Contemporary Engineering Sciences, Vol. 11, 2018, no. 11, 523 - 536
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2018.811

Performance Analysis of Solar Drying System Using Double Pass Solar Air Collector with Finned Absorber for Drying Copra

M. Yahya

Fakultas Teknologi Industri, Institut Teknologi Padang
25143 Padang, West Sumatra, Indonesia

Abstract

A solar drying system using double-pass solar air collector with finned absorber was designed, fabricated, and evaluated for drying copra (coconut meat). The coconut meats were dried to moisture content of 0.120 dry basis (10.73 % wet basis) from 1.113 dry basis (52.68% wet basis) during 23 hours, with an air mass flow rate of 0.083 kgs^{-1}, whereas, the open sun drying during 67 hours. The drying rate was found between 0.067kg/h and 0.72 kg/h, and 0.002kg/h and 0.50 kg/h, with average values of 0.191kg/h and 0.055kg/h for solar drying system and open sun drying, respectively. The minimum, maximum, and average of the efficiency of solar air collector were found of about 28.37% and 81.15%, and 58.33%, respectively. The values of the specific moisture extraction rate (SMER) and the specific energy consumption (SEC) were calculated between 0.093 kg/kWh and 0.845 kg/kWh, and 1.184 kWh/kg and 10.779 kWh/kg, respectively. The efficiency of solar drying system and the energy utilization ratio were calculated between 6.19 % and 56.34 %, and 5.61% and 45.0 %, with average values of 16.64 % and 17.61%, respectively. The average values of the improvement potential rate and exergy efficiency of solar drying system were estimated of about 87.98 J/s and 39.47%, respectively.

Keywords: solar air collector, solar drying, performance, copra

1 Introduction

Indonesia is the first largest coconut producing country in the world and having an area of about 3.57 million hectares. It annually produces 2.960 million ton [1]. Copra is one of the major traditional products processed from coconuts. Fresh coconut meat contains high moisture (52% wet basis), threfore, to produce concentrate the oil content the coconut meat need to be dried to achieve moisture content of about 7% wet basis [2]. Open sun drying and smoke drying are commonly used in Indonesia to dry coconut meat. In the open sun drying, where the coconut meat to be dried by exposing directly to the sun, which has many disadvantages such as degradation by wind-blown debris, rain, insect infestation, human and animal interference which will result in contamination of the product, and also long drying times. In the smoke drying, the coconut meat is heated directly by smoke and hot combustion gases of the fuel, usually resulting in a very inferior heavily smoked product. Solar drying system provides an alternative to the use of open sun drying and smoke drying for drying of coconut meat. One of the most important component of a solar drying system is the solar air collector . Solar air collector as a heat exchanger transfers solar radiations to air from absorber panel [3]. Thus, hot air is obtained from these collectors and they are used in drying of coconut meat. The principal types of the solar air collector were classified as single pass and double-pass [4]. Solar drying system using single-pass solar air collectors have been used to dry foods or other heat sensitive, biologically active products such as pistachio [5], herbs and spices [6], onion [7], long green peper [8], copra [2], bananas [9], mint leaves [10], fruit and vegetables [11], Sweet basil [12].

Aldabbagh *et al*., [13], have tested and compared the performance of the single-pas solar air collector with the double-pas solar air collector. They found that the efficiency of the double pass was obtained to be higher than the single pass by 34–45%, maximum efficiencies were found for the single-pas solar air collector and the double-pas solar air collector as 45.93% and 83.65% respectively. Many studies have been reported on solar drying system using double-pass solar air collector for drying of foods or other heat sensitive, biologically active products such as palm oil fronds [14], thymus and mint [15], red chili [16].

Banout *et al*., [17], reported the use of a solar drying system using double-pass solar air collector for drying red chilli. Drying 45 kg of red chilli using this dryer, the moisture content reduced from 90% wet basis to 10% wet basis during 32 hours. The collector, drying system and pick-up efficiencies were found about 61.62%, 15.22% and 22.04%, respectively. Good quality products were obtained.

Fudholi *et al*., [18], reported the use of a solar drying system using double-pass solar air collector for drying red seaweed with a drying capacity of 40 kg, the dryer was able to reduce the moisture content of 90% wet basis to 10 % wet basis during 15 hours. The collector, drying system and pick-up efficiencies were found about 35%, 27% and 95%, respectively. Good quality products were obtained. However, to our knowledge, information is limited on literature about the drying of coconut meat in solar drying system using double-pass solar air collector. Also, Indonesia is lacated in the equator line receives abundant solar radiation with a daily average of about 4 kWh/m^2 [19]. This can be used as heat energy sources in drying process. Therefore, the purpose of this paper is to design and evaluate the performance of solar drying system using double-pass solar air collector with finned absorber for drying copra (coconut meat).

2 Materials and Methods

2.1. Experimental Set-Up

The photographs and schematics diagram of solar drying system (SDS) are shown in Figs. 1and 2. The solar drying system consists of main components: finned double-pass solar air collector array, drying chamber and blower. The solar air collector consists of several main parts: transparent cover glass material, absorber finned plate made from aluminum and black-painted opaque, angular iron frame, inside and outside collector coated with 1 mm-thick aluminum, and insulation using fiber glass materials. Two solar collectors are connected in series with an area of 1.8 m^2 each. The cabinet-type drying chamber has a dimension of 1.0 m (width) × 1.0 m (length) × 1.35 m (height). The chamber contains drying trays with adjustable racks to place the coconut meat sample. The triple-layer walls of the chamber consist of an aluminum sheet as outside layer, insulated glass fiber material as middle layer, and aluminum sheet as inner layer. Drying air was circulated using a blower with an electrical capacity of 0.75 kW.

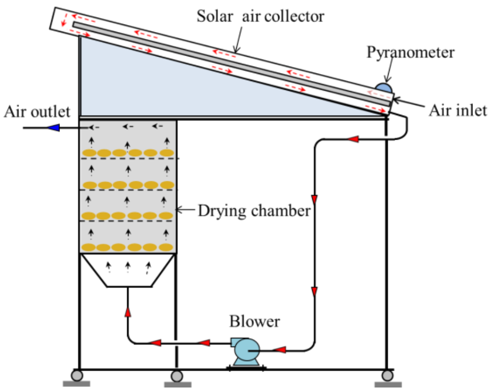

Fig1. Photograph of the SDS Fig 2. Schematic diagram of the SDS

2.2. Experimental Procedure

The experiments were performed at Institut Teknologi Padang, West Sumatra, Indonesia. Coconuts were purchased from a farmer in Padang, as much as 40 kg were placed into the drying chamber for the drying process as shown in Fig.3. The air temperatures at the inlet and outlet of the solar air collector and drying chamber during the operation of the drying system were measured by using T type copper-constantan thermocouples with an accuracy of ± 0.1°C, and operating temperature range (-200°C to 400°C). The solar radiation was measured by an LI-200 pyranometer in ± 0.1Wm^{-2} accuracy, and with maximum solar radiation of 2000 Wm^{-2}, operating temperature range (-40°C to 400°C) and operating relative humidity range (0% to 100%). The air velocity was measured with 0-30 ms^{-1} range an HT-383 anemometer, an accuracy of ± 0.2 ms^{-}1, and with operation temperature range (-10°C to 45°C). The air temperature and the solar radiation were recorded by an AH4000 data logger with reading accuracy of ± 0.1°C. The mass change of the coconut meat was measured within 0-15 kg range by using a TKB-0.15 weighing scale, with an accuracy ± 0.05kg. Coconut meat mass change was weighed and temperature was measured every 60 minutes. The uncertainty was calculated using the following equation [10]:

$$W_R = \left[\left(\frac{\partial R}{\partial x_1} w_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} w_2 \right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} w_n \right)^2 \right]^{1/2} \quad (1)$$

Where W_R is total uncertainty in result measurement, w_1, w_2,...w_n is uncertainties in independent variables, and x_1,x_2,...x_n is independent variables.

Fig 3. Photograph of coconut meat in drying chamber.

2.3. Drying Kinetics Analysis

The moisture content of the coconut meat was calculated by two methods such as wet and dry basis using the following equations [20]:
The moisture content wet basis was calculated as follow:

$$M_{wb} = \frac{m_{wetcm} - m_d}{m_{wetcm}} \quad (2)$$

The moisture content dry basis was calculated as follow:

$$M_{db} = \frac{m_{wetcm} - m_d}{m_d} \quad (3)$$

Where m_d is the mass of bone dry of the coconut meat, and m_{wetcm} is mass of wet coconut meat.

The drying rate is the mass of water evaporated from the wet coconut meat per unit time. It was calculated using the following equation [21]:

$$DR = \dot{m}_{water} = \frac{m_{water}}{t} \quad (4)$$

Where m_{water} is the mass of water evaporated and *t* is drying time.

The mass of the water evaporated (m_{water}) from the wet coconut meat was calculated using the following equation [19]:

$$m_{water} = \frac{m_{wetcm}\left(M_{wb,i} - M_{wb,f}\right)}{\left(100 - M_{wb,f}\right)} \quad (5)$$

Where m_{wetcm} is initial mass of wet coconut meat, $M_{wb,i}$ is initial moisture content on wet basis and $M_{wb,f}$ is final moisture content on the wet basis.

2.4 Energy Analysis

The thermal efficiency of a solar air collector is the ratio of useful heat gain by solar air collector to the energy incident in the plane of the collector. It was calculated using the following equation [18]:

$$\eta_{coll} = \frac{\dot{m}_{air} C_{Pair} (T_{out,SC} - T_{in,SC})}{I_T\, A_{SC}} \quad (6)$$

Where $\dot{m}_{air}$ is air mass flow rate, C_{Pair} is specific heat of air, $T_{in,SC}$ and $T_{out,SC}$ are the air temperatures at inlet and outlet of solar air collector, respectively. A_{SC} is an area of collector and I_T is solar radiation incident in the collector.

The energy utilization ratio (EUR) was calculated using the following equation [10]:

$$EUR_{dc} = \frac{\dot{m}_{da} (h_{dcai} - h_{dcao})}{\dot{m}_{da} C_{Pda} (T_{dcai} - T_a)} \quad (7)$$

Where C_{Pda} is specific heat of drying air, $\dot{m}_{da}$ is mass flow rate of drying air, T_a is ambient temperature, T_{dcai} is inlet air temperature of drying chamber, and h_{dcai}

and h_{dcao} are enthalpy of air inlet and outlet of drying chamber, respectively.

The specific moisture extraction rate (SMER) is the ratio of the moisture evaporated from wet coconut meat to the energy input to drying system. It is calculated as [22]:

$$SMER = \frac{\dot{m}_{water}}{I_T A_{SC} + W_B} \tag{8}$$

Where W_B is the electrical energy consumed by blower.

Specific energy consumption (SEC) is the measure of the energy used to remove 1 kg of water in the drying process. The specific energy consumption of the solar drying system was calculated using the following equations [23]:

$$SEC = \frac{I_T A_{SC} + W_B}{\dot{m}_{water}} \tag{9}$$

The thermal efficiency of dryer is the ratio of the energy used for moisture evaporation to the energy input to drying system. It is calculated as [17]:

$$\eta_{th} = \frac{\dot{m}_{water} H_{fg}}{I_T A_{SC} + W_B} \tag{10}$$

Where H_{fg} is latent heat of vaporization of water (kJ/kg).

2.5 Exergy Analysis

The exergy values are calculated by using the characteristics of the working medium from a first-law energy balance. For this purpose, the general form of exergy equation applicable for a steady flow system may be expressed as [5]:

$$Ex = \dot{m}_{da} C_{Pda} \left[(T - T_a) - T_a \ln \frac{T}{T_a} \right] \tag{11}$$

For exergy input (inflow) to drying chamber was calculated as:

$$Ex_{dci} = \dot{m}_{da} C_{Pda} \left[(T_{dcai} - T_a) - T_a \ln \frac{T_{dcai}}{T_a} \right] \tag{12}$$

For exergy output (outflow) to drying chamber was calculated as:

$$Ex_{dco} = \dot{m}_{da} C_{Pda} \left[\left(T_{dcao} - T_a \right) - T_a \ln \frac{T_{dcao}}{T_a} \right] \quad (13)$$

Where T_{dcao} is outlet air temperature of drying chamber

However, during the solar drying process, the exergy losses are determined using equation as:

$$Ex_{loss} = Ex_{dci} - Ex_{dco} \quad (14)$$

Exergy efficiency for drying chamber calculated as:

$$\eta_{Ex} = \frac{Ex_{dco}}{Ex_{dci}} = 1 - \frac{Ex_{loss}}{Ex_{dci}} \quad (15)$$

The improvement potential (IP) of a solar drying system or process was calculated as [18]:

$$IP = \left(1 - \eta_{Ex}\right) Ex_{loss} \quad (16)$$

3 Results and Discussions

The variations of temperature and relative humidity at inlet and outlet of drying chamber are shown in Fig.4. The temperature at inlet and outlet of drying chamber were recorded in the range of 37.10°C-57.30°C, and 31.50°C-41.54°C, with average values of 47.23°C and 41.54°C, respectively. The relative humidity at inlet and outlet of the drying chamber were also recorded in the range of 16.45 %-53.74%, and 29.12%-76.23%, with average values of 31.37% and 45.03%, respectively.

The variations of moisture content of dried coconut meat in the solar drying system and open sun drying with drying time are shown in Fig.5. The moisture content was dried of coconut meat to final moisture content of about 0.120 dry basis (10.73 % wet basis) from 1.113 dry basis (52.68% wet basis). The time to reach the final moisture content, for solar drying system was found of about 23 hours, with an air mass flow rate of 0.083 kgs^{-1}, whereas, the drying time of open sun drying was found of about 67 hours. Fig.6. Shows the variations of drying rate for solar drying system and open sun drying with drying time. The drying rate for solar drying system and open sun drying system were calculated in the range of 0.067kg/h-0.72 kg/h and 0.002kg/h-0.50 kg/h, with average values of 0.191kg/h and 0.055kg/h, respectively.

The variations of solar radiation and efficiency of solar air collector with drying time are shown in Fig.7. The solar radiation was recorded in the range of 376.64 W/m^2-997.24 W/m^2, with average value of 692.27 W/m^2, respectively.

The efficiency of solar air collector was calculated in the range of 28.37%-81.15%, with average value of 58.33%, respectively, under an air mass flow rate is about 0.083 kgs^{-1}. As observed from the figure the solar air collector is very sensitive to solar radiation, if the solar radiation fluctuates, the solar collector efficiency also fluctuates.

The variations of SMER and SEC with drying time are shown in Fig. 8. The SMER varies from 0.093 kg/kWh to 0.845 kg/kWh with an average of 0.250 kg/kWh, respectively. The SEC varies from 1.184 kWh/kg to 10.779 kWh/kg, with average value of 5.495 kWh/kg, respectively.

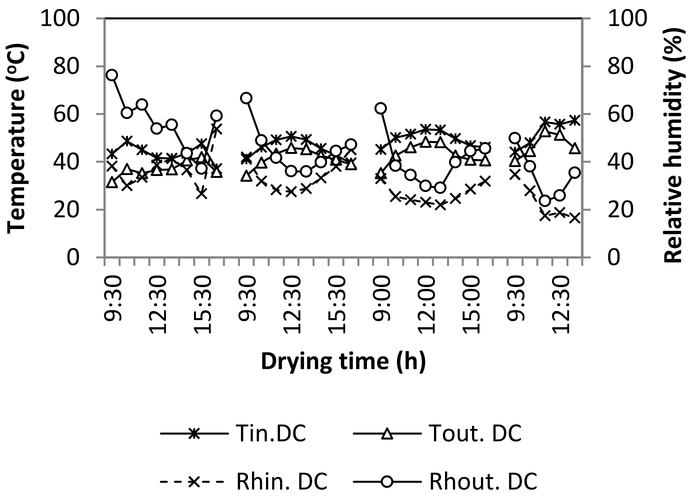

Fig.4. The variation of temperature and relative humidity with drying time.

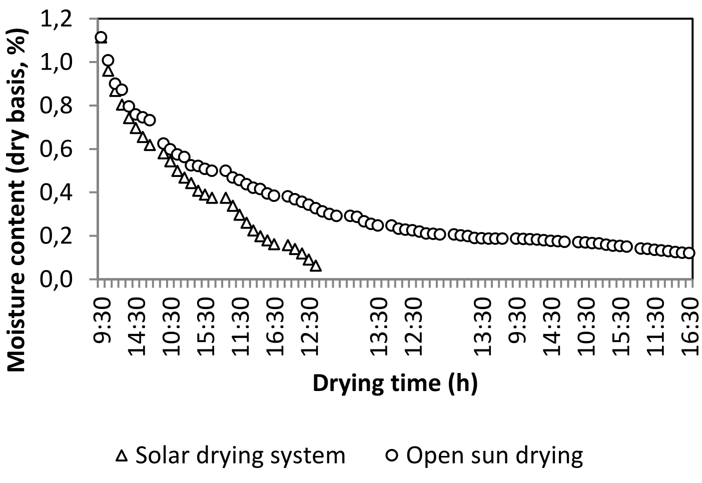

Fig.5. The variation of moisture content with drying time.

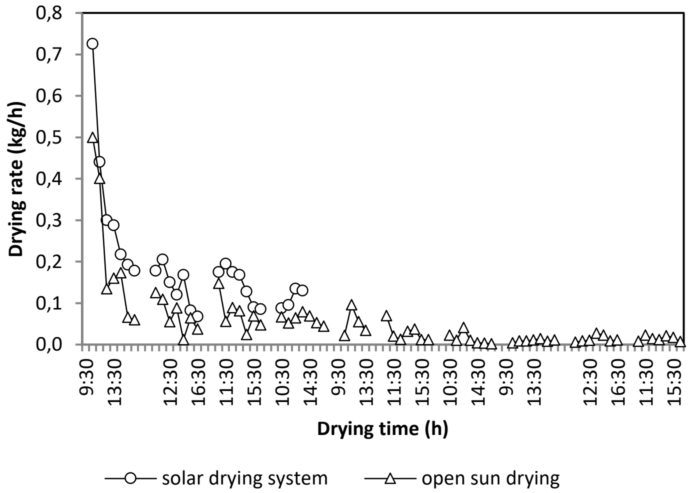

Fig. 6. The variation of drying rate with drying time.

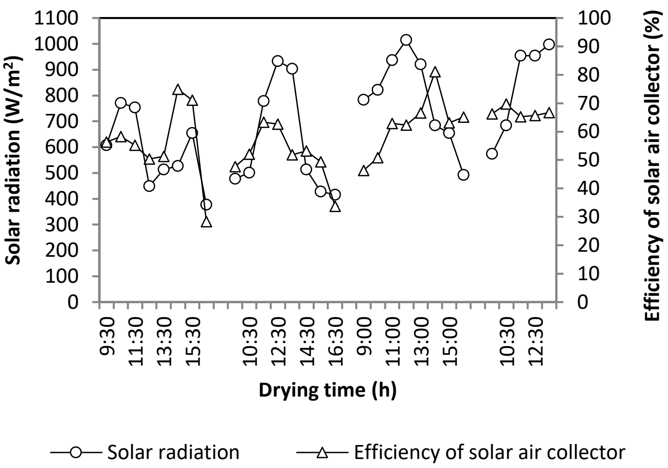

Fig. 7. The variation of solar radiation and efficiency of solar air collector with drying time.

Fig. 9. Shows the variations of efficiency of solar drying system and energy utilization ratio with drying time. The efficiency of solar drying system ranged from 6.19 % to 56.34 %, with average value of 16.64 %, respectively. Whereas, the energy utilization ratio ranged from 5.61% to 45.0 %, with average value of 17.61%, respectively.

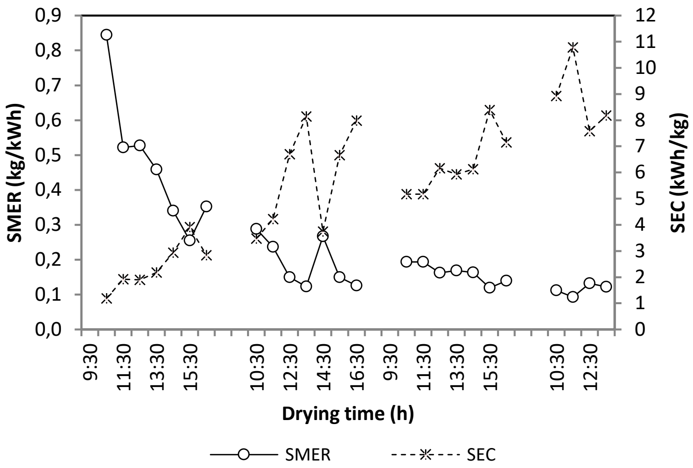

Fig. 8. The variation of SMER and SEC with drying time.

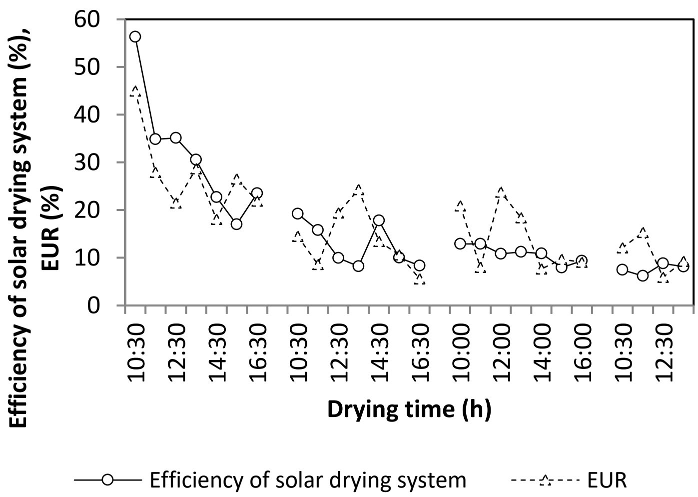

Fig. 9. The variation of efficiency of solar drying system and energy utilization ratio (EUR) with drying time.

The variations of exergy inflow, exergy outflow and exergy loss with drying time are shown in Fig. 10. The exergy inflow, exergy outflow and exergy loss were estimated in the range of 27.12 J/s- 591.53 J/s, 8.02 J/s-401.74 J/s, and 10.56 J/s-229.09 J/s, with average values of 242.02 J/s, 105.21 J/s, and 136.80 J/s, respectively.

The variations of improvement potential rate and exergy efficiency with drying time are shown in Fig. 11. The maximum, minimum, and average of improvement potential rate and exergy efficiency were calculated of about 288.84 J/s, 1.66 J/s and 87.98 J/s, and 84.25%, 1.20% and 39.47%, respectively.

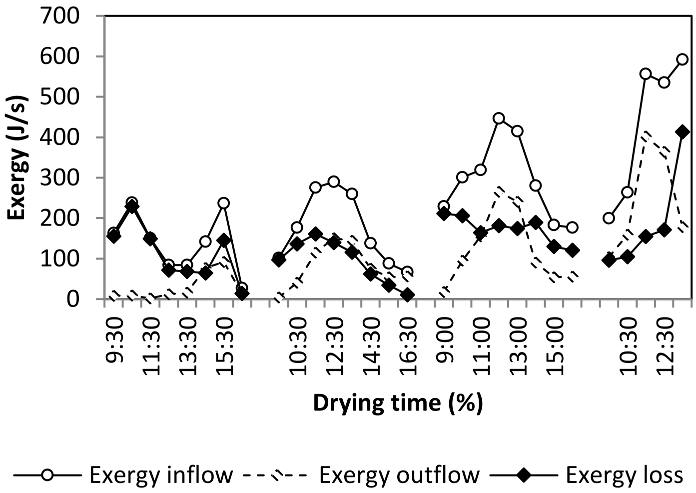

Fig. 10. The variation of exergy with drying time.

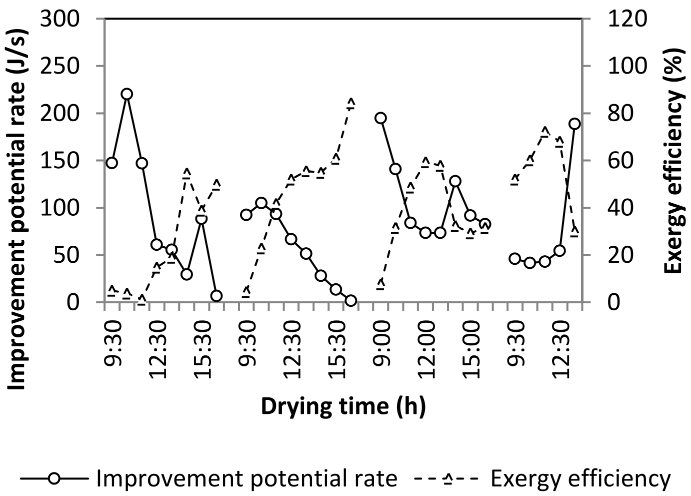

Fig. 11. The variation of improvement potential rate and exergy efficiency with drying time.

4 Conclutions

A solar drying system using double-pass solar air collector with finned absorber was designed, fabricated, and evaluated for drying copra (coconut meat). The coconut meats were dried to moisture content of 0.120 dry basis (10.73 % wet basis) from 1.113 dry basis (52.68% wet basis) during 23 hours, with the averages drying chamber temperature, drying chamber relative humidity, and an air mass flow rate of 47.23^{o}C, 31.37%, and 0.083 kgs^{-1}, respectively. While, the open sun drying during 67 hours. The drying rate was found between 0.067kg/h and 0.72

kg/h, and 0.002kg/h and 0.50 kg/h, with average values of 0.191kg/h and 0.055kg/h for solar drying system and open sun drying, respectively. The minimum, maximum, and average of the efficiency of solar air collector were found of about 28.37% and 81.15%, and 58.33%, respectively. The values of the specific moisture extraction rate (SMER) and the specific energy consumption (SEC) were calculated between 0.093 kg/kWh and 0.845 kg/kWh, and 1.184 kWh/kg and 10.779 kWh/kg, with average values of 0.250 kg/kWh and 5.495 kWh/kg, respectively. The efficiency of solar drying system and the energy utilization ratio were calculated between 6.19 % and 56.34 %, and 5.61% and 45.0 %, with average values of 16.64 % and 17.61%, respectively. The exergy inflow, exergy outflow and exergy loss were estimated in the range of 27.12 J/s- 591.53 J/s, 8.02 J/s-401.74 J/s, and 10.56 J/s-229.09 J/s, with average values of 242.02 J/s, 105.21 J/s, and 136.80 J/s, respectively. The average values of the improvement potential rate and exergy efficiency of solar drying system were estimated of about 87.98 J/s and 39.47%, respectively.

Conflict of interest. The author declared that this article current has no conflicts of interest.

References

[1] Tree Crop Estate Statistics of Indonesia, Coconut, *Directorate General of Estate Crops, Jakarta*, 2016.

[2] M. Mohanraj and P. Chandrasekar, Drying of copra in a forced convection solar drier, *Biosystems Engineering*, **99** (2008), 604-607. https://doi.org/10.1016/j.biosystemseng.2007.12.004

[3] S. Sevik, Design, experimental investigation and analysis of a solar drying system, *Energy Conversion and Management*, **68** (2013), 227-234. https://doi.org/10.1016/j.enconman.2013.01.013

[4] F. K. Forson, M. A. A. Nazha and H. Rajakaruna, Experimental and simulation studies on a single pass, double duct solar heater, *Energy Conversion and Management*, **44** (2003),1209–1227. https://doi.org/10.1016/s0196-8904(02)00139-5

[5] A. Midilli and H. Kucuk, Energy and exergy analyses of solar drying process of pistachio, *Energy*, **28** (2003), 539-556. https://doi.org/10.1016/s0360-5442(02)00158-5

[6] S. Janjai and P. Tung, Performance of a solar dryer using hot air from roof-integrated solar collector for drying herbs and spices, *Renewable Energy*, **30** (2005), 2085-2095. https://doi.org/10.1016/j.renene.2005.02.006

[7] P. N. Sarsavadia, Development of a solar assisted dryer and evaluation of energy requirement for drying of onion, *Renewable Energy*, **32** (2007), 2529-2547. https://doi.org/10.1016/j.renene.2006.12.019

[8] E. K. Akpinar and Y. Bicer, Mathematical modeling of thin layer drying process of long green pepper in solar dryer and under open sun, *Energy Conversion and Management*, **49** (2008), 1367-1375. https://doi.org/10.1016/j.enconman.2008.01.004

[9] R. Smitabhindu, S. Janjai and V. Changkong, Optimization of a solar-assisted drying system for drying bananas, *Renewable Energy*, **33** (2008), 1523-1531. https://doi.org/10.1016/j.renene.2007.09.021

[10] E. K. Akpinar, Drying of mint leaves in solar dryer and under open sun: modelling, performance analyses, *Energy Conversion and Management*, **51** (2010), 2407-2418. https://doi.org/10.1016/j.enconman.2010.05.005

[11] A. Sreekumar, Tecno-economic analysis of a roof-integrated solar air heating system for drying fruit and vegetables, *Energy Conversion and Management*, **51** (2010), 2230-2238. https://doi.org/10.1016/j.enconman.2010.03.017

[12] F. Gulcilmen, H. Karakaya and A. Durmus, Drying of sweet basil with solar air collector, *Renewable Energy*, **93** (2016), 77-87. https://doi.org/10.1016/j.renene.2016.02.033

[13] L. B. Y. Aldabbagh, F. Egelioğlu and M. Ilkan, Single and double pass solar air heaters with wire mesh as packing bed, *Energy*, **35** (2010), 3783–3787. https://doi.org/10.1016/j.energy.2010.05.028

[14] Supranto, K. Sopian, W.R.W. Daud, M. Y. Othman and B. Yatim, Design of an experimental solar assisted dryer for palm oil fronds, *Renewable Energy*, **16** (1999), 643-646. https://doi.org/10.1016/s0960-1481(98)00243-2

[15] A. A. El-Sebaii and S. M. Shalaby, Experimental investigation of an indirect- mode forced convection solar dryer for drying thymus and mint, *Energy Conversion and Management*, **74** (2013), 109-116. https://doi.org/10.1016/j.enconman.2013.05.006

[16] V. R. Khawale, S. B. Thakare and R. P. Khawale, Performance evaluation of a double pass indirect solar drier for drying of red chili, *International Journal of Innovative and Emerging Research in Engineering*, **3** (2016), 514-518.

[17] J. Banout, P. Ehl, J. Havlik, B. Lojka, Z. Polesny and V. Verner, Design and

performance evaluation of a Double-pass solar drier for drying of red chilli (*Capsicum annum* L.), *Solar Energy*, **85** (2011), no. 3, 506–515. https://doi.org/10.1016/j.solener.2010.12.017

[18] A. Fudholi, K. Sopian, M. Y. Othman and M. H. Ruslan, Energy and exergy analyses of solar drying system of red seaweed, *Energy and Building*, **68** (2014), 121-129. https://doi.org/10.1016/j.enbuild.2013.07.072

[19] M. Yahya, Performance analysis of solar assisted fluidized bed dryer integrated biomass furnace with and without heat pump for drying of paddy, *International Journal of Photoenergy*, **2016** (2016), 1-17. https://doi.org/10.1155/2016/3801918

[20] M. Yahya, Design and performance evaluation of a solar assisted heat pump dryer integrated with biomass furnace for red chilli, *International Journal of Photoenergy*, **2016** (2016), 1-14. https://doi.org/10.1155/2016/8763947

[21] S. Kooli, A. Fadhel, A. Farhat and A. Belghith, Drying of red pepper in open sun and greenhouse conditions.: Mathematical modeling and experimental validation, *Journal of Food Engineering*, **79** (2007), no. 3, 1094–1103. https://doi.org/10.1016/j.jfoodeng.2006.03.025

[22] M. Yahya, A. Fudholi, H. Hafizh and K. Sopian, Comparison of solar dryer and solar-assisted heat pump dryer for cassava, *Solar Energy*, **136** (2016), 606–613. https://doi.org/10.1016/j.solener.2016.07.049

[23] M. Yahya, A. Fudholi and K. Sopian, Energy and exergy analyses of solar-assisted fluidized bed drying integrated with biomass furnace, *Renewable Energy*, **105** (2017), 22-29. https://doi.org/10.1016/j.renene.2016.12.049

Received: January 18, 2018; Published: March 26, 2018