Available online at www.sciencedirect.com
ScienceDirect
Applied Thermal Engineering 27 (2007) 1543–1551
APPLIED THERMAL ENGINEERING
www.elsevier.com/locate/apthermeng

Experimental study of regenerative desiccant integrated solar dryer with and without reflective mirror

V. Shanmugam [a,*], E. Natarajan [b]

[a] Department of Mechanical Engineering, Sathyabama University, Chennai, 600 119, India
[b] Institute for Energy Studies, College of Engineering, Anna University, Chennai, 600 025, India

Received 8 July 2005; accepted 19 September 2006
Available online 19 December 2006

Abstract

An indirect forced convection with desiccant integrated solar dryer has been built and tested. The main parts are: a flat plate solar air collector, a drying chamber, desiccant bed and a centrifugal blower. The system is operated in two modes, sunshine hours and off sunshine hours. During sun shine hours the hot air from the flat plate collector is forced to the drying chamber for drying the product and simultaneously the desiccant bed receives solar radiation directly and through the reflected mirror. In the off sunshine hours, the dryer is operated by circulating the air inside the drying chamber through the desiccant bed by a reversible fan. The dryer is used to dry 20 kg of green peas and pineapple slices. Drying experiments were conducted with and without the integration of desiccant unit. The effect of reflective mirror on the drying potential of desiccant unit was also investigated. With the inclusion of reflective mirror, the drying potential of the desiccant material is increased by 20% and the drying time is reduced. The drying efficiency of the system varies between 43% and 55% and the pick-up efficiency varies between 20% and 60%, respectively. Approximately in all the drying experiments 60% of moisture is removed by air heated using solar energy and the remainder by the desiccant. The inclusion of reflective mirror on the desiccant bed makes faster regeneration of the desiccant material.

Keywords: Forced convection; Solar dryer; Desiccant drying; Pick-up efficiency; Thermal efficiency

1. Introduction

Solar drying is the most preferred method for drying agricultural products. Though well developed, and still a good deal of work is continuing in this direction throughout the world. For commercial producers, the ability to process continuously throughout the day is very important to dry the produces to its safe storage level.

Various designs of solar dryers are developed and tested for their performance. Each differs in design and is developed for a specific product. Passive type of solar crop dryers is well realized and it overcomes the problems existing in open sun dryer and cabinet type of dryers [1]. Normally thermal storage systems are employed to store thermal energy, which includes sensible heat storage, chemical energy storage and latent heat storage [2]. Common systems include water tanks or gravel beds, sand, granite, concrete, etc. [3] where energy is stored in the form of sensible heat.

Latent heat storage is also an efficient and suitable heat storage means, it include hydrated salts, paraffin's, non-paraffin [4] and fatty acids, but the drawback is its low thermal conductivity. Solar drying systems with sensible and latent heat storage are successfully demonstrated by many researchers [5–8]. Generally the equipment required to store and exchange heat by sensible and latent heat storage is not practical for solar drying.

The drying potential in a regenerated desiccant material represents one of the most promising mechanisms of

* Corresponding author. Tel.: +91 44 24929565; fax: +91 44 24502344.
E-mail address: v_shanmugam63@yahoo.co.in (V. Shanmugam).

1359-4311/$ - see front matter
doi:10.1016/j.applthermaleng.2006.09.018

Nomenclature

A	cross sectional area of pipe connecting drying chamber (m^2)
C_a	specific heat capacity of air (kJ/kg K)
C_d	specific heat capacity of desiccant (kJ/kg K)
dM/dt	drying rate at any time of drying (kg water/ kg dry matter.min)
h_{as}	adiabatic saturation humidity of air entering the chamber (kg water/kg dry air)
h_i	absolute humidity of air entering the chamber (kg water/kg dry air)
h_{fg}	latent heat of vaporization of water (kJ/kg)
I	solar insolation (W/m^2)
k	drying constant (s^{-1})
m_a	mass flow rate of air (kg/s)
m_d	mass of desiccant (kg)
m_w	mass of moisture evaporated in time 't' (kg)
M_e	equilibrium moisture content (kg water/kg dry matter)
M_f	final moisture content (kg water/kg dry matter)
M_o	initial moisture content (kg water/kg dry matter)
M_t	moisture content at any time of drying (kg water/kg dry matter)
MR	moisture ratio
P_f	blower power (W)
t	time (s)
T_a	ambient temperature (°C)
T_{co}	collector outlet temperature (°C)
T_{di}	initial temperature of desiccant (°C)
T_{df}	final temperature of desiccant (°C)
T_{fi}	collector air inlet temperature (°C)
W_d	mass of dry matter (kg)
W_0	weight of sample at $t = 0$ (kg)
W_t	weight of sample at any time 't' (kg)
W_{wet}	mass of wet matter after drying in a solar dryer (kg)
η_p	pick-up efficiency
η_d	drier thermal efficiency

thermal storage for the purpose of solar drying [9]. In this process, the moisture removal from the drying air could be realized by adsorption in a desiccant unit regenerated by solar energy. The heat generated during such exothermic adsorption is nearly equivalent to the latent heat of vaporization of the removed moisture. The desiccant bed serves as an open adsorption–desorption cycle where solar energy is stored during the desorption stage as sensible heat. It is recovered later during the adsorption stage where a relatively humid and cold air is drawn through the adsorbent bed and the exiting warm and dry air can be used for drying. The sensible heat storage in the packed beds is also shown to be a sufficiently efficient system [10]. Several studies were conducted using regenerated solid desiccants such as silica gel, but it requires high temperature typically above 150 °C for regeneration and high cost of desiccant material. Though silica gel has got high moisture sorption capacity its dust particles have shown to be carcinogenic and make it unsuitable for direct food processing applications. Thoruwa et al. [11] developed and studied the efficacy of various $CaCl_2$ based solar regenerative solid desiccant material and showed that 60% bentonite, 10% $CaCl_2$, 20% vermiculite and 10% cement gave a maximum moisture sorption of 45% dry weight basis (dwb) and is suitable for grain drying applications.

The purpose of this work is to study the possibility of using $CaCl_2$ based solid desiccant for grain drying applications for the typical climatic conditions of Chennai, Tamilnadu, India. Experiments have been conducted on the fabricated forced convection and desiccant integrated solar dryer for drying green peas and pineapple. In order to increase the intensity of solar radiation on the desiccant bed a reflective mirror is incorporated and its effects were studied.

2. Experimental set up

The experimental set up consists of an indirect forced convection solar dryer with a solar flat plate air collector, 0.1 kW centrifugal blower with an air flow rate up to 300 m^3/h, drying cabinet consisting solid desiccant material stacked at the top, a reflective mirror to increase the concentration of solar radiation on the desiccant bed and a 0.01 kW reversible fan to circulate the drying air inside the drying chamber in the night. The schematic of the experimental setup is shown in Fig. 1. The solar air collector had dimensions of 1.2 m × 2.4 m. A 0.9 mm thick copper sheet painted black was used as an absorber plate for incident solar radiation. It was oriented southward with a tilt angle of 30°. A 6 mm plain window glass is used as a transparent cover for the air collector to prevent the top heat losses. The frame is made of thick wood. For insulation, fine saw dust is used at the sides and bottom of the collector.

The drying cabinet was constructed with insulated wooden walls of dimensions 1.2 m × 1.2 m cross sectional area and 1 m height consisting of 10 shelves for holding the products. At the top of the drying chamber, a double glazing with an air gap of 50 mm was provided with an inclination as that of collector to absorb the incident solar radiation. A perforated tray is provided just below the double glassing to stack 75 kg of solid desiccant material. The desiccant material is a mixture of 60% bentonite, 10% calcium chloride, 20% vermiculite and 10% cement and is molded in the shape of cylinders and is processed in a vac-