

# Performance of Desiccant wheel for Low Humidity Drying System

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*Abstract:* - Drying is an important process for preserving food and non-food products. Solar desiccant drying system has been designed and fabricated for the production of dried products. The system has controllable drying temperature, humidity and flow rate of commercial/industrial capacity in accordance with the characteristics of the material, so that it is not damaged in the drying process. This system consists of heat pipe evacuated tube, cross flow heat exchanger, desiccant wheel, hot water pump, the hot water tank, drying chamber and electrical air heater. Experiments were conducted with two modes: (1) Heat exchanger to heat the air in the regeneration process and (2) Heat exchanger to heat the air after the dehumidification process, while the regeneration process utilized an electrical air heater. Experiment on the desiccant wheel of mode (1) showed that the average effectiveness of sensible dehumidification, sensible regeneration, latent dehumidification and latent regeneration were 72.61%, 82.13%, 79.32% and 78.91% respectively. In mode (2), the average effectiveness of sensible dehumidification, sensible regeneration, latent dehumidification and latent regeneration were 71.4%, 71.99%, 66.97% and 72.8% respectively. Mode (1) was better than mode (2) with mean drying air temperature and absolute humidity were 58°C and 0.0167 kg<sub>(H<sub>2</sub>O)</sub>/kg<sub>(dry air)</sub> respectively. The system was able to evaporate 10.8 kg<sub>(H<sub>2</sub>O)</sub>/hr of water in the materials at drying efficiency of 60%.

*Keywords:* - Desiccant wheel, temperature and humidity, water evaporation.

## 1 Introduction

Depleting of fossil and gas reserves, combined with the growing concerns of global warming has necessitated an urgent search for alternative energy sources to cater to the present day demands. An alternative energy resource such as solar energy is becoming increasingly attractive. Solar energy is a permanent and environmentally friendly source of renewable energy. One of the most important components of a solar energy system is the solar collector. Solar collectors are key components in many engineering applications. It can be used for many applications in drying of agricultural products, space heating, solar desalination, etc. Improving their performance is essential for commercial acceptance of their use in such applications [1-5].

Various types of solar drying systems for agricultural and marine products have been reviewed [6]. Solar drying system is one of the most attractive and promising applications of solar energy systems in tropical and subtropical countries. The

technical development of solar drying systems can proceed in two directions. Firstly, simple, low power, short life, and comparatively low efficiency-drying system. Secondly, high efficiency, high power, long life expensive drying system [7,8].

Drying process plays an important role in the preservation of agricultural products. Air drying is the most frequently used dehydration operation in the food and chemical industry. The wide variety of dehydrated foods, which today are available to consumers and the interesting concern for meeting quality specifications and energy conservation, emphasize the need for a thorough understanding of the drying process [9]. 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.

Desiccant wheel is widely used to lower the humidity of air in the cooling system. Desiccant wheel has a good ability to absorb water in air [10]. In the process of air through 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 [11-18].

## 2 Drying System

This system consists of heat pipe evacuated tube collectors with area of 13.32 m<sup>2</sup>, cross flow heat exchanger for regeneration and to heat the air after dehumidification, desiccant wheel with model no. 770 WSG produced by NOVELAIRE having operating system 1:1 and maximum flow rate of 1.500 cfm, hot water pump with maximum capacity of 12 liters/minute, the hot water tank with maximum capacity of 230 liter, drying chamber and electrical air heater for use when there is no sun or to increase the temperature. The use of desiccant wheel for absorbing the moisture in the dryer system is appropriate because not only the air becomes drier, but it also becomes hotter due to isotherms process. Performance of the collectors was determined. The water flow rate of 8 liters/minutes was the optimum flow in the drying process. Experiments were conducted with two modes: (1) Heat exchanger to heat the air in the regeneration process and (2) Heat exchanger to heat the air after the dehumidification process, while the regeneration process utilized an electrical air heater.

Flow rate in this experiment was made at the 929.6 cfm / 1,579.5 m<sup>3</sup> / h for both processes (regeneration and dehumidification), mean ratio between the regeneration of the desiccant wheel and dehumidification 1:1.

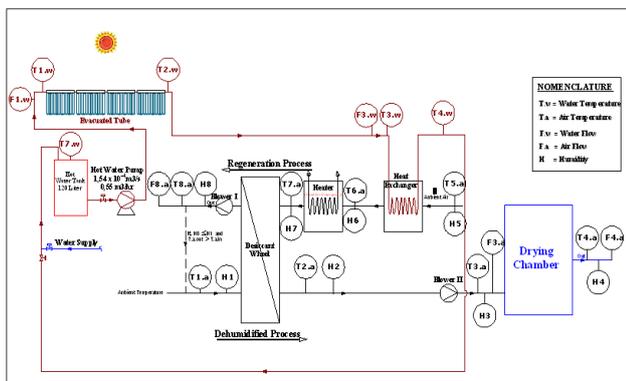


Fig.1 schematic diagram of solar desiccant drying system mode (1)

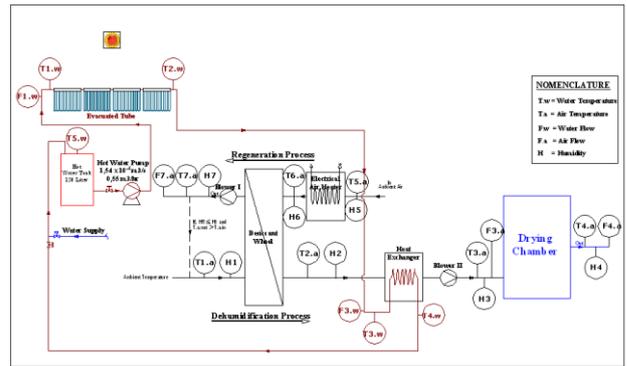


Fig.2 schematic diagram of solar desiccant drying system mode (2)



Fig.3 the 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 and heat the air after the dehumidification process. This paper will only discuss the performance of desiccant wheel and the estimate 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 [17]. 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 [20].

To determine the desiccant wheel performance will be evaluated effectiveness dehumidification and regeneration process (Sensible and latent), and the adiabatic effectiveness [11].

### 3.1 Dehumidification Process

Sensible/thermal Effectiveness

$$\varepsilon_{dh.sbl} = \frac{\dot{m}_{dh} T_1 - T_2}{\dot{m}_{min} T_1 - T_7} \quad (1)$$

Latent Effectiveness

$$\varepsilon_{dh.ltm} = \frac{\dot{m}_{dh} w_1 - w_2}{\dot{m}_{min} w_1 - w_7} \quad (2)$$

From the equation above, the temperature and absolute humidity of air which has passed the dehumidification process can be calculated by the following equation:

$$T_2 = \frac{\dot{m}_{min}}{\dot{m}_{dh}} \varepsilon_{dh.sbl} (T_7 - T_1) + T_1 \quad (3)$$

$$w_2 = \frac{\dot{m}_{min}}{\dot{m}_{dh}} \varepsilon_{dh.ltm} (w_7 - w_1) + w_1 \quad (4)$$

### 3.2 Regeneration Process

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

Sensible / thermal Effectiveness

$$\varepsilon_{reg.sbl} = \frac{\dot{m}_{reg} T_8 - T_7}{\dot{m}_{min} T_1 - T_7} \quad (5)$$

Latent Effectiveness

$$\varepsilon_{reg.ltm} = \frac{\dot{m}_{dh} w_8 - w_7}{\dot{m}_{min} w_1 - w_7} \quad (6)$$

Thus the temperature and absolute humidity of air that has passed through the process of regeneration can be written with the following equation:

$$T_{reg.out} = \frac{\dot{m}_{min}}{\dot{m}_{dh}} \varepsilon_{reg.sbl} (T_1 - T_7) + T_7 \quad (7)$$

$$w_{reg.out} = \frac{\dot{m}_{min}}{\dot{m}_{dh}} \varepsilon_{reg.ltm} (w_1 - w_7) + w_7 \quad (8)$$

Adiabatic efficiency can be calculated by the following equation:

$$\varepsilon_{adiabatic} = 1 - \frac{(h_2 - h_1)}{h_1} = \frac{(2h_1 - h_2)}{h_1} \quad (9)$$

### 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 [21].

$$\eta_p = \frac{w_{out} - w_{in}}{w_{as} - w_{in}} = \frac{W}{\rho v t (w_{as} - w_{in})} \quad (10)$$

If,  $W = m_o - m_t$  then,

$$\eta_p = \frac{m_o - m_t}{\rho v t (h_{as} - h_{in})} \quad (11)$$

$$m_t = m_o - (\rho v t (w_{as} - w_{in}) \eta_p) \quad (12)$$

The decrease in the per time period

$$m_{t,n+1} = m_{o,n+1} - (\rho v t (w_{as} - w_{in}) \eta_p)_{n+1} \quad (13)$$

$$\varepsilon_a = \frac{\dot{m} C_p}{(w_{in} + 1)} = \frac{v}{(w_{in} + 1)} \quad (14)$$

## 4. Results 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 process regeneration and air 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 latent. Sensible process occurs because the process is valid isotherm process.

**4.1 Dehumidification Process**

Dehumidification is a process that is expected in the use of desiccant wheel. dehumidification process is the process of absorption of water in the air by an absorbent material (silica gell) so that the air becomes drier. The air that has passed through this process will become more dry and increases of temperature. This process is influenced by the air used to dry the silica gell (regeneration process).

**4.1.1 Dehumidification Process Mode (1)**

Dehumidification process on this mode produces the appropriate temperature and humidity for the drying process. and regeneration process incoming with inlet air temperature an average were 33.9°C and 67°C will result air temperature of 58°C, this process can be seen in figure 20. Experiment results show that the dehumidification process in the same conditions produce air temperature of 58°C, this indicates that the results approached theritic and experiment, the results can be seen in Figure 4. Sensible effectiveness of this system an average of 73% is shown in Figure 5. Absolute humidity at the inlet air regeneration and dehumidification process were 0.0148 kg<sub>H2O</sub>/kg<sub>dry.air</sub> and 0.024 kg<sub>H2O</sub>/kg<sub>dry.air</sub> respectively, will result absolute humidity of air in theoretic and experiment were 0.017 kg<sub>H2O</sub>/kg<sub>dry.air</sub> and 0.0167 kg<sub>H2O</sub>/kg<sub>dry.air</sub> respectively.

From the results of these experiments is known latent effectiveness in this mode an average of 79.3%. This process can be seen in Figure 6 and 7.

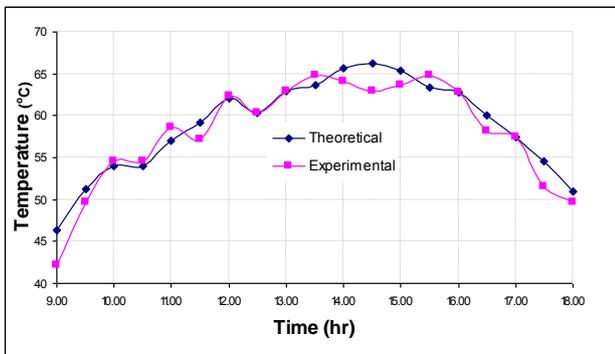


Fig.4 Theoretical and experimental sensible dehumidification

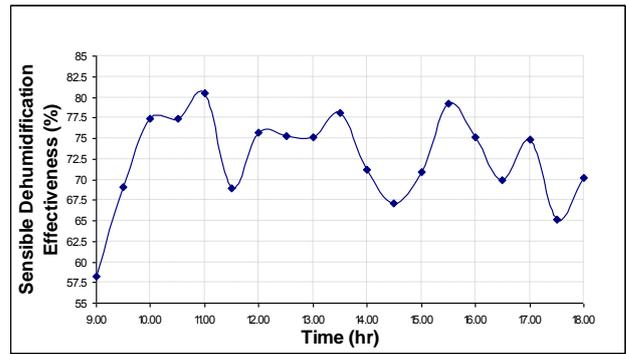


Fig.5 dehumidification sensible effectiveness

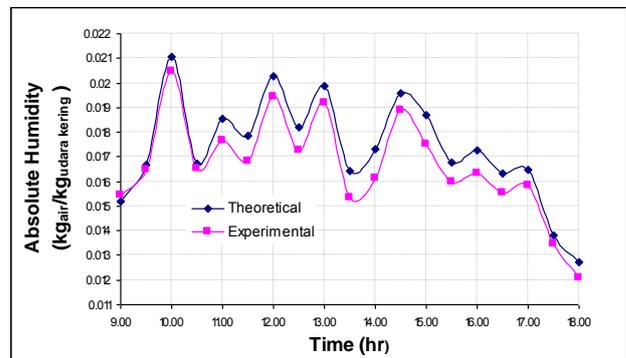


Fig.6 theoretical and experimental latent dehumidification

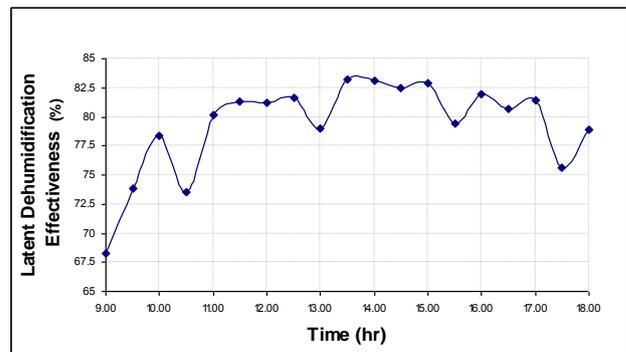


Fig.7 Dehumidification Latent Effectiveness

**4.1.2 Dehumidification Process Mode (2)**

In the mode (2) this air is used for the regeneration process is heated with electrical air heater. Dehumidification and regeneration process incoming with inlet air temperature an average were 34°C and 48°C will result air temperature of 45°C, this process can be seen in figure 22. Experiment results show that the dehumidification process in the same conditions produce air temperature of 44.5°C,

this indicates that the results approached theritic and experiment, the results can be seen in Figure 8. Sensible effectiveness of this system an average of 71.4% is shown in Figure 9. Absolute humidity at the inlet air regeneration and dehumidification process were 0.0189 kg<sub>H2O</sub>/kg<sub>dry.air</sub> and 0.0205 kg<sub>H2O</sub>/kg<sub>dry.air</sub> respectively, will result absolute humidity of air in theoretic and experiment were 0.0167 kg<sub>H2O</sub>/kg<sub>dry.air</sub> and 0.0169 kg<sub>H2O</sub>/kg<sub>dry.air</sub> respectively.

From the results of these experiments is known latent effectiveness in this mode an average of 72.8%. This process can be seen in Figure 10 and 11.

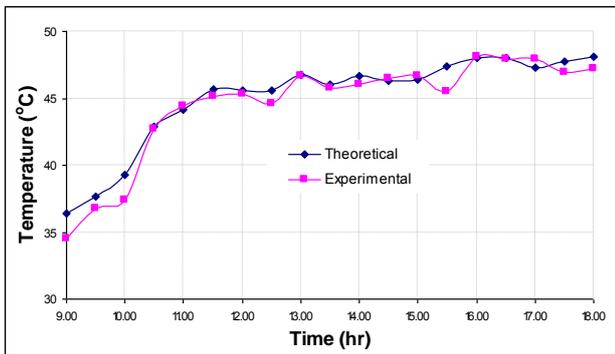


Fig.8 theoretical and experimental sensible dehumidification

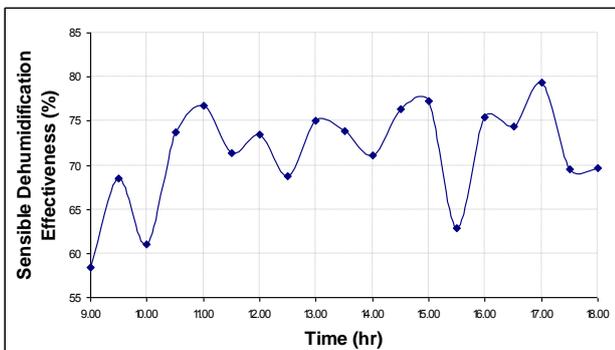


Fig.9 dehumidification sensible effectiveness

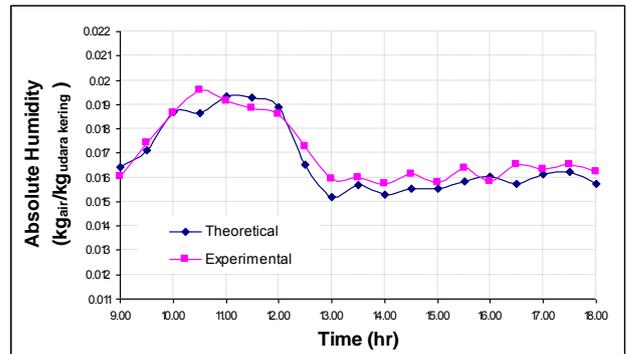


Fig.10 theoretical and experimental latent dehumidification

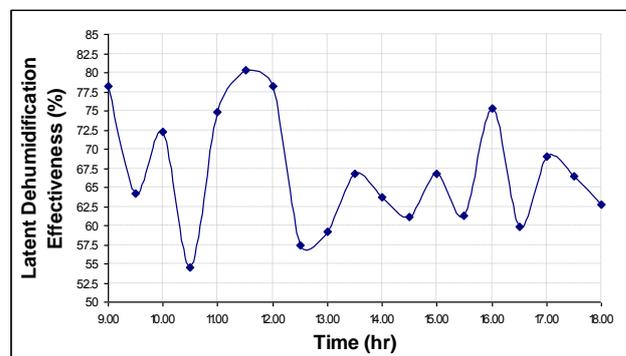


Fig.11 dehumidification latent effectiveness

## 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.

### 4.2.1 Regeneration Process Mode (1)

In the mode (2), theoretic and experimental regeneration process with an average temperature were 42°C and 39.8°C respectively, absolute humidity of air which has been used for the regeneration process will also increase, the theoretic and experimental an average were 0.022 kg<sub>H2O</sub>/kg<sub>dry.air</sub>, and 0.0218 kg<sub>H2O</sub>/kg<sub>dry.air</sub> respectively, it can be seen in Figure 12 and 14. Average sensible and latent regeneration effectiveness were 82% and 78.9% respectively, can be seen in figure 13 and 15. While the adiabatic effectiveness desiccant wheel can be seen in Figure 24 is an average of 93%.

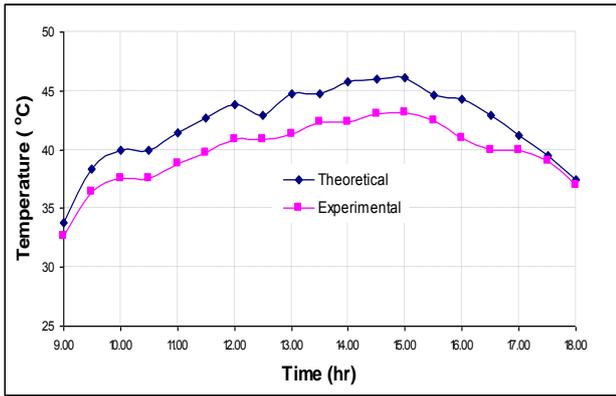


Fig.12 theoretical and experimental sensible regeneration

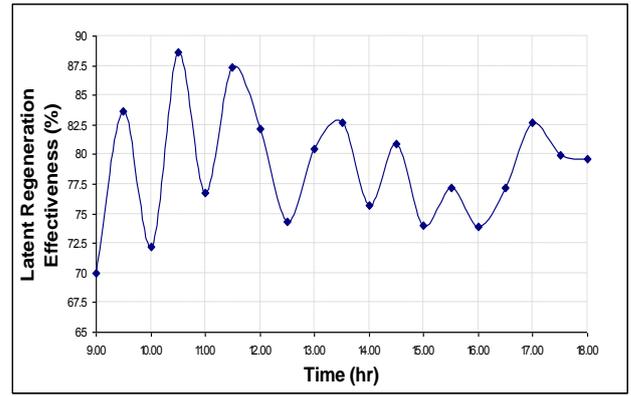


Fig.15 regeneration latent effectiveness

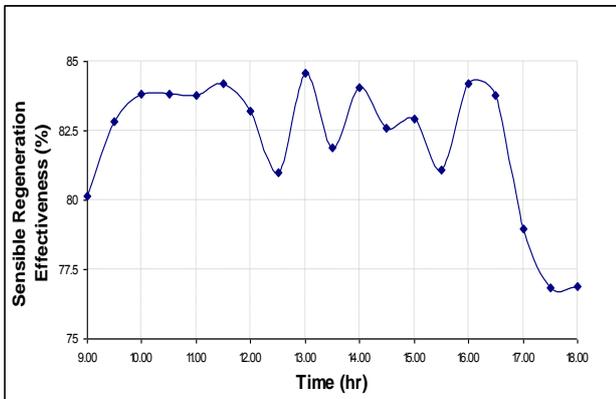


Fig.13 sensible regeneration effectiveness

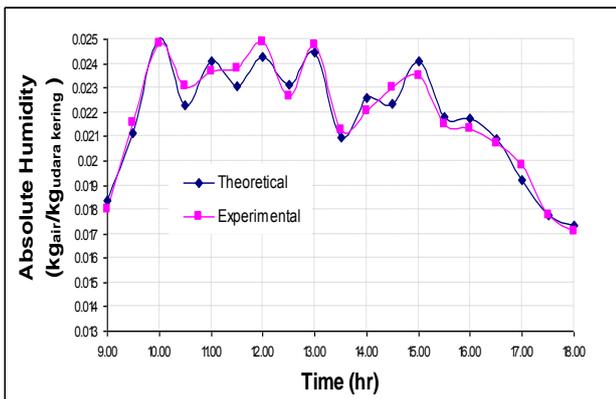


Fig.14 theoretical and experimental latent regeneration

#### 4.2.1 Regeneration Process Mode (2)

Theoretic and experimental regeneration process in the mode (2) with an average temperature were 37.6°C and 38°C respectively, absolute humidity of air which has been used for the regeneration process will also increase, the theoretic and experimental an average were 0.0189 kg<sub>H2O</sub>/kg<sub>dry.air</sub>, and 0.0191 kg<sub>H2O</sub>/kg<sub>dry.air</sub> respectively, it can be seen in Figure 16 and 18. Average sensible and latent regeneration effectiveness were 72% and 72.8% respectively, can be seen in figure 17 and 19. While the adiabatic effectiveness desiccant wheel can be seen in Figure 25 is an average of 96%.

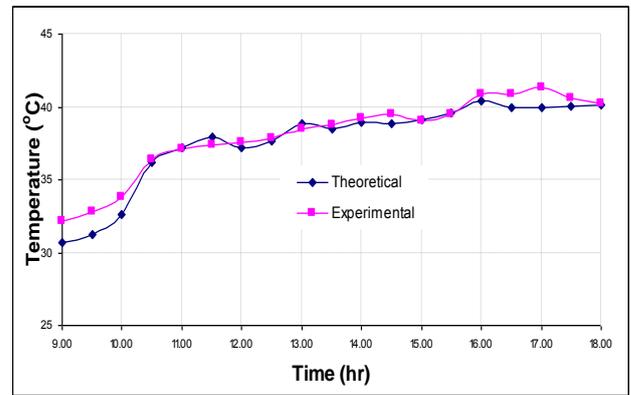


Fig.16 theoretical and experimental sensible regeneration

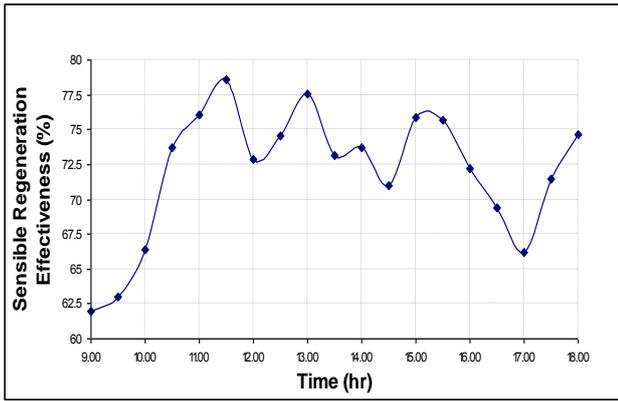


Fig.17 Sensible Regeneration effectiveness

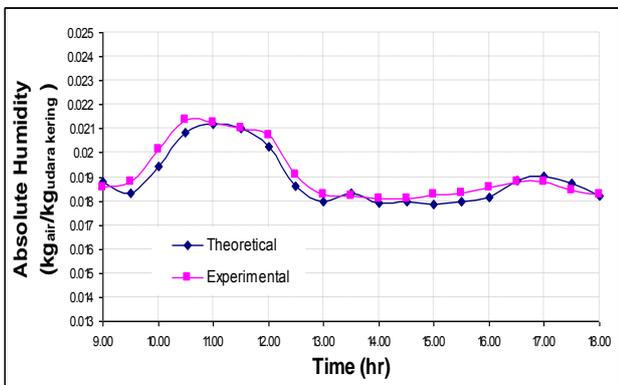


Fig.18 theoretical and experimental latent regeneration

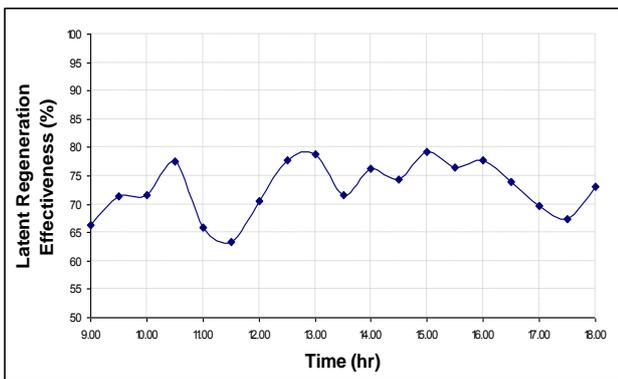


Fig.19 Regeneration latent effectiveness

### 4.3 Desiccant Wheel Process

#### 4.3.1 Dehumidification and Regeneration Process Mode (1)

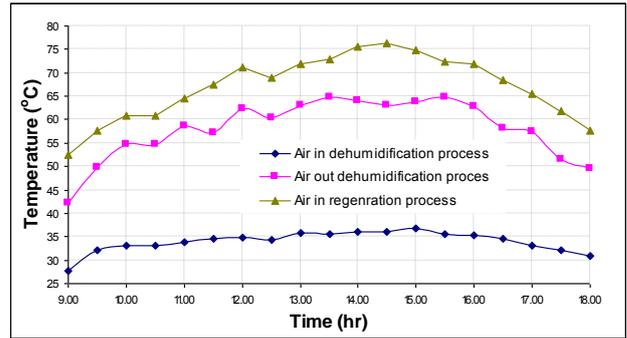


Fig.20 sensible desiccant wheel process

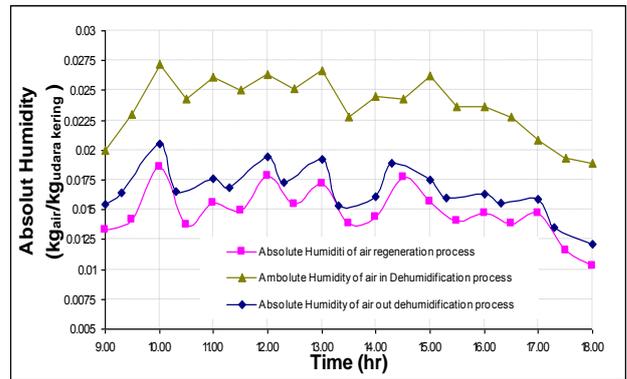


Fig.21 latent desiccant wheel process

#### 4.3.2 Dehumidification and Regeneration Process Mode (2)

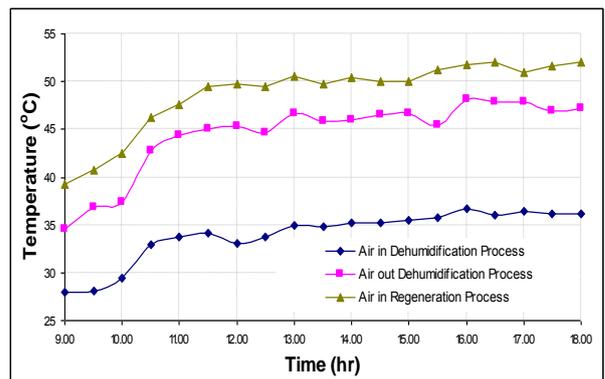


Fig.22 sensible desiccant wheel process

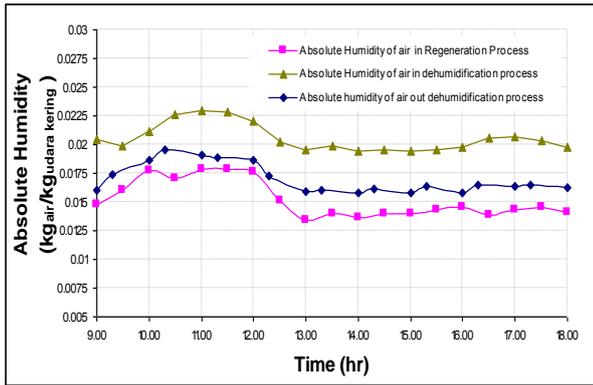


Fig.23 latent desiccant wheel process

#### 4.4 Adiabatic Effectiveness

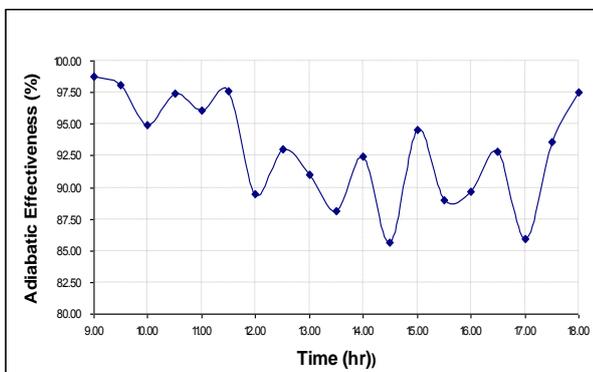


Fig.24 adiabatic effectiveness mode (1)

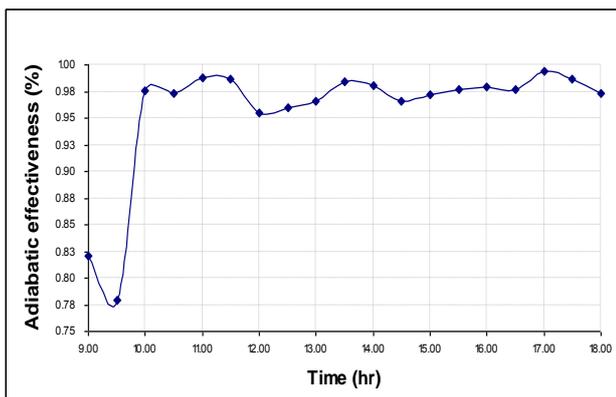


Fig.25 Adiabatic effectiveness mode (2)

#### 4.5 Drying Estimate

The results of experiments on this system indicates dry air flow rate 1,684.6 kg<sub>dry.air</sub>/hr , inlet air absolute humidity drying chamber average of 0.0167 kg<sub>H2O</sub>/kg<sub>dry.air</sub>, at drying efficiency of 60%,

the system is capable to evaporate of water in the dried material 10.8 kg<sub>H2O</sub>/h. 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<sub>H2O</sub>, then by using equation (16) can be predicted drying time 7.2 hours.

#### 4. 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 Mode (1) was better than mode (2) with mean drying air temperature and absolute humidity were 58°C and 0.0167 kg<sub>(H2O)/kg<sub>(dry air)</sub></sub> respectively. Average Sensible and latent effectiveness were 73% and 79.3% respectively. 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<sub>H2O</sub>/kg<sub>dry.air</sub>, and the results of experiments 0.0218 kg<sub>H2O</sub>/kg<sub>dry.air</sub>. Sensible effectiveness 0.82, while the regeneration effectiveness latten 78.9%.

With a flow rate of air into the drying chamber 1,684.6 kg<sub>dry.air</sub>/hr, inlet air absolute humidity drying chamber average of 0.0167kg<sub>H2O</sub>/kg<sub>dry.air</sub>, at drying efficiency of 60%, the system is expected to evaporate water in the dried material 10.8kg<sub>H2O</sub>/hr.

#### Nomenclature

- $\varepsilon$  Effectiveness
- $\dot{m}_{dh}$  Mass air flow rate for dehumidification process (kg<sub>dry.air</sub>/hr)
- $\dot{m}_{rh}$  Mass air flow rate for regeneration process (kg<sub>dry.air</sub>/hr)
- $\dot{m}_{min}$  Minimum value of either mass flow rate (kg<sub>dry.air</sub>/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)

$w_1$	Absolute humidity of air in to dehumidification process ( $^{\circ}\text{C}$ )
$w_2$	Absolute humidity of air out from dehumidification process ( $^{\circ}\text{C}$ )
$w_7$	Absolute humidity of air in to regeneration process ( $^{\circ}\text{C}$ )
$w_8$	Absolute humidity of air out from regeneration process ( $^{\circ}\text{C}$ )
$w_{in}$	Absolute humidity of air entering the drying chamber (%)
$w_{out}$	Absolute humidity of air leaving the drying chamber (%)
$w_{as}$	Absolute humidity of the air entering the dryer at the point of adiabatic saturation (%)
$h_1$	Enthalpy of air in dehumidification process (kJ/kg)
$h_2$	Enthalpy of air out dehumidification process (kJ/kg)
$s$	Dry matter content (%)
$t$	Drying time (seconds)
$V$	Volumetric airflow rate ( $\text{m}^3/\text{s}$ )
$W$	Weight of water evaporated from the product (kg)
WAC	Water absorption capacity
$\rho$	Density of air ( $\text{kg}/\text{m}^3$ )
$\eta_{hc}$	Heat collection efficiency
$\eta_p$	Pick-up efficiency
$\eta_s$	Drying system efficiency
$\dot{G}_a$	Dry air Mass air flow rate ( $\text{kg}_{\text{dry,air}}/\text{hr}$ )

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