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Performance of novel solar dryer

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ABSTRACT

The effect of rotary desiccant wheel on the thermal performance of the solar dryer unit is numerically investigated. The solar dryer unit integrated with rotary desiccant wheel consists of rotary desiccant wheel, solar air collector, and drying unit. The theoretical models of the desiccant wheel and solar collector have been validated using an experimental data. Also, the effects of desiccant wheel rotation speed on the performance of this system are investigated. The numerical results of this study show that; for using rotary desiccant wheel in the solar drying units, dry and hot air are produced that, in turn, improve the drying process. Also, for using rotary desiccant wheel in the solar drying units, the temperature of drying air increased from 65 °C to 82 °C while the humidity ratio decreased from 15 to 8.8 $g_{water}/kg_{dry\ air}$ compared to the solar drying units without using a desiccant wheel, at the same ambient conditions. Furthermore, the results show that the optimal rotation speed of the desiccant wheel which about 15 rph to obtained the maximum drying air temperature and minimum humidity ratio inlet to dryer unit. The percentage increase in the system useful heat gain for using the solar drying unit integrated with rotary desiccant wheel about 153% in average compared to the solar drying unit without rotary desiccant wheel. The advantages of using rotary desiccant wheel in a solar drying unit introduces a continuous drying along the daily time, an increase the rate of drying due to dry and hot air out from rotary desiccant wheel, an increase the quality of the dry products, and a decrease in the time required for drying the product.

1. Introduction

Solar drying method is a good alternative;this is because it is a free and inexhaustible source of solar energy. In the drying method, a mass andheat transfer occurs to remove water from the products by evaporation. The advantages of using rotary desiccant wheel in a solar drying unit include; a continuous drying along the daily time, the desiccant wheel production dry and hot air that improving the drying process, an increase the rate of drying due to dry and hot air generated by desiccant wheel, and increasing the quality of the dry products.

The drying methodof the product is divided into two processes. Initially, the surface and center of the product has the same amount of moisture. In the first process the water in the surface will be evaporated when it is heated by dry hot air. In the second process when the surface has dried up, the moisture will be move from the center to the surface of the product and then evaporated (Fournier and Guinebault, 1995). Also, some products do not present two process. Belessiotis and Delyannis (2011) defined another process, third process, for hygroscopic products where the moisture in the productwill continue to decreaseuntil a state of equilibrium.

Dissa et al. (2009) numerically and exprimentally studied the mango drying by the solar energy. The thickness of the mango slices was 8 mm. The results show that, three days required to drying the mango. The drying rate in the three days are 50%, 40%, and 5%, repectively. Dilip and Tewari (2015) studied the indirect drying with phase change material to storage the thermal energy. Tunde-Akintunde (2011) numerically studied the directdrying process of chilli pepper for using solar

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Nomenclature

A	area (m^2)
C_p	constant pressure specific heat (J/(kg K))
D_a	mass diffusion diffusivity of the water vapor in the air
D_h	hydraulic diameter (m)
f_m	mass friction of desiccant in the wheel
F_R	heat removal factor
G_t	solar energy (W/m^2)
h	convective heat transfer coefficient (W/(m^2 K))
H_{sor}	heat of sorption (kJ/kg)
K_m	mass transfer coefficient (kg/(m^2 s))
K_a	air thermal conductivity (W/(m K))
$\dot{m}$	mass flow rate (kg/s)
P_{fa}	perimeter of flow channel (m)
Q_u	rate of useful heat (W)
Q_{add}	heat energy added to reactivation air (W)
Q_{gain}	system useful heat gain (kW)
T_∞	ambient air temperature (°C)
T	temperature (°C)
u	velocity (m/s)
U_L	coefficient of heat-loss in solar collector (W/(m^2 °C))
W	amount of water in desiccant wheel (kg_{wv}/kg_{des})
Y_{fa}	air humidity ratio ($kg_{wv}/kg_{dry\ air}$)
Y_{des}	desiccant humidity ratio ($kg_{wv}/kg_{dry\ air}$)

Greek symbols

ρ	density (kg/m^3)
α	absorptance
τ	transmittance

Subscripts

da	dry air
des	desiccant
fa	flow air
l	liquid
reg	regeneration air
wv	water vapor

energy. Kamil et al. (2006) studied the drying cycle of the thin layer organic tomato for using solar drying units. Romero et al. (2014) numerically studied the drying cycle of vanilla in an indirect solar drying unit. Stefan and Andrzej (2015) studied the drying process of apple slices in a solar drying units. Kavak Akpinar and Bicer (2008) studied the characteristics of the drying of thin layer in a solar drying unitunder the natural and forced convection.

Gas-side resistance model used to calculate the thermal performance of a rotary desiccant wheel It was created by Zhang and Dai (2003) and valided by Jia et al. (2007) to predict the rotary desiccant wheel performance. It is reported that the difference between the simulated data and the experimental results is about 15–20%. Ge et al. (2010) conducted a numerical simulation to study the effect of different parameters of the performance of the desiccant cooling system. Chung et al. (2009) numerically investigated the effect of the wheel rotation speed and the area ratio of reactivation to dehumidification process on the behavior of desiccant wheel.

This paper aims to study the effect of rotary desiccant wheel on the thermal performance of a solar drying unit under the different climate conditions. The performance of the solar drying unit integrated with rotary desiccant wheel are numerically investigated. Also, the effect of desiccant wheel rotation speed on the performance of solar drying unit integrated with rotary desiccant wheel are investigated. A mathematical model used in this study is validated by the previus exprimental work.

2. Description of the novel solar dryer

2.1. System description

Fig. 1 shows the schematic diagram of the solar drying units. Two systems are illustrated: system (a) solar drying unit integrated with rotary desiccant wheel and system (b) solar drying unit without rotary desiccant wheel. The solar drying unit integrated with rotary desiccant wheelconsistof rotary desiccant wheel, solar air collector, drying unit, and auxillary air heater. The auxillary air heater used to rise the temperature of reactivation air to the required temperature. The cross-section of the rotor desiccant wheel is divided into two- parts: one for drying air and the other for regeneration air, with a central angle 240° for drying air and for regeneration air 120°. Also, a solar drying unit integrated with rotary desiccant wheel consist of two air paths, path of drying air (state 1–3) and path of reactivation air (state 3–5). The drying air cycle is as follows: drying air at state point 1 passes through the desiccant wheel, where its moisture is removed and temperature is increased due to the adsorption heat effect. Then this hot dry air is sensibly heat from state point 2–3 in a solar air collector as shown in Fig. 2. For reactivation air cycle, the part of drying air out from solar air collector is heated in the auxilary air heater from state 3–4. After that, these hot air flow through the desiccant wheel to desorb water vapor and regenerate desiccant wheel and exit at state points 5. But, for the solar drying unit without rotary

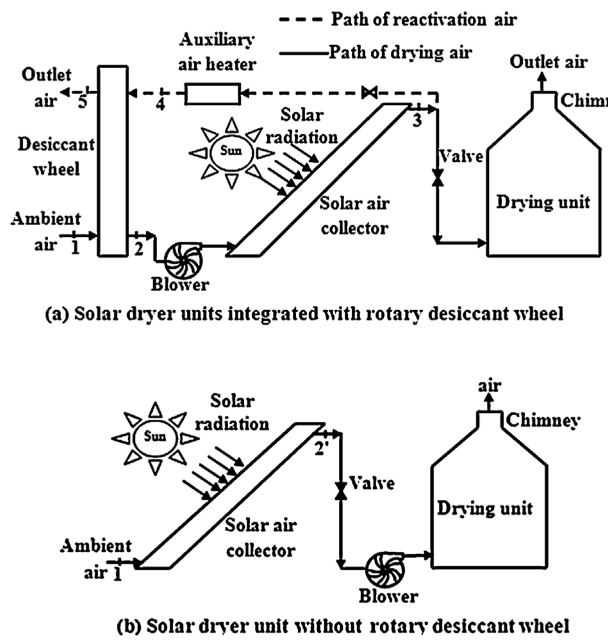

Fig. 1 – Schematic of the drying units; (a) solar dryer unit integrated with rotary desiccant wheel, (b) solar dryer unit without rotary desiccant wheel.