Research Journal of Applied Sciences, Engineering and Technology 13(6): 473-480, 2016
DOI:10.19026/rjaset.13.3007
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: September 3, 2015 Accepted: September 16, 2015 Published: September 15, 2016

Research Article

Performances of Fluidized Bed Drying Integrated with Biomass Furnace for Drying of Paddy

[1]M. Yahya and [2]Ahmad Fudholi
[1]Fakultas Teknologi Industri, Institut Teknologi Padang, Indonesia
[2]Solar Energy Research Institute, University Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia

Abstract: A fluidized bed drying integrated with biomass furnace was tested for drying of paddy. The drying of 12 kg of paddy via this drying system reduced the moisture content from 23% (wet basis) to 14% (wet basis) in 1338s and 1007s with average temperature of 60°C and 70°C, respectively. The drying rate varies from 0.15 to 0.48 kg every 300s and 0.2 to 0.5 kg every 300s with the average of 0.27 and 0.335 kg every 300s for average air temperature drying of 60 and 70°C respectively. For temperature of 60°C obtained SMER maximum, minimum and average, respectively: 0.72 kg/kWh, 0.23 kg/kWh and 0.37 kg/kWh. For temperature of 70°C obtained SMER maximum, minimum and average, respectively: 0.66 kg/kWh, 0.26 kg/kWh and 0.38 kg/kWh. The thermal efficiency varies from 14.78 to 47.31% and 17 to 42.49% with the average of 24.31 and 24.93% for average air temperature drying of 60°C and 70°C respectively.

Keywords: Biomass furnace, drying rate, fludized bed drying, paddy, SMER, thermal efficiency

INTRODUCTION

The scientific name for paddy is *Oryza sativa* L. It belongs to the family of graminae and crops of rice which is the staple food of nearly 90% of Indonesia's population. Indonesia is the third biggest paddy producing country worldwide with its annual production of around 78 million ton (BPS (Badan Pusat Statistik Indonesia), 2015) and also an economic resource of more than 30 million farmers. Paddy after harvest generally have a high moisture content of about 20-23% wet basis in dry season and about 24-27% wet basis in wet season (Purwadaria, 1995). At the level of the moisture content, easily broken rice or not securely stored because it is very susceptible to attack by fungus and insect. Threfore, in order to secure long-term storage or prior to the launch, the paddy needs to be dried as soon as possible to achieve moisture content of about 14% wet basis (Badan Standardisasi Nasional, 2008).

Traditional sun drying and flat bed box dryer (artificial dryer) is commonly used for drying of paddy. Traditional sun drying, where the product to be dried is exposed direcly to the sun has many disadvantages such degradation by wind-blown debris, rain, insect infestation, human and animal interference which will result in contamination of the product and also slow process (Yahya *et al*., 2001). Flat bed box dryer also has many disadvantages such as cannot produce uniform moisture content and so, some parts of product will be over dried and some other parts will not be dried adequately which will result a lot of broken rice during milling process and slow process (Izadifar and Mowla, 2003). Also, some flat bed box dryers with kerosene burners (fossil fuels) as heat source. It is has many side effects, their combustion products produce pollution, acit rain and global warming. Further, prices of kerosene are steadily increasing (Fudholi *et al*., 2010; Bhandari and Gaese, 2008).

Recently, various design and performances of solar drying systems for agricultural and marine products were reported (Fudholi *et al*., 2015a, 2015b). Many studies have been reported on fluidized bed dryer for drying of paddy. The influence of drying temperature on quality products have been studied by Karbassi and Mehdizadeh (2008), Wiset *et al*. (2001), Soponronnarit (1999), Soponronnarit *et al*. (1995) and Bonazzil *et al*. (1997). The influence of final moisture content on quality products have been studied by Sutherland and Ghaly (1990). The influence of drying temperature and bed thicness on drying rate have been studied by Wetchacama *et al*. (2000) and Tunambing and Driscoll (1991).

Studies on drying kinetic have been reported by Khanali *et al*. (2012) and Law *et al*. (2004). However, there is little information in the literature on performances of fluidized bed drying for drying of paddy. Therefore, the pusposes of this study are to determine the experimental performances of fluidized

Corresponding Author: Ahmad Fudholi, Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia

bed drying for drying of paddy with biomass fuels as heat source.

MATERIALS AND METHODS

The photograph and the schematics diagram of the fluidized bed dryer integrated with biomass furnace as shown in Fig. 1 and 2. The drying system consists of main components such as biomass furnace, fluidized bed, cyclones and blowers. Biomass furnace consists of several main parts such as combustion chamber, heat exchanger, chimney and blower. Wall of combustion chamber uses brick, cement and still plate materials, heat exchanger pipe uses mild still with diameter and number of pipes are 2 inc and 16 unit, respectively, which dimensional of biomass furnace as shown in Fig. 3. Fluidized bed consists of drying chamber, air flow distribution, the inlet and exit of rice, the front part of

Fig. 1: Photograph of the fluidized bed drying system

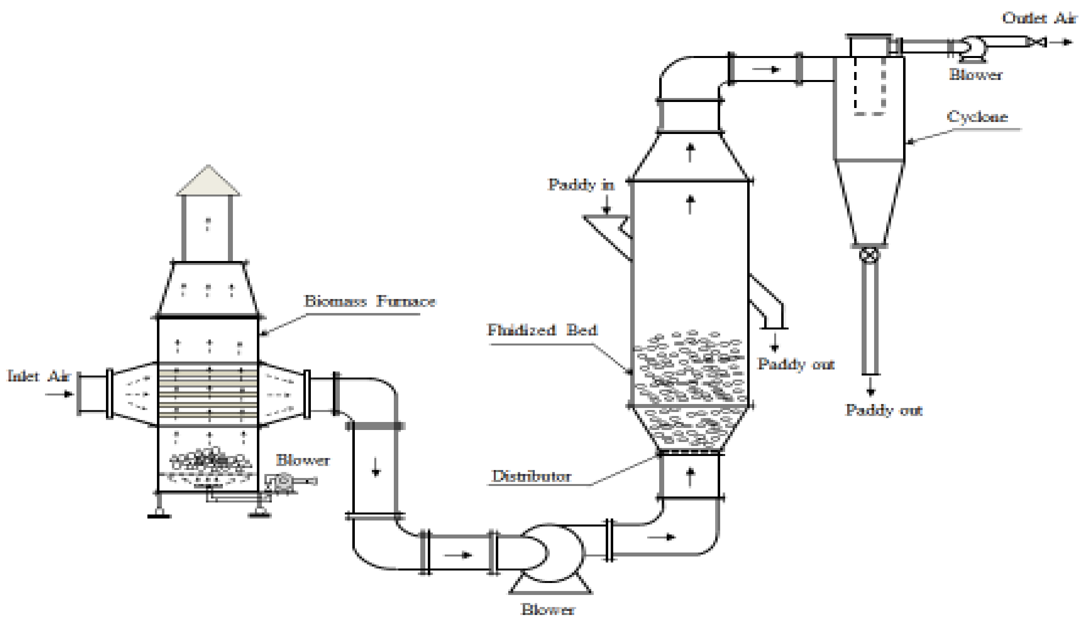

Fig. 2: Schematic diagram of the fluidized bed drying system

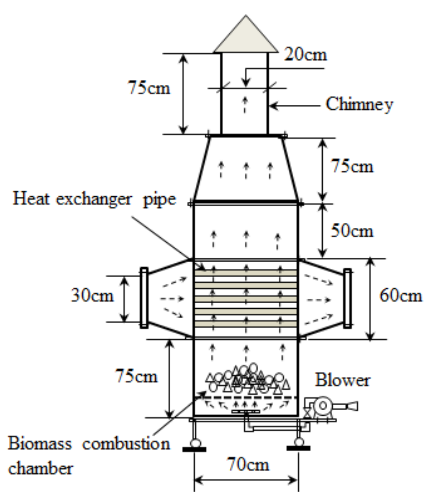

Fig. 3: Dimension of biomass furnace

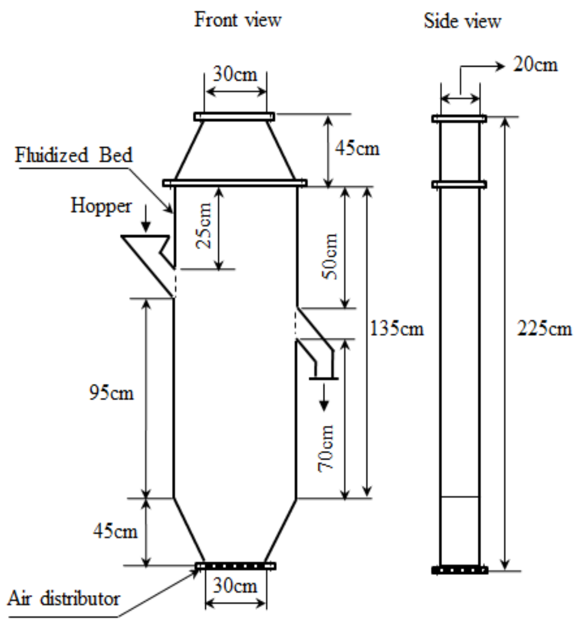

Fig. 4: Dimension of fluidized bed

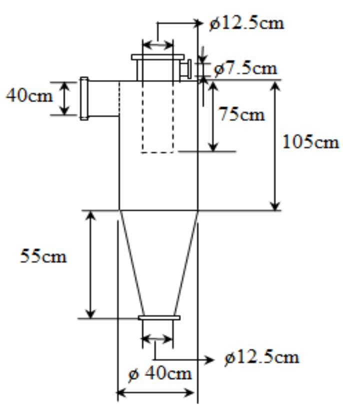

Fig. 5: Dimension of cyclone

the drying column is covered with clear glass with a thickness of 5 mm, the sides and back are covered with 3mm thick aluminum plate, while the air distributor used wire aluminum gauze and dimensions as shown in Fig. 4. Cyclone is covered with aluminum plate with 3mm thick and its dimensions as shown in Fig. 5. Blower used centrifugal types with 3,7kW power.

The experiments are carried out at the Institut Teknologi Padang, West Sumatra, Indonesia. Paddy farmers bought freshly harvested in Padang and as much as 12 kg put into the drying column for the drying process. Biomass fuels is used Coconut shell charcoal. Incoming and outgoing air temperature biomass furnace and drying column is measured using a thermocouple and air flow rate is measured using flow meter. Paddy weight change was measured using scales. Materials were weighed and measured the temperature every 5 minutes.

The performance of drying system was calculated using the following equation. The moisture content of paddy on wet basis was calculated as:

$$M_C = \frac{m_W}{m_W + m_d} \tag{1}$$

where, m_w is mass of water (kg) and m_d is mass of bone dry (kg).

The rate of extraction of heat from biomass furnace or heat energy that used for drying process was calculated as:

$$E_{Ubf} = \dot{m}_{air} C_{Pair} (T_o - T_i) \tag{2}$$

where, $\dot{m}_{air}$ is air mass flow rate (kg/s), C_{Pair} is specific heat of air (J kg^{-1} °C^{-1}) and T_i and T_o are inlet and outlet air tempetarures of biomass furnace (°C), respectively.

Drying rate is mass of water evaporated from the product per unit time was calculated using the following equation:

$$\dot{m}_{water} = \frac{m_{water}}{t} \tag{3}$$

where, m_{water} is mass of water evaporated (kg) and t is drying time (s).

The mass of water evaporated (m_{water}) from wet product can be calculated as (Fudholi *et al*., 2014b):

$$m_{water} = \frac{m_p (M_i - M_f)}{(100 - M_f)} \tag{4}$$

where,
m_p = Initial mass of product (kg)
M_i = Initial moisture content on wet basis (%)
M_f = Final moisture content on wet basis (%)

The specific moisture extraction rate (SMER) is ratio of the moisture evaporated from wet product to the energy input to drying system and was calculated as (Fudholi *et al*., 2014a, 2014b, 2015c):

$$SMER = \frac{\dot{m}_{water}}{E_{input}} \tag{5}$$

where, E_{input} is energy input to drying system (kWh). The energy input to drying system can be calculated as:

$$E_{input} = E_{bf} + E_b \tag{6}$$

where,
E_{bf} = Thermal energy of biomass fuel (coconut shell charcoal, kW)
E_b = Electrical energy consumed by blower (kW)

The thermal energy of biomass fuel can be calculated as:

$$E_{bf} = \dot{m}_{bf} CV_{bf} \tag{7}$$

where,
$\dot{m}_{bf}$ = Coconut shell charcoal consumption rate (kg/s)
CV_{bf} = Caloric value of coconut shell charcoal (kcal/kg) (CV_{bf} was considered as 7600 kcal/kg, Triyono, (2006))

The electrical energy consumed by blower can be calculated as:

$$E_b = \sqrt{3} V I Cos\varphi \tag{8}$$

where, V is line voltage (Volt), I is line current (Ampere) and $Cos\varphi$ is power factor.

Thermal efficiency of drying system is ratio of the energy used for moisture evaporation to the energy input to drying system, was calculated as:

$$\eta_{th} = \frac{E_{evap}}{E_{input}} \tag{9}$$

The energy used for moisture evaporatian can be calculated as:

$$E_{evap} = \dot{m}_{water} H_{fg} \tag{10}$$

where, H_{fg} is laten heat of vaporization of water (kJ/kg).

RESULTS AND DISCUSSION

Figure 6 shows the temperature of the drying chamber and air temperature inlet and outlet of the biomass furnace versus drying time at mass flow rate of 0.1256 kg/s. The temperature inlet and outlet of the biomass furnace varies from 34.3 to 38°C and 59.3 to 62.3°C with average is 36.6 and 61°C, respectively for average drying temperature of 60°C. For average drying temperature of 70°C, the temperature inlet and outlet of the biomass furnace varies from 34.7°C to 36.6°C and 68.6°C to 72.7°C with average is 35.4 and 71.3°C, respectively. On the other hand, the biomass energy used varies from 2715 W to 3518 W and the average biomass energy used is 3108 W for average drying temperature of 60°C. For average drying temperature of 70°C, the biomass energy used varies from 4210 W to 4848 W and the average biomass energy used is 4579 W.

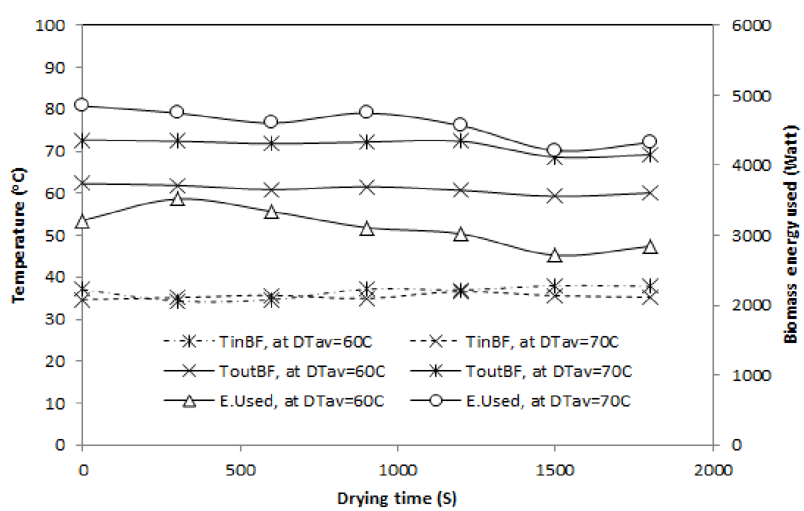

Fig. 6: The temperature and biomass energy used versus drying time at mass flow rate 0.1256 kg/s

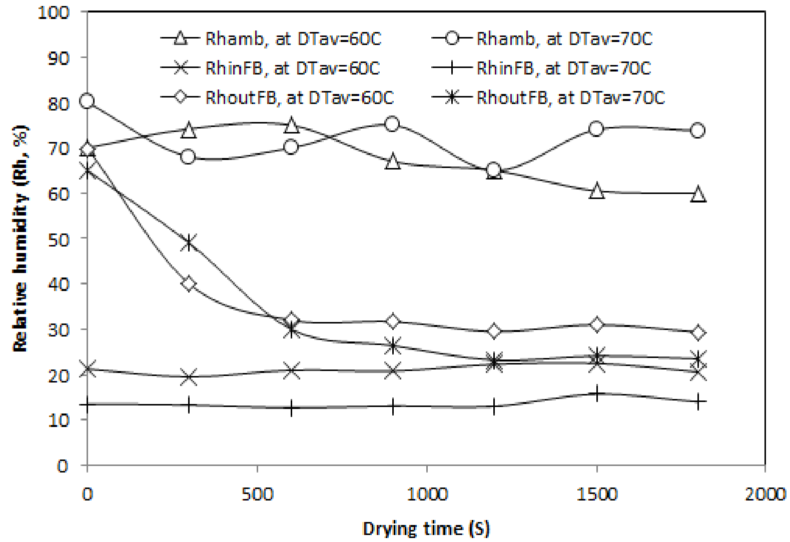

Fig. 7: The relative humidity versus drying time at mass flow rate 0.1256 kg/s

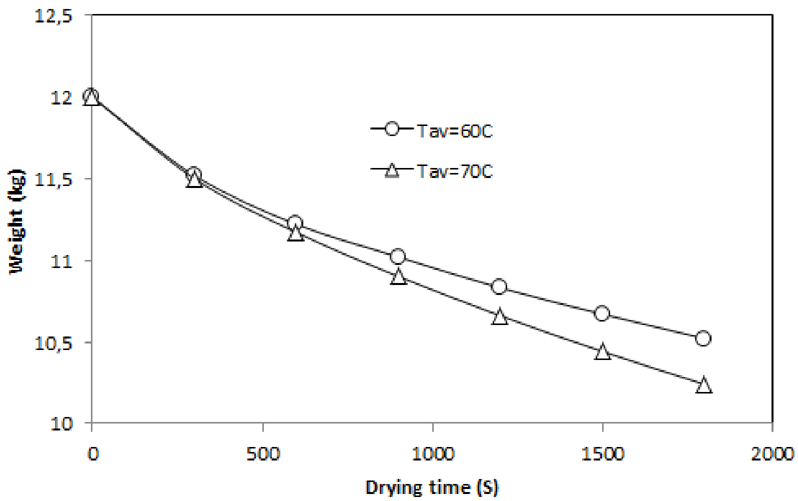

Fig. 8: Weight versus drying time

Figure 7 shows relative humidity ambient, inlet and outlet of the fluidized bed. Average relative humidity ambient found an average of 67.4% and 72.3% for air temperature drying of 60 and 70°C, respectively. The relative humidity inlet and outlet of the fluidized bed varies from 19.5 to 22.5 and 29.4 to 69.8%, respectively with average is 21.1% and 37.6% respectively for average drying temperature of 60°C. For average drying temperature of 70°C, the relative humidity inlet and outlet of the fluidized bed varies from 12.7 to 15.7% and 23.2 to 65% with average is 13.6 and 34.5% respectively.

Figure 8 shows a relationship of weight change of paddy to the drying time for average air temperature drying of 60°C and 70°C. The drying of paddy via fluidized bed drying integrated with biomass furnace at average air temperature drying of 60^{o}C reduced the weight from 12 to 10.74kg in 1338s. For average air temperature drying of 70°C, this system reduced the weight from 12 to 10.74 kg in 1007s.

Figure 9 shows relations moisture content of paddy to the drying time for different air temperature drying. Paddy was dried to final moisture content of 14% wet basis from 23% wet basis in 1338s and 1007s for average air temperature drying of 60 and 70°C, respectively. Figure 10 shows drying rate for drying of paddy via fluidized bed drying integrated with biomass furnace for average air temperature drying of 60°C and 70°C. For temperature of 60°C obtained drying rate maximum, minimum and average, respectively: 0.48, 0.15 and 0.27 kg every 300s. For temperature of 70°C obtained drying rate maximum, minimum and average, respectively: 0.5 kg, 0.2 kg and 0.335 kg every 300s.The SMER varies from 0.23 to 0.72 kg/kWh and 0.26 kg/kWh to 0.66 kg/kWh with the average of 0.37 kg/kWh and 0.38 kg/kWh for average air temperature

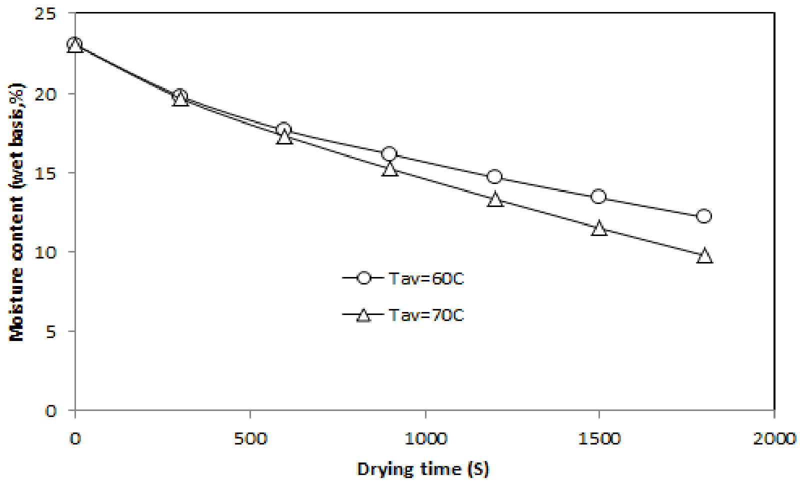

Fig. 9: Moisture content versus drying time

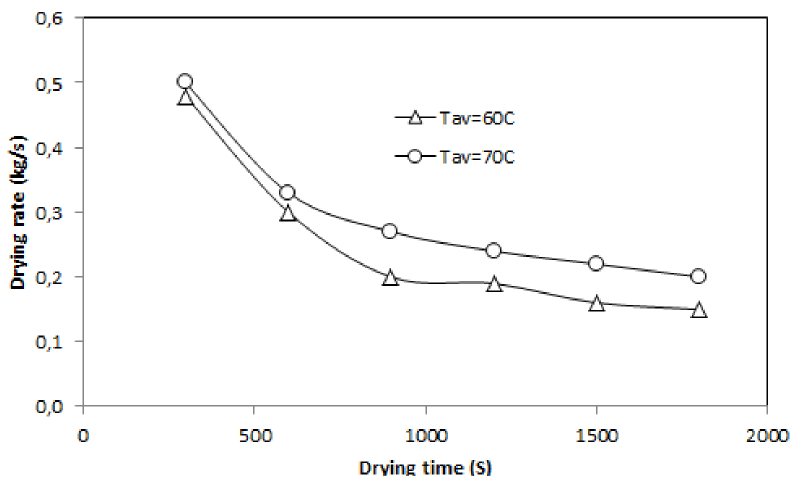

Fig. 10: The variation of drying rate versus drying time

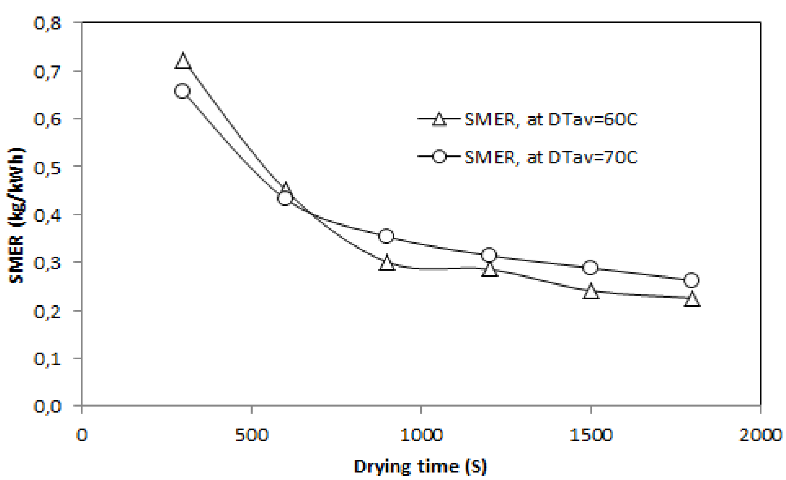

Fig. 11: The variation of SMER versus drying time

drying of 60 and 70°C, respectively, as shown in Fig. 11. Figure 12 shows thermal efficiency of fluidized bed drying integrated with biomass furnace for average air temperature drying of 60°C and 70°C at mass flow rate of 0.1256 kg/s. The thermal efficiency varies from 14.78 to 47.31% and 17 to 42.49% with the average of

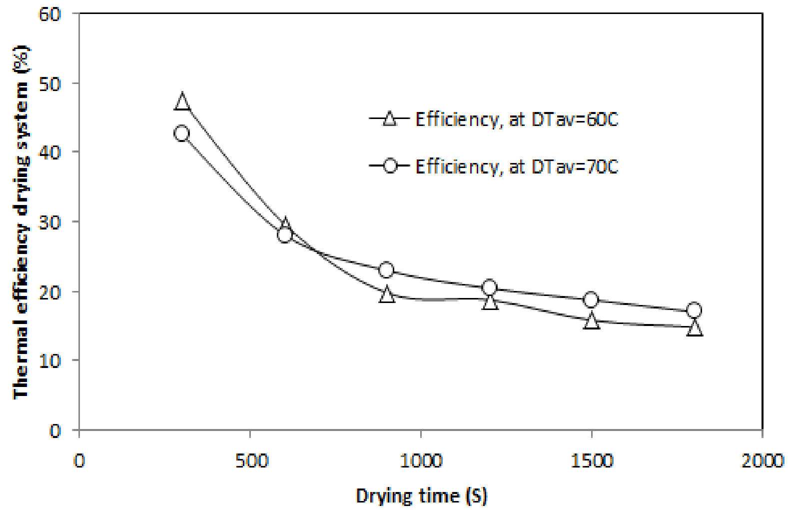

Fig. 12: The variation of thermal efficiency versus drying time

24.31 and 24.93% for average air temperature drying of 60 and 70°C, respectively.

CONCLUSION

A fluidized bed drying integrated with biomass furnace was tested for 12 kg of paddy. It was dried to the final moisture content of 14% from 23% (wet basis),which mass of water evaporated is 0.126 kg/s. The drying of paddy via this system at average air temperature drying of 60°C reduced the weight from 12 kg to 10.74 kg in 1338s using firing of 1.003 kg. For average air temperature drying of 70°C, this system reduced the weight from 12 kg to 10.74 kg in 1007 s using firing of 1.12 kg. The average SMER of 0.37 kg/kWh and 0.38 kg/kWh for average air temperature drying of 60°C and 70°C respectively. The average thermal efficiency of 24.31 and 24.93% for temperature drying of 60 and 70°C, respectively.

REFERENCES

Badan Standardisasi Nasional, 2008. Standar Nasional Indonesia Beras Giling, SNI 6128:2008. Badan Standardisasi Nasional, Jakarta, pp: 9.

Bhandari, R. and H. Gaese, 2008. Evaluation of box type paddy dryers in south Sumatra, Indonesia. Agricultural Engineering International: The CIGR Ejournal Manuscrip FP 08-011, Vol. X.

Bonazzil, C., M.A. du Peuty and A. Themelin, 1997. Influence of drying conditions on the processing quality of rough rice. Dry. Technol., 15(3-4): 1141-1157.

BPS (Badan Pusat Statistik Indonesia), 2015. Statistik Indonesia. BPSI, Jakarta.

Fudholi, A., K. Sopian, M.H. Ruslan, M.A. AlGoul and M.Y. Sulaiman, 2010. Review of solar dryers for agricultural and marine products. Renew. Sust. Energ. Rev., 14: 1-30.

Fudholi, A., K. Sopian, M.H. Yazdi, M.H. Ruslan, M. Gabbasa and H.A. Kazem, 2014a. Performance analysis of solar drying system for red chili. Sol. Energy, 99: 47-54.

Fudholi, A., K. Sopian, M.Y. Othman and M.H. Ruslan, 2014b. Energy and exergy analyses of solar drying system for red seaweed. Energ. Buildings, 68: 121-129.

Fudholi, A., K. Sopian, M. Gabbasa, B. Bakhtyar, M. Yahya, M.H. Ruslan and S. Mat, 2015a. Techno-economic of solar drying systems with water based solar collectors in Malaysia: A review. Renew. Sust. Energ. Rev., 51: 809-820.

Fudholi, A., K. Sopian, B. Bakhtyar, M. Gabbasa, M.Y. Othman and M.H. Ruslan, 2015b. Review of solar drying systems with air based solar collectors in Malaysia. Renew. Sust. Energ. Rev., 51: 1191-1204.

Fudholi, A., K. Sopian, M.A. Alghoul, M.H. Ruslan and M.Y. Othman, 2015c. Performances and improvement potential of solar drying system for palm oil fronds. Renew. Energ., 78: 561-565.

Izadifar, M. and D. Mowla, 2003. Simulation of a cross-flow continuous fluidized bed dryer for paddy rice. J. Food Eng., 58(4): 325-329.

Karbassi, A. and Z. Mehdizadeh, 2008. Drying rough rice in a fluidized bed dryer. J. Agric. Sci. Technol., 10(3): 233-241.

Khanali, M., S. Rafiee, A. Jafari, H. Hashemabadi and A. Banisharif, 2012. Mathematical modeling of fluidized bed drying of rough rice (*Oryza sativa* L.) grain. J. Agric. Technol., 8(3): 795-810.

Law, C.L., S.M. Tasirin, W.R.W. Daud and P.P. Ng, 2004. The effect of vertical internal baffles on fluidization hydrodynamics and grain drying characteristics. Chinese J. Chem. Eng., 12(6): 801-808.

Purwadaria, H.K., 1995. Problems and priorities of grain drying in indonesia. In: Grain drying in Asia. Proceeding of An International Conference Held at the 74 FAO Regional Office for Asia and the Pacific, ACIAR Proceedings No. 71, Bangkok, Thailand, pp: 201-209.

Soponronnarit, S., 1999. Fluidized bed paddy drying. Sci. Asia, 25: 51-56.

Soponronnarit, S., M. Yapha and S. Prachayawarakorn, 1995. Cross-flow fluidized bed paddy dryer: Prototype and commercialization. Dry. Technol., 13(8/9): 2207-2216.

Sutherland, J.W. and T.F. Ghaly, 1990. Rapid fluid-bed drying of paddy rice in the humid tropic. Proceeding of the 13th ASEAN Seminar on Grain Postharvest Technology. Bandar Seri Begawan, Brunai Darussalam, pp: 1-12.

Triyono, A., 2006. Karakteristik Briket Arang dari Campuran Serbuk Gergajian Kayu Afrika dan Sengon dengan Penambahan Tempurung Kelapa [skripsi]. Fakultas Kehutanan, Institut Pertanian Bogor, Bogor.

Tunambing, J.A. and R.H. Driscoll, 1991. Modeling the performance of continuous fluidized bed dryer for pre-drying of paddy. Proceeding of the 14th ASEAN Seminar on Grain Postharvest Technology, Philippines.

Wetchacama, S., S. Soponronnarit and W. Jariyatontivait, 2000. Development of a commercial scale vibro-fluidized bed paddy dryer. Kasetsart. J. Nat. Sci., 34(3): 423-430.

Wiset, L., G. Srzednicki, R.H. Driscoll, C. Nimmutarin and P. Siwapornrak, 2001. Effects of high temperature drying on rice quality. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript FP 01 003. Vol. III.

Yahya, M., K. Sopian, W.R.W. Daun, M.Y. Othman and B. Yatim, 2001. Design of solar assisted dehumidification of air drying system for medicinal herbs: Pegaga leaf. Proceeding of the 2nd Asian-Oceania Drying Conference (ADC, 2001). Batu Feringhi, Pulau Pinang, Malaysia, pp: 383-392.