Effect of Using Energy Storage Material in an Indirect-mode Forced Convection Solar Dryer on the Drying Characteristics of Grapes

S. M. Shalaby

***Abstract*—In this paper, the effect of using energy storage material in an indirect-mode forced convection solar dryer is experimentally studied under Tanta (latitude, 30^0 $47'$ N) prevailing weather conditions. The system consists of a double pass v-corrugated plate solar air heater connected to a drying chamber. A blower is used to force the heated air to the drying chamber. To study the effect of using an energy storage material on the performance of the indirect-mode forced convection solar dryer, 56 kg of sand is used as a storage material under the back plate of the solar air heater. Drying experiments have been performed for grapes with and without using energy storage material. It is found that the drying time of 1 kg of grapes is reduced by about 3 hrs or more when using a storage material.**

***Index* Terms—Solar drying; thermal performance, energy storage material**

I. Introduction

The indirect-mode forced convection solar dryer (IMFCSD) essentially consists of an air heater, drying chamber, and a blower to duct the heated air into the drying chamber. Many designs of indirect-mode forced convection solar dryers had been investigated in order to improve the thermal performance of solar dryers [1]-[10]. Several workers have explored different techniques for drying various agricultural products by considering the possible use of thermal storage materials, and developed the drying models to predict the performance [11]-[15].

II. Drying Analysis

In this section, the fundamental principles and basic definitions governing the drying process is presented. The moisture content on dry basis Mod is the weight of moisture present in the product per unit weight of dry matter in the product, written as [16];

$$M_{0d} = {(W_0 - W_d)}\Big/{W_d} \quad (1)$$

The Initial moisture content on wet basis W_{ow} is defined as;

$$M_{0w} = {(W_0 - W_d)}\Big/{W_0}\,. \quad (2)$$

The instantaneous moisture content Mt at any given time t on dry basis is computed using the following expression [17];

$$M_t = \left[\frac{(M_{od}+1)W_t}{W_0} - 1\right]. \quad (3)$$

The moisture contents on the wet and dry basis are inter-related according to the following equation [18];

$$M_w = 1 - \left(\frac{1}{M_d + 1}\right). \quad (4)$$

The moisture ratio *MR* is defined as;

$$MR = {(M_t - M_e)}\Big/{(M_0 - M_e)}\,. \quad (5)$$

The moisture ratio *MR* is simplified to M_t/M_0 by some investigators [19], [20] because of the equilibrium moisture content is significantly less than the initial moisture content and also due to the continuous fluctuation of the relative humidity of the drying air during the solar drying processes.

Nocturnal moisture re-absorption R_n is defined as the ratio of the rise in moisture content over the night period to the moisture content value at the sunset of the preceding day. R_n can be expressed as a percentage as [10];

$$R_n = \frac{(M_{sr} - M_{ss})}{M_{ss}} \times 100\,. \quad (6)$$

III. Experimental Procedure

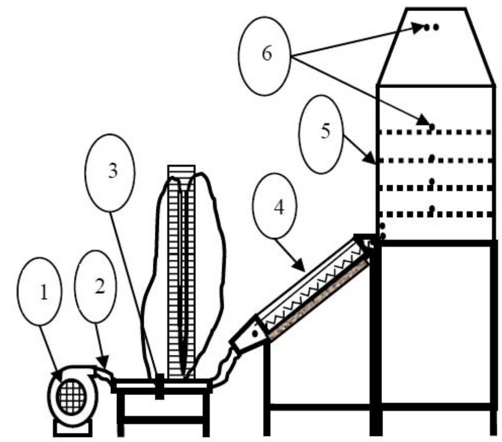
A. Construction of the Indirect Solar Dryer

An indirect-mode forced convection solar dryer was constructed as shown in Fig. 1. The heater and the drying chamber were fabricated, using the locally available materials, in Solar Energy Laboratory, Physics Department, Faculty of Engineering, Tanta University. Detailed description, method of analytical solution of the energy balance equations of the double pass v-corrugated plate solar air heater (DPVCPSAH) can be found elsewhere [21]. The drying chamber was fabricated from wood with dimensions 1 × 1 × 1.5 m^3 (length × width × height). The drying

Manuscript received March 24, 2012; revised July 13, 2012
This work was supported by the Tanta University.
S. M. Shalaby is with the Department of Engineering Physics and Mathematics, Tanta University, Tanta, Egypt (e-mail: saleh_shalaby@yahoo.cm)

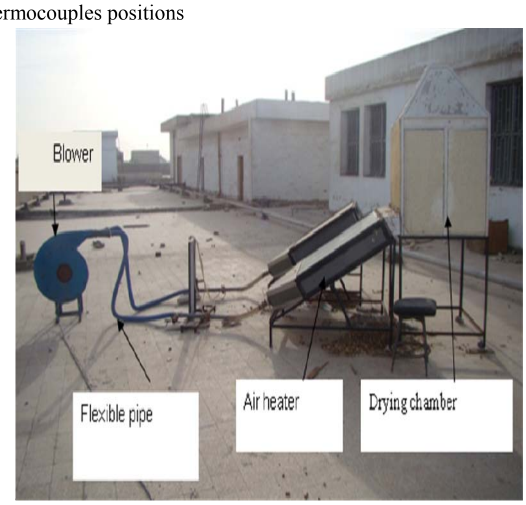
doi: 10.12720/jomb.1.1.56-58

chamber was insulated at all sides using foam as an insulating material with thickness 0.04 m. The drying chamber had four drying trays positioned at equal vertical spacing of 0.2 m. The drying tray was made of 0.002 m mesh stainless steel screen with area $0.855\times0.8m^2$. Each tray was kept on a wooden frame fixed to the inner sidewall of the drying chamber. The trays can be easily removed to load or unload the drying product from the door, which represents one side of the drying chamber.



(a)

1- Blower
2- Flexible pipe
3- Orifice meter
4- Solar air heater
5- Drying chamber
6- Thermocouples positions



(b)

Fig. 1. (a) A schematic diagram of the experimental set-up. (b) Photograph of the experimental set-up.

B. Experimental Setup

The indirect mode forced convection solar dryer was tested using the rig test shown in Fig. 1. To study the effect of using an energy storage material on the performance of the IMFCSD, 56 kg of sand is used as a storage material under the back plate of the DPVCPSAH. The IMFCSD is used, without (Experiment 1) and with (Experiment 2) storage material, for drying 1 kg of grapes on consecutive days of September and October 2009. Before starting the experiments, all joints of the ducts, inlet sections, and pipes fittings, were carefully examined against air leakage. The global solar radiation on a horizontal surface was measured using an Eppley-Precession Spectral Pyranometer (EPSP) coupled to an Instantaneous Solar Radiation Meter Model No. 445 (sensitivity of 8.79×10^{-6} (volts/W m2)). Calibrated NiCr-Ni thermocouples connected to a FLUKE 73 digital multimeter (accuracy ±0.5 0C) were used to measure the temperatures of the flowing air at the inlets and outlets of the solar air heater. The ambient temperature had been also measured. A three-phase induction motor (Type Y112M-2, 5.5 HP, 8.2/4.7 A, 380/660 V, 50 Hz, 2890 r/min) coupled with a fan (0.7 m diameter) was used to force the air throughout the heater and drying chamber. The flowing air through the channels of the heaters was controlled and measured with the help of a by-pass valve and an orifice-meter, respectively.

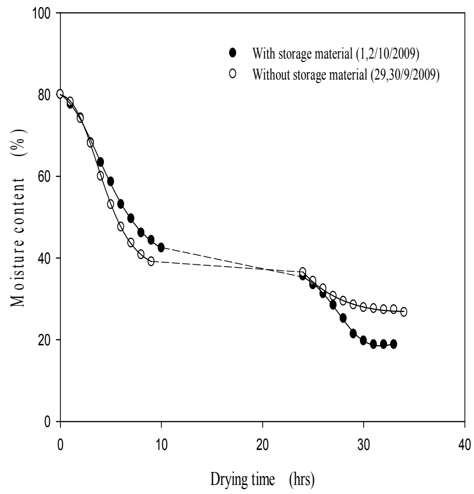


Fig. 2. Variation of moisture content versus the drying time for 1 kg of grapes with and without using storage material.

IV. Results and Discussions

To study the effect of using an energy storage material on the performance of the IMFCSD, 56 kg of sand is used as a storage material under the back plate of the DPVCPSAH. The IMFCSD is used, without (Experiment 1) and with (Experiment 2) storage material, for drying 1 kg of grapes on consecutive days of September and October 2009, when the mass flow rate of air equals 0.0223 kg/s. The average measured values of solar radiation and ambient temperature are 528 W/m2 and 31.2 0C, respectively, during the days of Experiment 1 compared with 541.5 W/m2 and

29.5 0C, respectively, during the days of Experiment 2. Fig. 2 presents the variation of moisture content of 1 kg of grapes vs. the drying time under conditions of Experiments 1 and 2. After 10 hrs (first day of sunshine), the moisture content of grapes is decreased form 80% to 39 and 42.4% in Experiments 1 and 2, respectively as obtained from the results of Fig. 2. The relatively slow drying rate in case of Experiment 2 compared to that of Experiment1 during the first day of sunshine is attributed to a part of heat energy is stored in the sand during the first 10 hrs of drying time, and this part of energy does not used yet. The effect of using storage material is clearly effective during the night where the moisture content of grapes is reduced from 42.4 to 35.5% under the conditions of Experiment 2 as clearly seen in Fig. 2. On the other hand, the moisture content of grapes is slowly decreases during the night from 39 to 36.4% under the conditions of Experiment 1. The nocturnal moisture re-absorption Rn is obtained as -6.6% during the night for grapes under the conditions of Experiment 1; while, the corresponding value of Rn under the conditions of Experiment 2 is found to be -16.3%. This result is expected because of the storage material is operating as the unique source of heat energy during the night. This source provides enough heat energy for drying during night. It is also seen in Fig. 2 that the advantages of using storage material is also appeared during the second day of drying, during which, the moisture content of grapes in Experiment 2 is reached its final value Mf of 18.5±0.5% after 7 hrs; while, the moisture content of the pretreated grapes in Experiment 1 is decreased to 26.5±0.5% after 10 hrs of the second day of drying.

From the results presented in Fig. 2, it is concluded that the drying time of 1 kg of grapes is reduced by about 3 hrs or more when using 56 kg of sand, as a storage material under the back plate of the DPVCPSAH.

REFERENCES

[1] K. E. J. A. Juamily, A. J. N. Khalifa, T. A. Yassen, "Testing of performance of fruit and vegetable solar drying system in Iraq," *Desalination*, vol. 209, pp.163–170, 2007.

[2] D. M. Kadam and D. V. K. Samuel, "Convective flat-plate solar heat collector for cauliflower drying. Biosystems Engineering," 2006, vol. 93, no. 2, pp.189–198.

[3] M. A. Karim and M. N. A. Hawlader, "Development of solar air collectors for drying applications," *Energy Conversion and Management*, vol. 45, pp. 329–344, 2004.

[4] S. Karsli, "Performance analysis of new-design solar air collectors for drying applications," *Renewable Energy*, 2007, vol. 32, pp.1645–1660.

[5] J. Banout, P. Ehl, J. Havlik, B. Lojka, Z. Polesny, and V. Verner, "Design and performance evaluation of a Double-pass solar dryer for drying of red chilli (Capsicum annum L.)," *Solar energy*, vol. 85, pp. 506-515, 2011.

[6] A. Akbulut and A. Durmus, "Energy and exergy analyses of thin layer drying of mulberry in a forced solar dryer," *Energy*, vol. 35, pp. 1754–1763, 2010.

[7] A. E. Beltagi, G. R. Gamea, and A. H. A. Essa, "Solar drying characteristics of strawberry," *Journal of Food Engineering*, vol. 78, pp. 456–464, 2007.

[8] A. O. Dissa, J. Bathiebo, S. Kam, P. W. Savadogo, H. Desmorieux, and J. Koulidiati, "Modeling and experimental validation of thin layer indirect solar drying of mango slices," *Renewable Energy*, vol. 34, pp. 1000-1008, 2009.

[9] M. Mohanraj and P. Chandrasekar, "Drying of copra in forced convection solar dryer," *Biosystems Engineering*, vol. 99, pp. 604–607, 2008.

[10] A. A. E. Sebaii, S. A. Enein, M. R. I. Ramadan, and H. G. E. Gohary, "Experimental investigation of an indirect type natural convection solar dryer," *Energy Conversion and Management*, vol. 43, pp. 2251–2266, 2002.

[11] G. N. Tiwari, P. S. Bhatia, A. K. Singih, and R. K. Goyal, "Analytical studies of crop drying cum water heating system," *Energy Conversion and Management*, vol. 38, no. 8, pp. 751–759, 1997.

[12] G. N. Tiwari, P. S. Bhatia, A. K. Singih, and R. F. Sutar, "Design parameters of a shallow bed solar crop dryer with reflector," *Energy Conversion and Management*, vol. 35, no. 6, pp. 542-635, 1994.

[13] P. M. Chauhan, C. Choudhury, and H. P. Garg, "Comparative performance of coriander dryer coupled to solar air heater and solar air-heater-cum-rockbed storage," *Applied Thermal Engineering*, 16(6): pp. 475–86, 1996.

[14] D. Jain and R. K. Jain, "Performance evaluation of an inclined multi-pass solar air heater within built thermal storage on deep-bed drying application," *Journal of Food Engineering*, vol. 65, pp. 497–509, 2004.

[15] D. Jain, "Modeling the system performance of multi-tray crop drying using an inclined multi-pass solar air heater with in-built thermal storage," *Journal of Food Engineering*, vol. 71, pp. 44–54, 2005.

[16] V. Shanmugam and E. Natarajan, "Experimental investigation of forced convection and desiccant integrated solar dryer," *Renewable Energy*, vol. 31, pp. 1239-1251, 2006.

[17] J. Mumba, "Design and development of a solar grain dryer incorporating photovoltaic powered air circulation," *Energy Conversion and Management*, vol. 37, pp. 615-621, 1996.

[18] M. A. Zaman and B. K. Bala, "Thin layer solar drying of rough rice," *Solar Energy*, vol. 42, pp. 167-171, 1989.

[19] E. K. Akpinar, "Drying of mint leaves in a solar dryer and under open sun: Modelling, performance analyses," *Energy Conversion and Management*, vol. 51, pp. 2407–2418, 2010.

[20] A. Midilli and H. Kucuk, "Mathematical modelling of thin layer drying of pistachio by using solar energy," *Energy Conversion and Management*, vol. 44, pp. 1111–1122, 2003.

[21] A. A. E. Sebaii, S. A. Enein, M. R. I. Ramadan, S. M. Shalaby, and B. M. Moharram, "Investigation of thermal performance of-double pass-flat and v-corrugated plate solar air heaters," *Energy*, vol. 36, pp. 1076-1086, 2011.

S. M. Shalaby Place and Date of birth: Tanta –Egypt, 10/2/1974.Education: Ph D. Degree in Engineering Physics and Mathematics (Engineering Physics) on 2012 from Tanta University, Tanta, Egypt. The thesis is entitled "Investigation of thermal performance of indirect solar drying systems". M. SC. Degree in Engineering Physics and Mathematics (Engineering Physics) on 2005 from Tanta University, Tanta, Egypt. The thesis title is "Utilization of solar energy in some flat plate solar collectors". B. SC. Degree in Machines and Electrical Power Engineering with grade "very good with honor" on 1997 from Tanta University, Tanta, Egypt.

He was ADMINISTRATOR at Engineering Physics and Mathematics Dep., Faculty of Engineering, Tanta Univ. from 28/3/1998 to 28/11/2005. He was ASISTANT LECETURER at Engineering Physics and Mathematics Dep., Faculty of Engineering, Tanta Univ. from 28/11/2005 to 28/2/2012. Currently he is a LECTURER at Engineering Physics and Mathematics Dep., Faculty of Engineering, Tanta Univ. from 28/2/2012.

Dr. Shalaby is a senior member of Asia-Pacific Chemical, Biologicaland Environmental Engineering Society (APCBEES).