Design of a Continuous Coffee Bean Solar Dryer

H Ambarita\textsuperscript{1}, H K J Munthe\textsuperscript{1}, and T Hutagalung\textsuperscript{1}

\textsuperscript{1}Mechanical Engineering Department, Faculty of Engineering, Universitas Sumatera Utara, Jl. Almamater, Kampus USU, Medan, 20155, Medan Indonesia

Email: himsar@usu.ac.id

Abstract. As one of the renewable energy that can be utilized in various fields, solar energy is a potential energy source considering that Indonesia has a tropical climate. One of the uses of solar energy is in agriculture. Various agricultural commodities need to be dried before further processing. Also in coffee commodities that are being favored by many people nowadays. For this reason, as a solution to the problem of long drying times with weather changes issue, a room is made as a drying medium. By sucking hot air from a 2.576 m\textsuperscript{2} solar collector using the exhaust, it is expected that heat will be maintained in the space that has been isolated. The 2.4 m\textsuperscript{2} dryer rack design is made in three trays to make the most of the space. The results of the room that have been made is able to keep the lowest temperature at night at 26.6 °C and the highest temperature at 60.7 °C during the day. The highest average temperature in the room is on the bottom shelf near the hot air source.

1. Introduction

Coffee is one of the most popular beverages in the world. It has become a habit and lifestyle for some people. Nearly 25 million farmers in 50 countries around the world depend on coffee for a significant part of their livelihoods [1]. Like Indonesia that became the world’s fourth-largest coffee producer countries, Indonesia must be able to take advantage of the enormous opportunities available to improve the quality and quantity of coffee production [2]. The process of producing coffee itself to be consumed is quite long. Starting from picking coffee beans, can already affect the quality of coffee flavor later. One process is very important, that is the drying process before roasted. Drying is important to decrease the moisture content from 45-50 \% to 10-12 \% and for safe storage of the coffee beans for a long period of time [3].

Various methods are used for drying. The most conventional way is by drying in the direct sunlight. The solar drying system is environmentally friendly and enhances energy conservation [4]. Likewise in drying coffee beans, direct drying under the sun is the main choice. However, this conventional method has problems when it is cloudy or rainy so the drying process must be postponed. And also at night can’t do the drying process because there is no source of drying energy. In fact, coffee beans tend to increase their water content because of the humid night air. Solar flat plate collector has been extensively used for producing hot air to dry the product. Many researchers have worked on drying to obtain drying characteristics of fruits, vegetables, etc [5], [6], [7]. Suzihaque and Driscoll [8] design and optimization of coffee drying. This solar collector can drying coffee for three days up to moisture content 12 \%. The objective of this work is to the applied a solar collector to used to collect heat from the sun and heat transferred to the drying box. The thermal performance of the
2. Method

2.1. Sample Preparation
Coffee fruit were collected from Berastagih regency of North Sumatra Province of Indonesia. The coffee beans placed in drying room contain three trays, 5 kg coffee was spread all around the trays with initial moist content from 30% to 32%.

2.2. Design of solar collector
A prototype solar dryer has been fabricated and used in the experiment. The solar dryer is shown in Fig.1. The solar dryer consist of two main components: the drying chamber; and a solar collector. The drying chamber is a room with a dimension of 1,135 mm × 1,135 mm × 1,135 mm. Every side of the room was isolated by a 30 mm styrofoam and a layer of aluminum foil. Coffee beans were spread on the three trays that each dimension of 1,000 mm × 800 mm. The tray made of aluminum plate and aluminum net. There are two solar collectors: 0° slope; and 20° slope made of extended flat plate type which collector has 1,135 mm × 1,135 mm dimension. The plate was black painted made of galvanized steel sheet with 0.8 mm thickness. Two plain window glasses separated by an 18 mm air gap were used as a transparent cover to prevent heat loss from the top.

The solar dryer was operated into modes, daytime and night. In the daytime, the cocoa beans are dried inside the drying chamber by using hot air that had been sucked by two exhaust fan. The fans are placed on the top of a side chamber wall. In the night, all of the slots like on the fan and the edge of the collector. In the experiment, mass of the beans, temperature, relative humidity and solar radiation was recorded every ten minutes. The mass of the beans was measured using a load cell weight that integrated a data logger. The temperature and relative humidity were measured by a sensor DHT-11 that placed on each tray. An Agilent was used to measure the temperature of the solar collector. A HOBO-micro station was used to record solar radiation.

![Figure 1. Experimental Setup of Drying Process](image-url)
2.3. Drying Effectiveness

The final moisture content of the material is the ultimate goal of the drying process, the final moisture content will determine the length of the drying process the drying time is defined as the total time needed from the beginning until the equilibrium is reached.

\[ M = \left( \frac{(W_i - W_d)}{W_i} \right) \times 100\% \]  

(1)

The energy received by solar collectors comes from solar radiation:

\[ Q_r = F' (I A \tau \alpha) - Q_l \]  

(2)

Where \( F' \) is the factor efficiency of the collector that is assumed 0.9 and \( I, A, \tau, \alpha \), solar intensity \([W/m^2]\), solar collector area \([m^2]\), transmittance, and absorption coefficient, respectively. The total heat loses from the collector is calculated by the following equation

\[ Q_t = Q_{\text{w}} + Q_{\text{b}} + Q_{\text{t}} \]  

(3)

Where \( Q_{\text{w}} \) \([W]\), \( Q_{\text{b}} \) \([W]\), \( Q_{\text{t}} \) \([W]\) are the heat loses from the wall, bottom, and the top of the solar collector, respectively. The heat loss from the wall and the bottom of the collector are calculated using the following equations, respectively:

\[ Q_{\text{w}} = U_w A_w (T_p - T_\infty) \]  

(4)

\[ Q_{\text{b}} = U_b A_b (T_p - T_\infty) \]  

(5)

Here \( U_w \) \([W/M^2 K]\) and \( U_b \) \([W/M^2 K]\) are overall heat transfer coefficient of wall and bottom of the solar collector, respectively. They are calculated using the thermal resistant and analogy as depicted in while, the heat loses from the top of the collector is determined using the following equation:

\[ Q_{\text{t}} = U_t A_t (T_p - T_\infty) \]  

(6)

Where \( U_t \) \([W/m^2 K]\) is overall heat transfer coefficient from the top of the double glasses cover.

2.4. Drying Effectiveness

Drying characteristics of the cocoa beans will be discussed in the form of moist content versus time curve. Non-dimensional moisture content (MR) was used and defined as:

\[ MR = \frac{(M - M_e)}{M_i - M_e} \]  

(7)

Where \( M, M_e, \) and \( M_i \) are moisture content at time, moisture content at equilibrium, and moisture content at initial condition, respectively. In this study, the cocoa bean is assumed as asphere with radius of \( r \) [m]. The local moisture content (M) can be written as the following governing equation:

\[ \frac{\partial M}{\partial t} = D_{\text{eff}} \frac{\partial^2 M}{\partial r^2} + \frac{2}{r} \frac{\partial M}{\partial r} \]  

(8)

Where \( D_{\text{eff}} \) \([m^2/s]\) is an effective diffusivity. This parameter is a coefficient for mass transfer of the water within the object. The phase of water includes liquid and vapor.
3. Result and Discussion
Drying experiment have been done on April 23 at Medan city, Indonesia with geographic coordinate 3°34’ North and 98°40’ East. Duration of the daytime drying is 10 hours from 8 am to 6 pm and the duration of the night conditioning was carried out until April 24 at 8 am.

3.1 Temperature and Humidity
In these part will be shown the temperature and humidity RH.

![Temperature and Humidity Graphs](image)

**Figure 2.** Temperature (a) and Humidity (b) of the Tray in Drying Chamber

From Figure 2(a) showed that at 8 am to 1 pm, the temperature continues to rise around 60 °C same with increase of the solar radiation. From 1 am to 2 pm, showed the temperature fluctuate but reaches its highest daily temperature at 60.7 °C. The decline occurred due to cloudy weather. From 2 pm to 4 pm there was a decrease in temperature due to a decrease in solar radiation. Starting at 4 pm there was a drastic decrease in temperature until 7 am in the morning next day. It can be seen that the temperature of TEMP1 is always a reach highest point of temperature than the other temperatures. This happens because TEMP1 are the lowest tray so that they are closest to the source of hot air inlet.

Humidity decreases as the temperature increases. So it can be said that the temperature and humidity that occur in the room are inversely proportional. Where when 11 am to 3 pm, the air humidity level tends to be low with the lowest level is 5%, that is HUM1. For the night the humidity level tends to rise until 7 am in the morning next day where the highest level is 85.4% on HUM1.
3.2 Mass and Intensity
In these part will be show Mass and Intensity, and these is the comparison number of solar radiation between mass of coffee beans, if solar radiation is increase it will be reduce the weight of coffee beans, as shown below:

![Figure 3](image)

**Figure 3.** Comparison between Mass and Intensity of Solar Radiation

Figure 3 showed of the Intensity of radiation and Mass of coffee Beans, the minimum Intensity of radiation occur 234.4 w/m² at the time 8.00 am and maximum Intensity of radiation 688.1 w/m² at the time 13.18 pm, with Massa from 5.112 kg at the time 8.00 am and can be reduce maximum 4.291 kg at the time 17.21 pm.

![Figure 4](image)

**Figure 4.** Comparison between Moisture Ratio (MR) and Intensity of Solar Radiation

From Figure 4 showed that from experiment day 0.14991 at the time 5 pm. The results of drying in these section show that, the higher the intensity of solar radiation will reduce the drying moisture ratio.
4. Conclusion
Effectiveness of continuous solar coffee beans dryer has been studied experimentally. The average temperature in the drying chamber varied from 36.6 °C to 37.6 °C. The maximum temperature varied from 56.3 °C to 60.7 °C. These temperatures are very suitable for drying coffee beans. The average humidity in the night varied from 50.2 % to 63.8 %. The maximum can keep the humidity up to 79.1 % and the temperature 26.6 °C. The higher the intensity of solar radiation will reduce the drying moisture ratio and can be reduce of mass coffee faster.

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