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Coffee Beans Drying Using Pilot-Scaled Fluidized Bed Dryer Assisted with Zeolite Adsorbent

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A B S T R A C T

Drying is a common method applied to agricultural and plantation products to prevent the growth of bacteria and other microorganisms. This research aims to determine the optimum temperature and humidity of the heating air for coffee beans drying in a fluidized bed dryer (FBD) without the addition of adsorbents, to study the effectiveness of zeolite adsorbent as air dehumidifier in order to improve the drying process, and to determine energy consumption in the coffee drying process in an FBD. This research was conducted using 500 grams of Arabica coffee, air temperature variations of 40°C, 50°C and 60°C with an average air velocity of 4.91 m/s. The addition of 1.08 kg of zeolite as an adsorbent was carried out to improve process performance and to reduce the drying time. Coffee bean quality was determined by moisture test using gravimetric method, protein test using Kjeldahl's method and carbohydrate test using Luff-Schoorl's method. The results showed that the optimum conditions for drying coffee beans to reduce the moisture content from 28% to 12.45% using an FBD without adsorbent were obtained at a drying air temperature of 50°C with a drying time of 3 hours. Coffee bean drying assisted by Zeolite adsorbent was able to reduce the drying time by 11% with the most efficient energy consumption of 76,200 kJ/kg.

INTRODUCTION

In 2022 Indonesia is the fourth largest coffee producing country in the world with a capacity of 794,800 tons [1]. Coffee bean is a seasonal commodity, so it is a paramount importance to reduce the moisture content of the freshly harvested beans (45 - 55% wet basis/ w. b.) in order to extend shelf life to be consumed in the next season and to ease handling during transportation.

External factors such as temperature, air relative humidity (R_H), and mechanical damage will affect the membrane structure which determines the quality of the coffee bean. In order to extend the shelf life, the coffee bean moisture content must be maintained at around 12% (wb), and the water activity (A_w) of around 0.76 [2]. Drying coffee beans at 40 °C, after being stored for 180 days at a temperature of 23 °C and 60% relative humidity gives almost the same results as sun dried coffee and also gives good product quality [3][4], while drying with air temperature of 60 °C shows a decrease in quality [5].

A modeling on drying coffee beans at 40 °C showed a decrease in water content from 25% (wb) to 16.3% (wb) for 10 hours [6]. Exposure of coffee beans to air with temperatures higher than 50 °C causes brittleness of products and protein denaturation [7][8]. Relative humidity shows the ability of air to capture moisture from the surface of the material. The lower the relative humidity of the drying air, the greater the capacity of the air to absorb moisture from the grain surface.

Fluidized bed drying (FBD) is a suitable drying method for solid particles which are sensitive to elevated temperatures, including coffee grains. By using dry air supplied from the bottom of the column, the bed of coffee bean will be fluidized. Coffee bean drying using an FBD provides intensive contact between dry air and solid particles, so heat and mass transfer takes place within a short time, thereby preventing overheating [9].

Drying of grain material with FBD assisted by adsorbent is able to reduce the drying time [10][11][12]. The capacity of adsorbent to adsorb molecules is influenced by several factors, including the pore geometry structure and the internal properties of the adsorbent which determine the interaction between water molecule and the adsorbent. The pore geometry structure of the adsorbent includes the total internal surface area of the adsorbent, the pore size distribution, as well as the shape and joints of the adsorbent pores.

Zeolite is a rock that forms very regular crystals with pores connected to each other in all directions which makes a larger surface area so that it is effective to adsorb water vapor. Zeolites are hydrated aluminosilicates, having a three-dimensional AlO_4 and SiO_4 tetrahedral structure coordinated by oxygen atoms [13]. The adsorption of water vapor occurs due to the high specific surface area (40 - 800 m^2/g) and is also influenced by temperature and vapor pressure. At the same pressure, the adsorption capacity of zeolite on water at high temperatures is lower than that at low temperatures [14].

Drying of coffee beans in a fluidized bed dryer with zeolite as an adsorbent will increase the capacity of air to absorb moisture, thereby reducing drying time [11]. Thus, drying of coffee beans must maintain its proximate composition, namely 60.2% carbohydrate, 10.39% protein, 12.98% fat, 4.63% ash and less than 12.5% of water [15].

The objectives of this study are determining optimum conditions for coffee beans drying, namely temperature and relative humidity (R_H) of the heating air in an FBD without adsorbent, finding the effectiveness of zeolite adsorbents in air dehumidification to reduce the drying time, and evaluation of energy consumption in the coffee drying process in FBD.

METHODS

Wet Arabica coffee beans obtained from the East Bandung area (6.93° South Latitude, 107.72° East Longitude, 706 m above sea level) were pretreated by drying the sun to a moisture content of around 30%. Then 500 g of pretreated coffee beans were put into a semi conical column of pilot-scale FBD "AEROMATIC AG" unit with a top diameter of 30 cm, a bottom diameter of 17 cm, a height of 48 cm, which has a capacity of 400 g - 6,000 g. The drying process is carried out using steam-heated air. The hot air that flows from the bottom of the column fluidizes the coffee beans bed so that the beans undergo water evaporation process which results in reduction of water content. The drying process was terminated when the moisture content reached around 12.5 % w. b. Moisture content of coffee bean was measured using gravimetric method. The diagram of the drying process in FBD is presented in **Figure 1.**

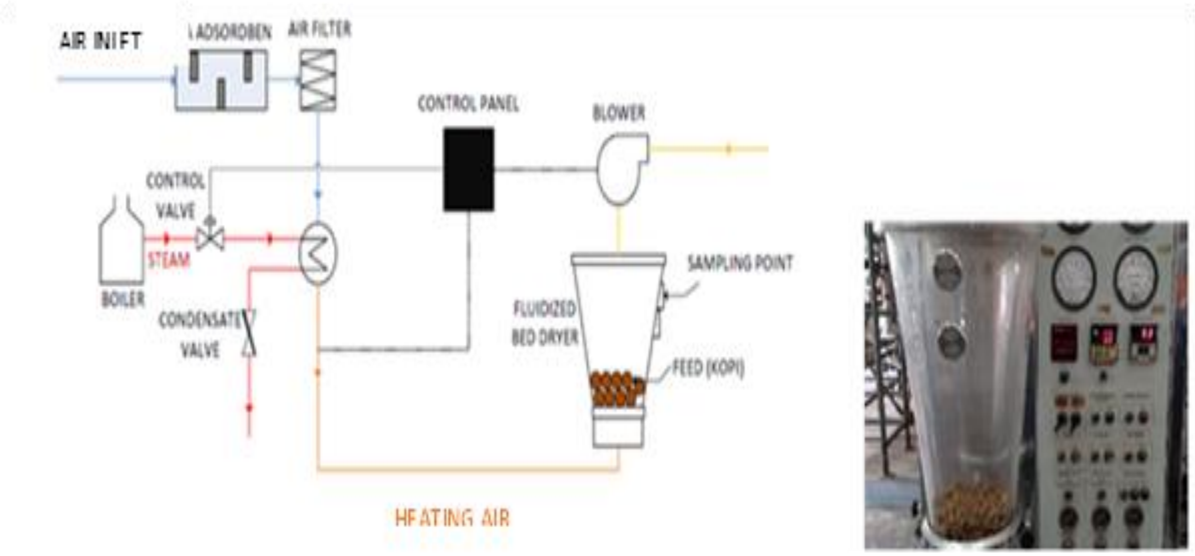

Figure 1. Flow Diagram of FBD

Based on temperature trials and previous studies [14] [15][16], the drying process was carried out using air temperatures of 40 °C, 50°C and 60°C. Having fluidization trials with 500 gram of coffee beans, the maximum capacity of the available blower was capable to homogeneously fluidize the coffee beans feed at an air velocity of around 4.91 m/s. The air velocity was measured with an anemometer, while the temperature and relative humidity of the drying air were measured using a thermo-humidity meter.

To examine the effect of heating temperature on the quality of the components contained in coffee beans, this was done by analyzing carbohydrate and protein levels of the product [15]. Energy consumption for steam generation was measured by collecting condensate produced during the drying process. The drying experiment was carried out in two stages, first is drying process without adsorbents to obtain the best drying air temperature, then it is continued by drying experiments utilizing adsorbent under the best temperature of the first stage experiment. The drying time and energy consumption resulted from the two drying procedures were then compared to obtain the most profitable process.

RESULT AND DISCUSSION

The effect of air temperature on drying time and moisture content of coffee beans is presented in **Figure 2.** The figure shows that the drying time is shorter according to the increase of drying air temperature. The elevated drying air temperature results in increasing partial pressure of water vapor inside the coffee beans, meanwhile the R_H of the drying air decreases. Increasing the difference between water vapor pressure in coffee beans and the relative humidity of the drying air will increase the driving force of water mass transfer, that results in reduction of the drying time.

The drying process took place relatively fast at air temperature of 60 °C and 50 °C with drying time of 130 and 150 minutes, and the drying rate was 0.09 gram/minute and 0.12 gram/minute respectively. Meanwhile at temperature of 40 °C the drying took place slowly (drying time of 320 minutes, and a drying rate of 0.05 g/minute).

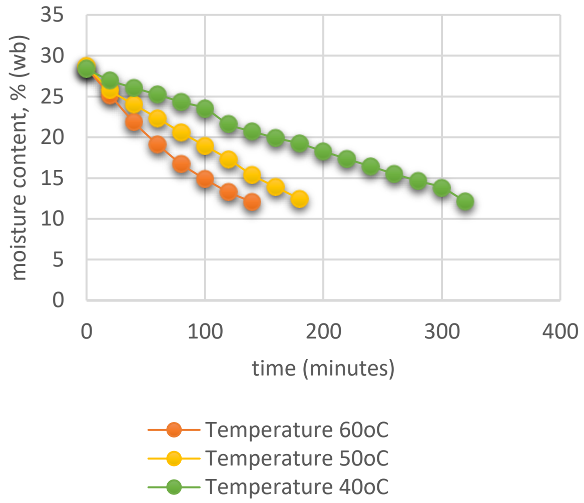

Figure 2. Effect of temperature on drying time and moisture content of coffee beans

Protein and Carbohydrate Levels

The results of protein and carbohydrate content of products are shown in **Figure 3**. Product of drying at 50°C own a decreased protein and carbohydrates content by 17.43% and 17.43% of the initial conditions. While drying products at 60°C, the levels of protein and carbohydrates decreased by 17.14% and 16.91%. The decrease in protein and carbohydrate levels at 50°C were slightly greater because the drying process took place at a longer duration than that of 60°C. A relatively small decrease in protein and carbohydrate levels will provide the ideal aroma and taste of brewed coffee.

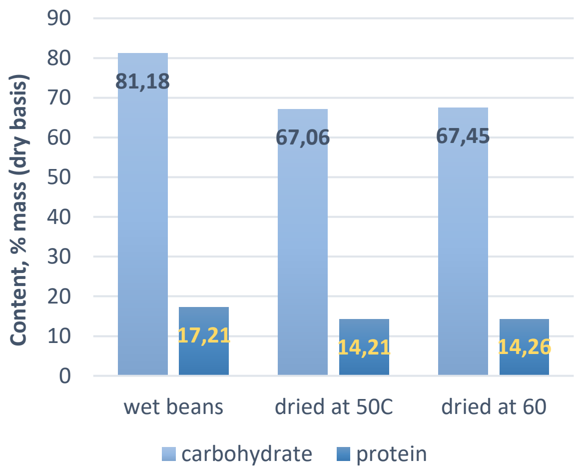

Figure 3. Effect of drying temperature on coffee's carbohydrate and protein content

The Effect of Zeolite Adsorbents in Drying Operation

The effect of utilizing zeolite adsorbent on drying time is presented in **Figure 4**, which shows that coffee bean drying assisted by zeolite adsorbents were able to reduce the drying time by 11% than that of drying time without zeolite (which are 180 and 160 minutes respectively). The drying air pretreated with zeolite adsorption has a reduced R_H value that results in a reduced dying time. Air heating at a temperature of 50°C without zeolite showed an R_H level of 30.7%, while heating air with zeolite resulted in a reduced R_H level to 28.5%.

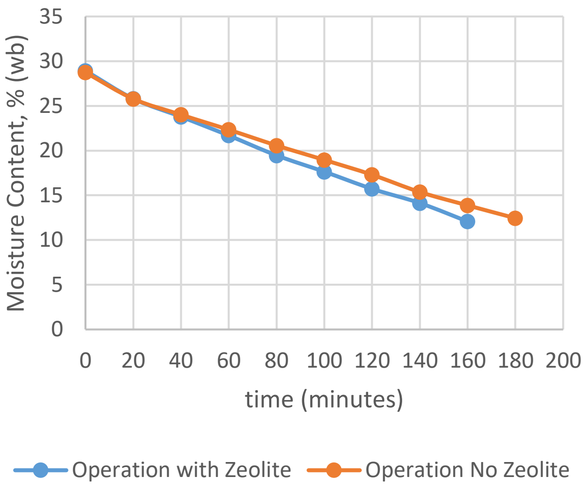

Figure 4. Effect of zeolite adsorbent

Installation of zeolite adsorbent with a baffle-shape at the air inlet line causes a pressure drop due to collisions between the air and the adsorbent sag. Therefore, the fluidized air flow rate decreased from 4.91 m/s to 3.66 m/s due to the pressure drop.

Drying Energy Requirement

The coffee bean drying process utilizing FBD requires two components of energy, which are energy for blower driving and energy for steam production. The energy requirement for drying at three different temperatures without adsorbent and drying at the best temperature assisted with the addition of zeolite adsorbents are shown in **Figure 5.** The results of the coffee bean drying operation without adsorbent indicated that as the drying temperature increased, the blower energy during the drying reduced. Energy consumption for blower is directly proportional to the drying air temperature, as the higher the operating temperature, the shorter the time required.

The steam requirement for drying at a temperature of 40°C is relatively large, due to longer drying time. The lowest steam consumption occurs at drying air temperature of 50°C, and increases at 60°C. The high increase in steam consumption at 60°C does not reflect the real consumption, which is indicated by uncondensed part of the steam (the condensate comes out mixed with steam). The lowest total energy requirement occurs at a drying air temperature of 50°C. In the drying operation assisted by zeolite adsorbent, the lowest total energy consumption was obtained, namely 76,200 kJ/kg. The use of steam with a relatively high pressure and temperature will result in inefficient conditions, which is indicated by uncondensed part of steam at the outlet.

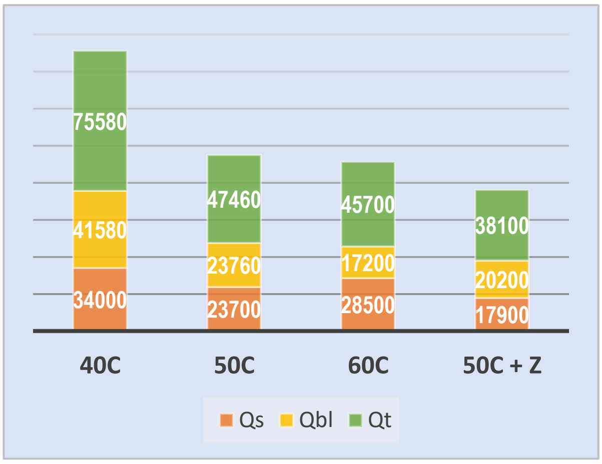

Figure 5. Energy consumption

The large opening of the steam valve increases the mass flow rate of steam, but is not balance with the air flow rate (due to the limited capacity of the blower), so that the heat transfer that occurs between steam and air does not occur optimal.

CONCLUSION

Based on research conducted, it can conclude as follows, the optimum drying temperature using a fluidized bed dryer without adsorbents is 50°C with a drying time of 3 hours. The use of 1.08 kg of baffle-shaped zeolite adsorbents in the drying process was able to shorten the drying time by 15%. The most economical energy consumption is found at drying temperature of 50°C by utilizing zeolite adsorbent, which is 76,200 kJ/kg. The research will give a better result if it is carried out with a blower that can be operated with a larger air flow rate that balance to the column capacity, so as to create optimum fluidization conditions.

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