material as much as 89.7 kg\textsubscript{H2O}, then by using equation (13) can be predicted drying time 7.2 hours.

5 Conclusion

In this study the desiccant wheel is used for the dryer system. From the results obtained that the desiccant wheel suitable for the dryer system.

Experiment results dehumidification process on this system produces an average air temperature 58.02°C by absolute humidity 0.0167 kg\textsubscript{H2O}/kg\textsubscript{dry,air}. Sensible effectiveness 0.73 whereas the average effectiveness latten 0.793. In the process of regeneration in this system theoretic Sensible heat generating temperature of 42°C and experiment results of 39.8°C, latten a theoretic process produces 0.022 kg\textsubscript{H2O}/kg\textsubscript{dry,air}, and the results of experiments 0.0218 kg\textsubscript{H2O}/kg\textsubscript{dry,air}. Sensible effectiveness 0.82, while the regeneration effectiveness latten 0789. With a flow rate of air into the drying chamber 1,684.6 kg\textsubscript{dry,air}/hr, inlet air absolute humidity drying chamber average of 0.0167 kg\textsubscript{H2O}/kg\textsubscript{dry,air}, and assuming 55% efficiency of drying, then the system is expected to evaporate water in the dried material 10.8 kg\textsubscript{H2O}/hr.

Nomenclature

- $\varepsilon_{dh,bl}$: Dehumidification sensible effectiveness
- $\dot{m}_{dh}$: Mass air flow rate for dehumidification process (kg\textsubscript{dry,air}/hr)
- $\dot{m}_{dh}$: Mass air flow rate for regeneration process (kg\textsubscript{dry,air}/hr)
- $\dot{m}_{\text{min}}$: Minimum value of either mass flow rate (kg\textsubscript{dry,air}/hr)
- $T_1$: Dry bulb temperature of air in to dehumidification process (°C)
- $T_2$: Dry bulb temperature or air out from dehumidification process (°C)
- $T_7$: Dry bulb temperature of air in to regeneration process (°C)
- $T_8$: Dry bulb temperature of air out from regeneration process (°C)
- $h_1$: Absolute humidity of air in to dehumidification process (°C)
- $h_2$: Absolute humidity of air out from dehumidification process (°C)
- $h_7$: Absolute humidity of air in to regeneration process (°C)
- $h_8$: Absolute humidity of air out from regeneration process (°C)
- $h_{in}$: Absolute humidity of air entering the drying chamber (%)
- $h_{out}$: Absolute humidity of air leaving the drying chamber (%)
- $h_{ss}$: Absolute humidity of the air entering the dryer at the point of adiabatic saturation (%)
- $s$: Dry matter content (%)
- $t$: Drying time (seconds)
- $V$: Volumetric airflow rate (m\textsuperscript{3}/s)
- $W$: Weight of water evaporated from the product (kg)
- WAC: Water absorption capacity
- $\rho$: Density of air (kg/m\textsuperscript{3})
- $\eta_{hc}$: Heat collection efficiency
- $\eta_p$: Pick-up efficiency
- $\eta_s$: Drying system efficiency
- $G_a$: Dry air Mass air flow rate (kg\textsubscript{dry,air}/hr)
References:


