Performance Analysis of Indirect Clothes Dryer Using Solar Photovoltaic Energy

Safri Gunawan[1*], Binsar Maruli Tua Pakpahan[2], Diwki Muda Yulanto[1], Liana Atika[3], Sapitri Januariyansah[2]

{safri_gunawan@unimed.ac.id}

Automotive Engineering Education Department, Engineering Faculty, Universitas Negeri Medan, Jl. William Iskandar, Indonesia[1]
Mechanical Engineering Education Department, Engineering Faculty, Universitas Negeri Medan, Jl. William Iskandar, Indonesia[2]
Building Engineering Education Department, Engineering Faculty, Universitas Negeri Medan, Jl. William Iskandar, Indonesia[3]

Abstract. This study discusses the indirect clothes dryer using solar photovoltaic energy. The dryer is used to dry clothes and is designed to be practical, safe and environmentally friendly. The purpose of this study was to test the performance of an indirect clothes dryer in drying clothes. The results of drying clothes produced in the form of clothes that are ready to be ironed. The clothes dryer under study uses a solar thermal energy source which is converted from solar photovoltaic to charge electric current into the battery. The electric current is changed from DC to AC to turn on the 6-unit heater fan which is installed in a drying cabinet measuring 100 × 60 × 120 cm. The research showed that the solar photovoltaic dryer clothes dryer run well with an average drying room temperature of 40-41°C and could desiccate clothes made of polyester within 45 minutes of drying time.

Keywords: solar photovoltaic; clothes dryer; thermal energy; heater.

1 Introduction

Drying clothes is a process that consume huge energy. Many methods used to dry clothes. Typical method used to dry clothes in Indonesia using natural drying with solar energy, but in some commercial sectors using commercial drying machine [1]. Drying process can be found in varieties of agricultural, residental, indutrial and commercial application [2]. The utilization of direct solar energy has drawbacks such as spoilage due to rain and inability to control drying process, but the advantage is low cost capital budget and operating [3]. There are many methods used to dry some applications, such as using heat pump drying, heat exchanger, desiccant [2], solar thermal system [4], and electronic heating appliances [5].

Drying is a removal process of moisture content in a clothes that need a thermal energy as its required [6]. The thermal can be produced from solar energy to dry clothes. There are three

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method to dry clothes which are open sun drying by spreading solar radiation to thin layer, direct solar drying by collecting the sun's heat using solar collector onto cabinet dryer, and mixed solar drying method. Disign, development, technoeconomic study, physical characteristics, and performance analysis of solar dryer were reviewed by Kumar et al [7].

Photovoltaic (PV) is one of renewable energy that convert solar radiation to electricity [8]. The electricity that produced from PV can be used as energy source to run clothes dryer machine. Zhao [9] declared the efficiency that resulted by solar photovoltaic energy can reach to $18 \pm 2\%$, and Zazoum [10] stated the efficiency influenced by ambient temperature. Based on the reviews that have been done, the types of drying clothes have been carried out by many previous researchers as described. These are a good thing and the basic thing used to carry out this research. The objective of this study is to test the performance of dryer box in drying clothes by using PV as electricity power source for indirect clothes drying. The potential of potovoltaic in converting solar energy will be used as a source of electrical energy which will be used as a producer of heat energy to be used as an energy source of the dryer box.

There are many strategy to define a machine performance specially in drying machine. Michael [11] stated the main factor of resulting electricity and dryer box efficiency is solar radiation and PV module. Morfi [12] wrote an equation to impress drying rate process as followed:

$$\dot{m}_d = \frac{m_w - m_d}{t} \quad (1)$$

Where $\dot{m}_d$ is drying rate (kg/hr), t is time of drying processes, m_w and m_d are wet and dry clothes (kg), respectively. Moreover, Amiebenomo [13] declared that drying process is greatly influenced by temperature and humidity of dryer box. Indicator of dryer box performance is specific moisture extraction rate (SMER). SMER is the amount of water ratio that can be vapoured from clothes $\dot{m}_d$ with electricity energy in an hour, in other word it's an energy that needed to vapour 1 kg of water in unit of kg/kWh [12]. SMER can reflect the relationship between the moisture removed and the amount of electricity consumed. Its unit is kWh/kg. It is defined as the Equation [14]:

$$SMER = \frac{\dot{m}_d}{W_{in}} \quad (2)$$

Where W_{in} is power of electricity from PV and expressed as:

$$W_{in} = P \times t \quad (3)$$

Where P is power of electricity (watt). Another parameter to determine the performance of dryer box is specific energy consumption (SEC) kWh/kg as a reflection of SMER. It indicates the energy consumption of removing per kg water from the load. It can be expressed as Equation:

$$SEC = \frac{1}{SMER} \quad (4)$$

2 Method

The method used as the experimental set-up shown as **Figure 1.** The set-up designed as integrated one each other. It started from PV which directly placed outside and irradiated by solar radiation, as acquisition data, it's installed pyranometer to measure the value of solar radiation. The electricity that resulted from PV will be save to battery through solar charge controller. Inverter was installed to convert from direct current 12 volts to alternating current 220 Volts. After that, the current used to active fan heater. The set-up designed to 41°C of dryer box chamber. After reaching the temperature, the system won't active anymore and reactive at 40°C. The clothes such kind of polyester used in this experimental with 0.22 kg of wet clothes mass.

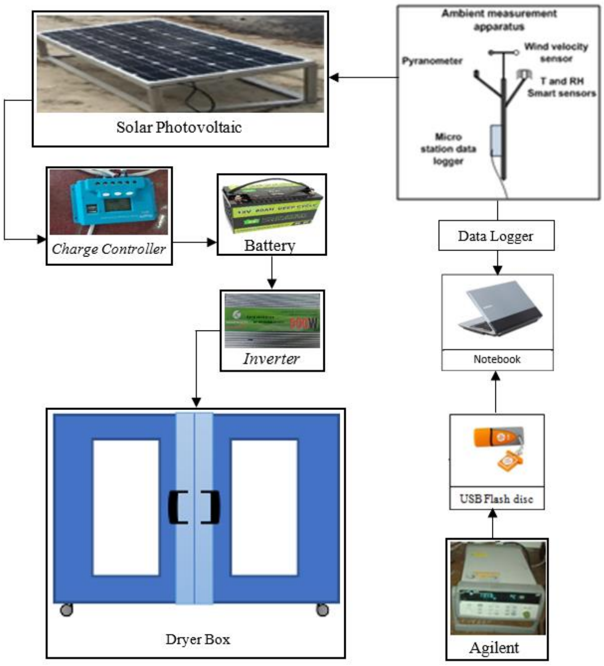

Fig. 1. Schematic diagram and experimental set-up

3 Result and Discussion

After conducting experimental research, the data collected and calculated as shown in the equation 1 to 4. The experimental set-up results that have been obtained and calculated are shown in Table 1.

Table 1. Experimental data

Clothes Type	m_w (kg)	m_d (kg)	$\dot{m}_d$ (kg/hr)	SMER (kg/kWh)	SEC (kWh/kg)
Polyester	0.22	0.18	0.053	0.162	6.187

The results for drying time shown in **Figure 2.** The experimental did in 45 minutes. Drying rate for drying is 0.053 kg/hr. The drying process occurs slowly until reaching the temperature of dry clothes.

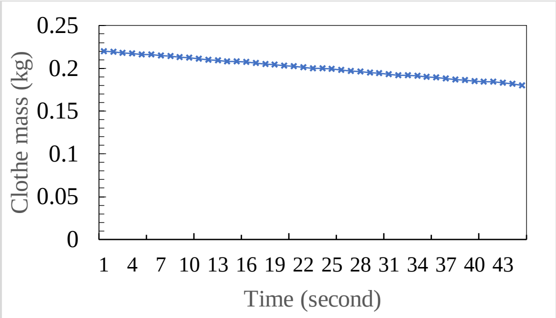

Fig. 2. Gradient of drying process

In this discussion only the results of drying with a constant air velocity from the heating fan are presented. Air temperature and humidity in the drying chamber, drying machine performance, drying rate, SMER and SEC are the parameters observed in term of using energy. The performance of box dryer analyzed using SMER. The parameter defined in Equation (2), in the above section. It can be shown as the energy consumed efficiency to remove the moist from the clothes dried [1]. In the other way, SEC is calculated to defined energy consumption of a product [15]. Furthermore the values of SMER and SEC are 0.162 kg/kWh and 6.187 kWh/kg, respectively. The average air temperature in the drying chamber is 40.22ºC with air humidity of 46.44%. A high SMER value will reduce the energy consumption required for drying. The amount of energy consumed to evaporate 1 kg of water from clothing is 0.162 kg/kWh. Air temperature will increase with increasing drying time. Meanwhile, the air humidity has decreased to a fairly dry condition. This is what supports faster drying of clothes because it results in a higher drying rate.

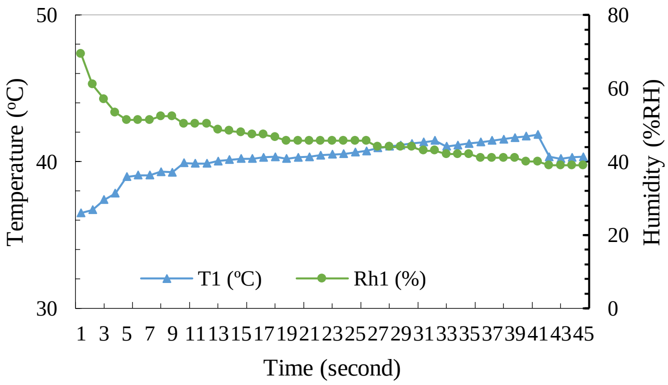

Fig. 3. Temperature characteristic and humidity in dryer box

4 Conclusion

The drying process using indirect solar PV ran well with an average drying room temperature of 40-41°C and desiccating clothes made of polyester within 45 minutes of drying time to dry 0.22 kg of clothes mass. The intermitten of solar radiation didn't give any effect significantly to the drying process for the utilization of battery. On the other side, the capacity of battery decrease. The drying rate of clothes is influenced by the amount of moisture in the clothes to the drying time. A high drying rate with lower energy consumption will result a high SMER and a low SEC. An increase in air temperature during the drying process indicates a higher heat transfer rate. The decrease in air humidity indicates a difference in the concentration of water vapor in the drying process. The vapor concentration can cause moisture to move from the clothes.

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