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Characteristic of Vertical Mixed Flow Dryer in Coffee Bean Drying Process

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Abstract. This paper proposes a new type of vertical mixed flow dryer and evaluates the characteristic of the dryer for coffee bean drying. The specific design of vertical mixed flow dryer was in the drying chamber that equipped with a perforated-sloped tray to retard grain flow while drying. The dryer characteristic was presented in a form of humidity and temperature behaviour during the drying process. This characteristic could be a database to get coffee with standard moisture content (MC). Parameter stated were air temperature (^oC), humidity (kg/kg dry air), coffee bean mass flow rate (kg/s), and air velocity (m/s). For air velocity of 2 m/s, this dryer was able to dry coffee bean from 52% initial MC to final 14% MC for 11,5 hours.

1. Introduction

Drying takes a role in a post-harvest treatment and is important from the energy consumption point of view. In coffee bean drying, the moisture content is decreased from 55% *w.b*.to 12% *w.b*. If the drying process is poor, microorganism could grow on coffee bean surface, lead to biochemical reactions that could be toxic and unconsumable. It could also affect sugar content [1], and changes in organoleptic properties such as taste, color, and aroma [2]. Besides the biodegradation, coffee trading requires a standard dried coffee bean.

Coffee has a moisture content (MC) of 50-60% (wet basis, w.b.) and unevenness in maturity. Therefore, drying should be performed immediately to reduce the high moisture content of the bean and to avoid unwanted fermentation [3]. However, thermal stress following with mechanical damage can occur if drying not performed correctly [4].

The most study of drying mechanism is based on an empirical approximation model. The model can give information to predict drying time in an experimental condition. A phenomenological-based model has been developed to get a whole feature of coffee bean drying. This type of model can be generalized to a different condition. A process modeling methodology [5,6] has been presented by several authors. The methodology that used empirical approximation model and phenomenological-based model give to a simple and intuitive procedure to be used in engineering.

2. Method

The investigation of a new type of vertical mixed flow dryer behaviour was performed experimentally. This dryer has an ability to keep contact between air and coffee bean in a specific drying condition that facilitates heat and mass transfer occurs simultaneously. The heat transfer was governed by introducing hot air, whereas mass transfer was controlled by the humidity of the air. The new design was referred to some prototypes of the dryer, whereas its behaviour based on both dryer phenomenological model and empirical model. Some drying model were used to approach the drying process of coffee bean in the drying chamber. The feature of the drying chamber related to relative humidity and temperature was performed. In this study, the coffee drying process was based on the specific design of vertical mixed flow dryer at Mechanical Engineering Laboratory Vocational School Diponegoro University. The coffee dryer consists of three main elements namely drying chamber, heat exchanger, and blower as seen in Figure 1.

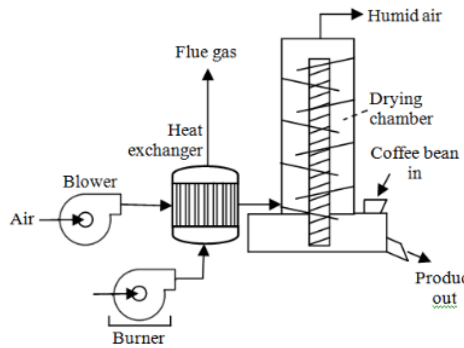

Figure 1. Schematic of vertical mixed flow dryer

Coffee bean fed into the bin and conveyed to the upside of the drying chamber by conveyor. The bean flows downward by gravity and flow on sloped-tray. Meanwhile, hot-dried air from heat exchanger flow upward in the drying chamber. This hot air contact with a coffee bean in a mixed flow pattern. The contact between coffee bean and air occurs in three-stage as seen in Figure 2. The first stage, hot air keep contact with bean in the coffee drying zone. The hot air capture moisture from coffee bean and become humid. In the second stage, the humid airflow passes pre-drying zone, stiring more moisture from the bean in this zone. Finally, in the third stage, humid airflow passes the wet coffee bean zone before going out of the chamber.

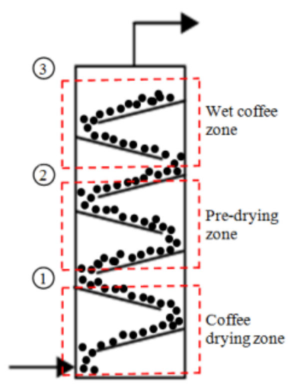

Figure 2. Schematic of drying process

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3. Materials and Devices Research

Raw materials to be used in this study is coffee cherry obtained from Ambarawa, Semarang District. The raw material is peeled in order to get a coffee bean. The 1 kg of the bean was prepared for every run. Liquified Petroleum Gas – LPG was used as fuel for heating the heat exchanger.

The main equipment used in this research is the vertical mixed flow dryer which is used to dry coffee bean by the mechanism of heat and mass transfer simultaneously. Supporting instruments needed include thermometer, hygrometer, grain moisture meter, stopwatch, a digital scale with 0,01 precision, and electric oven.

4. Variable Experiment

There are 3 variables in this experiment those are fixed variable, dependent variable and independent variable. The fixed variables including air temperature that stated at 60 ºC, and air velocity introduced to the drying chamber at 2 m/s. The dependent variables were temperature and humidity of the drying chamber, whereas the independent variable were mass flow rate of coffee bean that vary at 1 kg, 2 kg, and 3 kg per minutes.

5. Experimental procedure

In this experiment, the coffee cherries was peeled using a peeler machine to get a coffee bean. One kilogram bean was prepared to dry. The moisture content of the stock was measured by grain moisture meter before fed it into the drying chamber. The stock was conveyed upward by using screw conveyor. The coffee bean flows downward by gravity and flow on a perforated-slope tray in the drying chamber. While bean flowing downward, hot air was introduced into drying chamber. Contact between coffee bean and hot air occurs in drying chamber. The coffee bean was recirculated upward to experience frequent contact with hot air. Every 15 minutes, the moisture content of coffee bean was measured. Temperature and humidity in drying chamber were also measured and logged every 15 minutes. The drying process was stopped when the moisture content of coffee bean reach 14%.

6. Result and Discussion

Coffee bean drying using vertical mixed flow pattern with sloped-tray performed contact between hot air and bean individually. This contact leads to increase in the coefficient of convection heat transfer and increase the mass transfer coefficient. Higher convection heat transfer coefficient affects to heat energy flowing easily. The higher water reduction rates occur early in the process, as seen in Figure 1. This cause that small energy needed to evaporates free water content. The next course of drying seems that water reduction rates slower. In this stage, more energy needs to be required for evaporating more strongly bonded water. This drying profile was similar to studies from some authors [7][8][9].

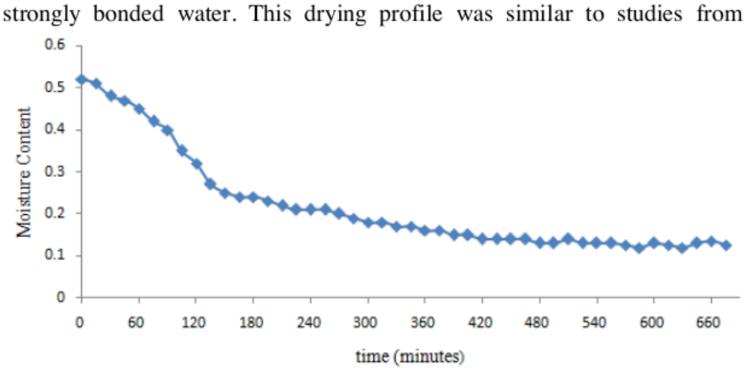

Figure 3 Profile of decreasing moisture content during coffee bean drying

As shown in Figure 3, the water reduction curve was steep in the first 130 minutes of drying period. This occupied 0,25 percent of drying period.

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The drying chamber temperature and humidity take a role to the drying process. This couple parameter, that shown at Fig. 4, determine water reducing rate. The profile of Fig.4 can be a database of this typical dryer to get water reduction profile at Fig.3.

The parameter are governed by an equation that is introduced by [10], as seen at equation 1 and 2.

$$\boldsymbol{h} = \frac{\left(-\frac{dX}{dt}\right)BL}{A(T_a - T_c)} \quad (1)$$

$$\boldsymbol{k} = \frac{h(T_a - T_c)}{L(Y_{sup} - Y_a)} \quad (2)$$

Where *X* refers to the average moisture content of coffee beans in kg water kg dry coffee^{-1}; *h* the coefficient of convective heat transfer W m^{-2} °C^{-1}; *k* the mass transfer coefficient in kg m^{-2} s^{-1}; *B* is the mass flow of coffee beans in kg s^{-1}; L is the latent heat of evaporation in kJ kg^{-1}; *A* the surface area of the coffee beans in m^2; *Ta* the air temperature in °C; *Tc* the temperature of the coffee beans in °C; *Ysup* the absolute moisture content on the surface of the coffee beans in kg water kg dry air^{-1} and *Ya* the absolute humidity of air in kg water kg dry air^{-1}.

As can be seen, the equations proposed are issued from general balances used to calculate the mass and heat transfer coefficients in a particular dryer configuration. Moreover, the evolution of the air temperature is not considered but measured which is part of the simplification of the proposed equations.

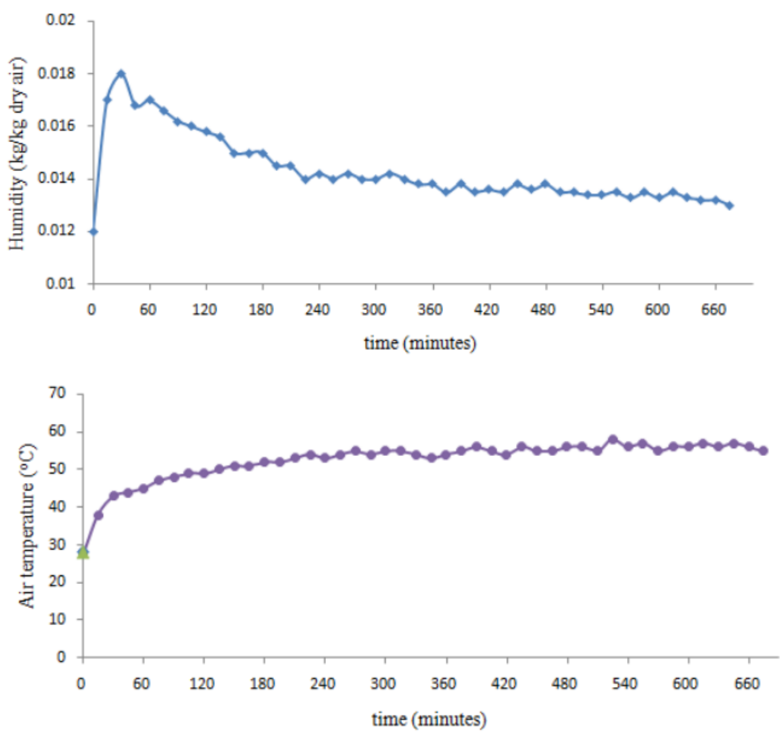

Figure 4 Profile of air temperature and humidity in drying chamber

7. Conclusion

At air velocity and temperature of 2 m/s and 60 °C, subsequently, the coffee bean can be dried from 52% initial MC to final 14% MC for 11,5 hours in this dryer. The drying rate can be increased by increasing air temperature and velocity, and humidity. The tray installed in the drying chamber has a role to retard drying contact time between air and coffee bean so that temperature of bean raise and leads to increase water diffusivity in the endosperm.

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