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Research Article

Design and Performance of Solar-assisted Fluidized Bed Drying of Paddy

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Abstract: A solar-assisted fluidized bed drying was evaluated for 12 kg of paddy. It was dried to the final moisture content of 14 from 20% (wet basis) in 40 min with temperature and relative humidity about 50°C and 23%. Also, a maximum and average drying rate of 0.04 kg/min and 0,022 kg/min, respectively. Result shows that this system capable of drying paddy quickly because the drying rate is quite high. The drying system consists of single-pass solar collector with fin, fluidized bed, cyclones, blower and drying chamber.

Keywords: Drying rate, fludized bed, paddy, SMER, solar-assisted drying, solar collector

INTRODUCTION

Most of the dried agricultural products are dried under the open sun. There is requiring large open space area and very much dependent on the availability of sunshine, susceptible to contamination with foreign materials such as litters, dusts and are exposed to rodents, insect and birds. As an alternative to open sun drying, Solar Drying System (SDS) is one of the most attractive and promising applications of SDSs. It is renewable and environmentally friendly technology, also economically viable in most developing countries (Fudholi *et al*., 2010). Recently, various SDSs with air and water based solar collectors were reported (Fudholi *et al*., 2015a, b). SDSs for agricultural and marine products were reported by Fudholi *et al*. (2011a, b; 2012a, b, c, d, e; 2013a, b, c, d; 2014a, b; 2015c).

Drying is an important preservation method in food, chemical and pharmaceutical industries. Several drying techniques are available for different applications; some of them are solar drying, cooling dehydration, microwave drying, ultrasonic-assisted drying, fluidized bed drying, etc. Among several methods for drying of moist granular materials, fluidized bed drying has been one of the most successful techniques. During fluidized bed drying, solid particles are suspended in a gas stream and high rates of heat and mass transfer take place between gas and solid phases (Ranjbaran and Zare, 2013). Fluidized bed drying have been used to dry agricultural products such as apple (Kaleta *et al*., 2013), brown rice (Cheevitsopon and Noomhorm, 2011), carrots (Hatamipour and Mowla, 2002), celery (Jaros and Pabis, 2006), chilli (Tasirin *et al*., 2007), corn (Syahrul *et al*., 2003), green peas (Hatamipour and Mowla, 2003) and wheat (Özbey and Söylemez, 2005). However, to our knowledge, there is little information in the literature about the drying behaviour of paddy in fluidized bed drying. Objective of this study is to design and performances evaluation of solar-assisted fluidized bed drying of paddy.

MATERIALS AND METHODS

The fresh paddy were purchased from farmer in Padang, Indonesia. 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. Paddy is also an economic resource of more than 30 million farmers in Indonesia. Paddy after harvest generally have a high water content of about 20-27% wet basis (Waries, 2006). At the level of the water content, easily broken rice or not securely stored because it is very susceptible to fungus. So 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).

Figure 1 and 2 show the photograph and schematics of solar-assisted fluidized bed drying. The main components are solar collector array, fluidized bed, cyclones, blowers and drying chamber. Solar collector consists of several main parts: use a transparent cover glass material, absorbent plate finned uses aluminum and black painted opaque, use of angle iron frame, inside and outside the collector coated with aluminum 1 mm thick and insulation using glass fiber materials. Two solar collectors connected in series with

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Fig. 1: Photograph and schematics of solar-assisted fluidized bed drying

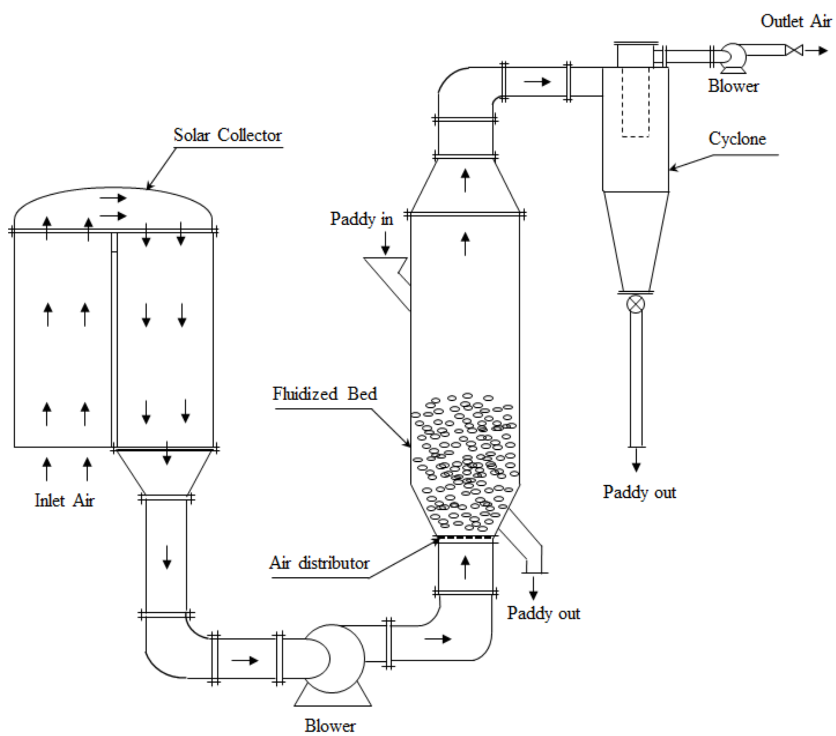

Fig. 2: Schematics of solar-assisted fluidized bed drying

an area of 1.8 m^2 each, which dimensional of single-pass solar collector as shown in Fig. 3. Fluidized bed consists of drying chamber, air flow distribution, the inlet and exit of rice, the front part of the drying column is covered with clear glass with a thickness of 5 mm, the sides and back are covered with 3 mm 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 3 mm thick and its dimensions as shown in Fig. 5. Blower used centrifugal types with 3, 7 kW power.

The working principle of this system is the air from the environment flows into the solar collectors using a blower. In the air is heated by the solar collectors harness solar energy, then poured into a column of hot air dryer for drying process. Paddy floated in the drying

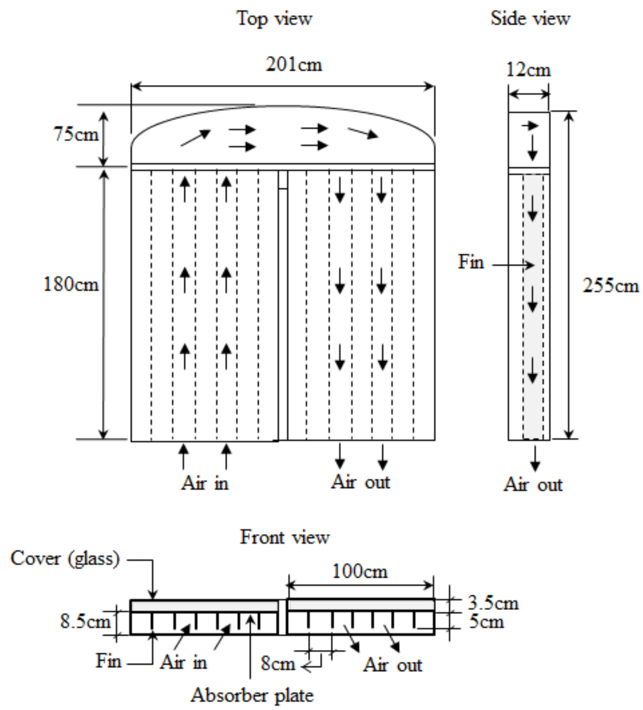

Fig. 3: Dimensions of single-pass solar collector with fin

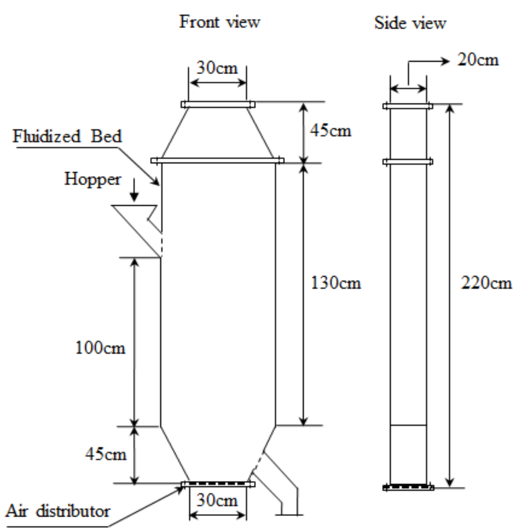

Fig. 4: Dimensions of fluidized bed

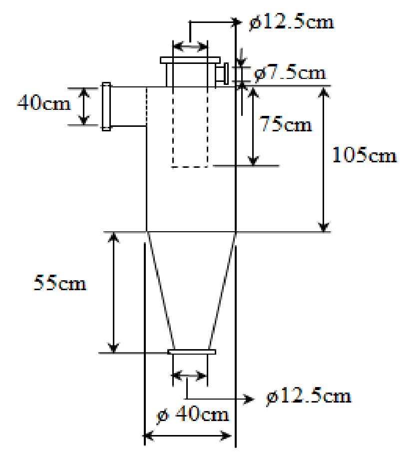

Fig. 5: Dimensions of cyclone

column by the hot air for paddy receives uniform heat energy and thus produces a uniform final moisture content of rice.

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. Incoming and outgoing air temperature solar collector and drying column is measured using a thermocouple, sun intensity is measured using a pyranometer and air flow rate is measured using flowmeter. Paddy weight change was measured using scales. Materials were weighed and measured the temperature every 5 minutes. The water content of paddy was analyzed using gravimetric methods.

The thermal efficiency of a solar collector is the ratio of useful heat gain to the solar radiation incident on the plane of the collector. It is defined as:

$$\eta_c = \frac{mC(T_o - T_i)}{A_c S} \times 100\% \tag{1}$$

where,

m = Mass flow rate (kg/s)

C = Specific heat of air (J/kg/°C)

A_c = Collector area (m^2)
T_i = Inlet air temperature (°C)
T_o = Outlet air temperature (°C)
S = Solar radiation intensity (W/m^2)

Performance evaluation for solar drying is Moisture Extraction Rate (MER). It is described as the mass of moisture removal per unit time from a dryer:

$$MER = \frac{W}{t} \tag{2}$$

where,
t = Drying time
W = Mass of water evaporated from the product (kg)

The mass of water removed (W) to from wet product can be calculated as:

$$W = \frac{m_o(M_i - M_f)}{100 - M_f} \tag{3}$$

where,
m_o = Initial total crop mass
M_i = Initial moisture content fraction on wet basis
M_f = The final moisture content fraction on wet basis

Another common rate is the Specific Moisture Extraction Rate (*SMER*). This one describes solar drying's effectiveness, which is the energy required to remove 1 kg of water and was calculated as:

$$SMER = \frac{W}{Q} \tag{4}$$

where,
Q = The total of energy consumtion which consists of the solar radiation, fuel and electrical which are consumed during the drying process.

RESULTS AND DISCUSSION

Designing and building paddy dryers with integrated fluidized type of solar collector as well as a review of the rate of drying has been carried out with a drying capacity of 12 kg and air mass flow rate 0.126 kg/s. The test results as shown in Fig. 6 to 10.

Figure 6 shows the intensity of the relationship of the sun, the air temperature in and out of the solar collectors to time, in Fig. 6 the weather looks quite bright with the intensity of the sun over 900 W/m^2, the average intensity of the sun 926,1 W/m^2 and average air temperature incoming solar collector obtained 36.07°C average air temperature solar collectors out as much as 51°C. Exit air temperature is influenced by the intensity of solar collectors and solar collector inlet air temperature, the higher the intensity of the sun and the air temperature entering the higher exit temperature solar collector as more solar energy is absorbed by the absorber plate solar collectors. On the other hand, the efficiency of collector varies from 53 to 60% and the average efficiency of collector was about 56% at solar radiation about 900 W/m^2.

Figure 7 shows air temperature and relative humidity environment, in and out of the drying column drying time. It can be seen that the relative humidity environment is very dependent on the ambient temperature, the higher the ambient temperature, the lower the relative humidity environment, with an average ambient temperature of 36.07°C, relative humidity environments found an average of 52.1%. Temperature and relative humidity average air into and out of each collector: 49.62°C, 45.6°C, 23.47% and 35.02%, respectively. From Fig. 7 also shows that the temperature of the air out of the drying column is gradually increasing and diminishing relative air humidity, this is due to the amount of water evaporated from the material dwindle.

Figure 8 shows a relationship of weight change of paddy to the drying time, also shows that the line of weight loss ingredients increasingly ramps, this is due to the obstacles of water that comes out of the higher material so that water evaporated from the surface of

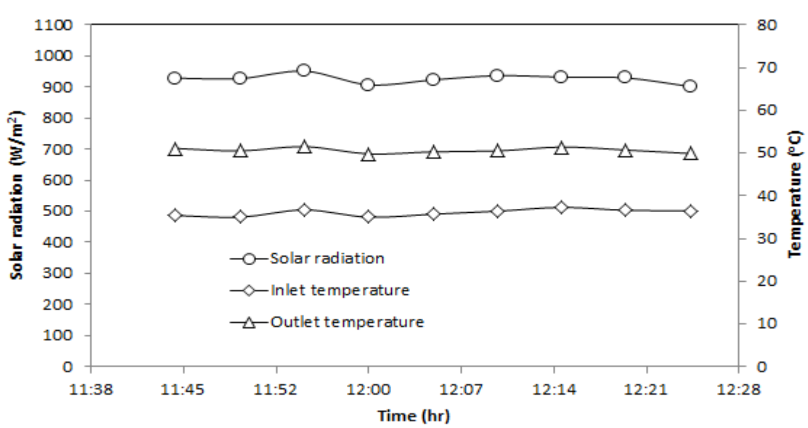

Fig. 6: The tempertaures and solar radiation versus drying time

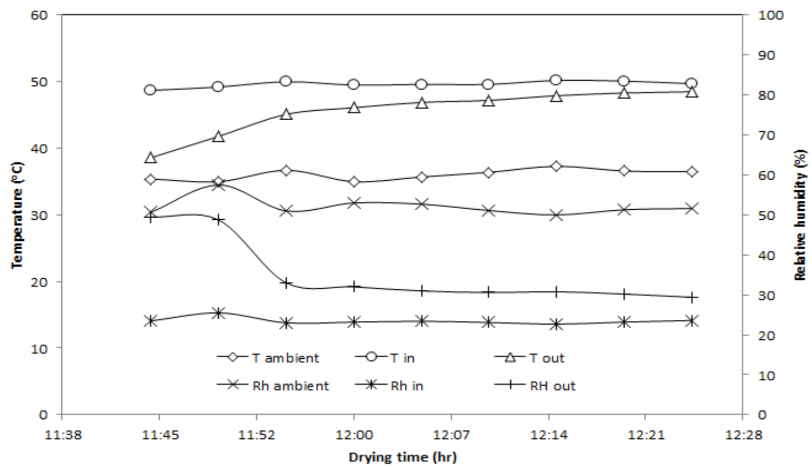

Fig. 7: The tempertaures and humidity (input and output fluidized bed) versus drying time

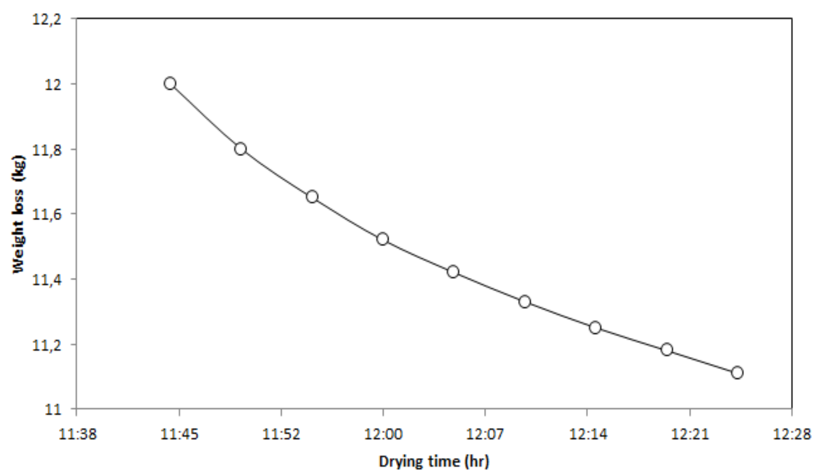

Fig. 8: Weight versus drying time

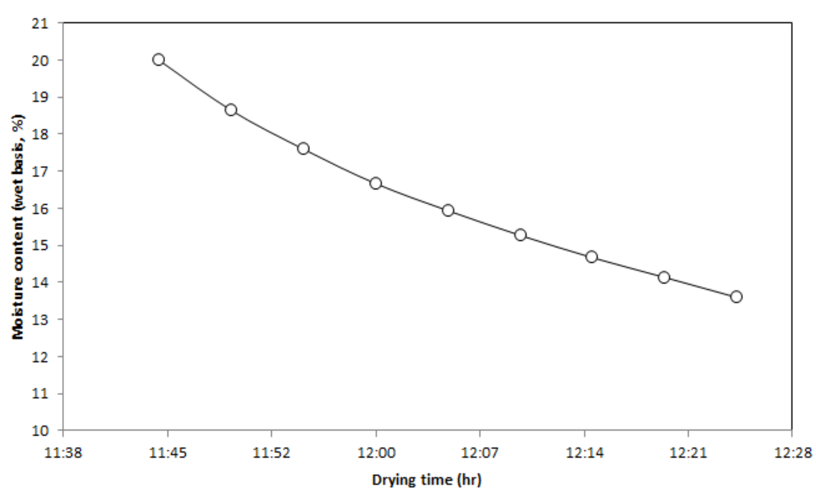

Fig. 9: Moisture content versus drying time

the material a little. The water is evaporated from the ingredients as much as 0.89 kg for 40 min with a weight of 12 kg dried material.

Figure 9 shows relations moisture content of paddy to the drying time. The initial moisture content of paddy 20% downgraded the Indonesian National Standard

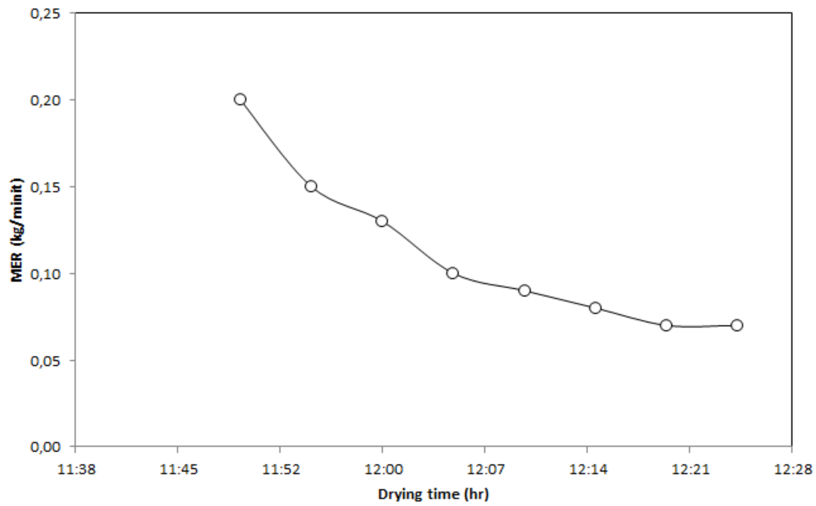

Fig. 10: The variation of MER versus drying time

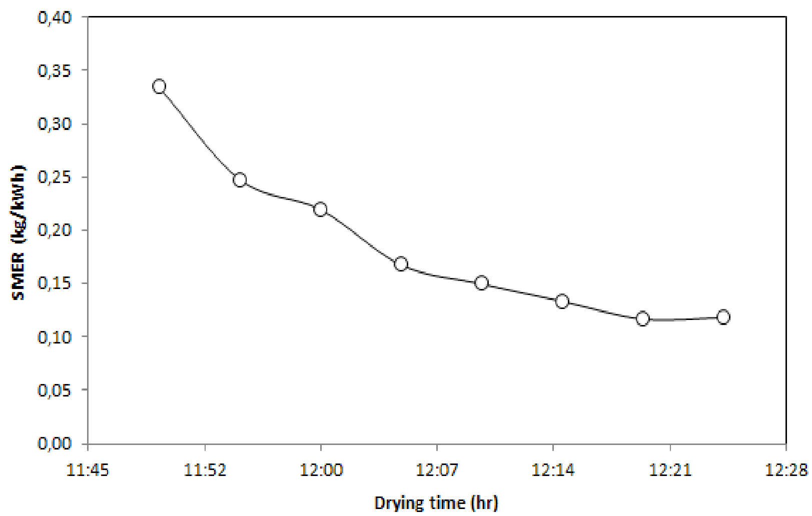

Fig. 11. The variation of SMER versus drying time

(SNI) final moisture content of paddy by 14% takes 40 min. Figure 10 shows relationship paddy drying rate of the drying time, which obtained drying rate maximum, minimum and average, respectively: 0.20, 0.07 and 0.11 kg, respectively every 5 min. The SMER varies from 0.12 to 0.33 kg/kWh and the average of 0.195 kg/kWh, as shown in Fig. 11.

CONCLUSION

A solar-assisted fluidized bed drying was designed, constructed and evaluated for paddy. Drying rate analysis has also been done. Paddy was dried to the final moisture content of 14% from 20% (wet basis) in 40 min with a temperature and relative humidity of 49.62°C and 23.47%. A maximum and average drying rate of 0.04 kg/min and 0,022 kg/min, respectively. The SMER varies from 0.12 to 0.33 kg/kWh and the average of 0.195 kg/kWh.

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