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The Effect Of Variations In Drying Room Temperature On A Rotary Dryer With A 5 Rpm Cylinder Rotation On Changes In Mass And Water Content Of Coffee Beans

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Abstract— Drying is a critical stage in post-harvest handling of coffee that directly affects the final quality and shelf life. This study aims to analyze the performance of a horizontal cylindrical rotary dryer at various drying chamber temperatures (40°C, 50°C, 60°C, and 70°C) on two main parameters: moisture content and mass of coffee beans. The method used is experimental with robusta coffee bean samples dried in a laboratory-scale rotary dryer unit. Data collection was carried out every 30 minutes until reaching a drying time of 360 minutes. The results showed that drying temperature significantly affected the reduction in moisture content and mass. At a temperature of 70°C, coffee beans reached the lowest final moisture content of 28% within 360 minutes, followed by temperatures of 60°C (29%), 50°C (50%), and 40°C (50%). Higher temperatures (60°C and 70°C) also result in a much faster mass loss than lower temperatures (40°C and 50°C), where the final mass at 360 minutes for a temperature of 70°C is 2600 grams, while at 40°C it is still 3600 grams. However, increasing the temperature needs to be carefully considered to avoid thermal damage to the beans that can reduce quality. A temperature of 60°C provides the optimal combination of drying time efficiency and the potential to maintain coffee bean quality in a horizontal rotary cylinder dryer system.

Keywords— Rotary dryer, coffee beans, drying temperature, mass, moisture content

I. INTRODUCTION

Coffee (Coffea spp.) is a strategic Indonesian plantation commodity with high economic value, both for the domestic and export markets. According to data from the Central Statistics Agency (BPS) in 2023, Indonesia's coffee export volume reached more than 400,000 tons per year, generating significant foreign exchange earnings. The final quality of coffee beans, which determines competitiveness in the global market, is heavily influenced by post-harvest handling, particularly the drying stage [1]. Drying aims to reduce the moisture content of the beans from the wet level after pulping (around 60-65% wet basis) to a safe storage level of 10-12% (wet basis), or equivalent to a specific water-binding energy value. This process not only serves as a preservative by inhibiting

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microbial growth and enzymatic activity, but also triggers a series of complex biochemical reactions that shape the coffee's characteristic flavor, aroma, and color [2].

Conventionally, coffee drying in Indonesia still relies heavily on direct sunlight. Although low operational costs, this method has several fundamental drawbacks, including: high dependence on weather conditions, which leads to uncertain drying times and the risk of contamination; the need for extensive land; and difficult-to-standardize quality control, potentially leading to wide quality variations [3]. Furthermore, delayed drying can trigger excessive fermentation and the growth of mycotoxin-producing molds, such as ochratoxin A, which pose a health hazard and reduce sales value. Therefore, the adoption of reliable, efficient, and controlled mechanical drying technology is essential to increase productivity, quality consistency, and added value in the national coffee processing industry.

Among various mechanical drying technologies, the horizontal-cylinder rotary dryer offers several advantages suitable for drying granular materials such as coffee beans. This system operates continuously, with the material rotated in a tilted cylinder while being subjected to a flow of hot air. The rotational motion causes continuous and homogeneous stirring and turning of the material. This mechanism provides several key advantages: 1. The effective contact surface area between the material particles and the drying medium (hot air) is larger and more even; 2. It avoids uneven drying and "case hardening" due to constant material turning; 3. It optimizes the rate of water vapor mass transfer from the material to the environment. and 4. Ease of integration with automatic control systems for process parameters [4].

In rotary dryer operation, drying air temperature is the most critical process parameter. Thermodynamically, temperature plays a direct role in determining the water vapor pressure within the material and the relative humidity of the air, which together form a vapor pressure gradient that acts as a driving force for the evaporation process [5]. Empirically, increasing temperature accelerates the drying rate and shortens the process time. However, for thermally sensitive materials such as coffee beans, the application of high temperatures must be approached with caution. Excessive temperatures can cause thermal degradation of volatile flavor and aroma components, protein denaturation, damage to cell structures, and undesirable color changes [6]. On the other hand, temperatures that are too low will slow the process, reduce production capacity, and increase specific energy consumption. Therefore, determining the optimal operating temperature range that balances process efficiency (speed and energy consumption) with final product quality is a crucial technical issue to address.

Based on the above description, this study was designed to experimentally assess the performance of a laboratory-scale horizontal cylinder rotary dryer in drying Robusta coffee beans. The main focus of this research is to analyze the effect of variations in drying chamber temperature, namely 40°C, 50°C, 60°C, and 70°C, on drying kinetics. Drying kinetics is analyzed through two approaches: 1. The profile of water content reduction over time, which describes the dynamics of water release from the material; and 2. Changes in coffee bean mass, which represents the rate of water evaporation per unit time. The results of this study are expected to provide scientific recommendations regarding the optimal operating temperature range for rotary dryers for coffee drying applications, which considers the process kinetics aspect and provides initial implications for the potential for quality preservation. These findings can be used as a reference in the design and optimization of semi-industrial and industrial scale coffee drying processes, in order to support the increase in the competitiveness of Indonesian coffee products.

II. Research Methods

a. Materials and Equipment

The main material used was Robusta coffee beans (Coffea canephora) with an average initial moisture content of 62%. Before drying, the coffee beans were cleaned of dirt and evenly sorted. The main research equipment was a laboratory-scale horizontal cylindrical rotary dryer equipped with an electric temperature control system, a cylinder rotation motor (with a constant rotation speed of 5 rpm), an anemometer, thermocouples for monitoring inlet and outlet temperatures, and a data logger. The drying cylinder was made of stainless steel with dimensions of 100 cm in length and 30 cm in diameter. The air was heated by an electric heater with a blower.

b. Research Design

The study used a completely randomized experimental design with one factor, namely the drying chamber temperature, consisting of four levels: 40°C, 50°C, 60°C, and 70°C. Each treatment was replicated three times. The parameters measured were:

- Coffee bean mass
- Moisture content: expressed as a percentage based on the data obtained, which indicates the wet moisture content.

Measurements were taken periodically every 30 hours for coffee bean mass and moisture content.

c. Drying Procedure

A total of 5,000 grams of wet coffee beans were loaded into a drying cylinder that had been heated to the specified operating temperature. The drying process was carried out at a constant cylinder rotation speed. Samples for moisture content analysis were taken at 30-minute intervals for 360 minutes.

d. Data Analysis

The mass and moisture content measurement data were analyzed quantitatively and presented in the form of graphs showing the relationship between drying time and the mass and moisture content of the coffee beans at each temperature. The analysis was conducted to evaluate the effect of temperature on the rate of mass and moisture loss, and to identify the characteristics of the coffee bean drying kinetics based on changes in the curve pattern during the drying process.

III. Results And Discussion

The change in mass of coffee beans during the drying process at four different temperatures (40°C, 50°C, 60°C, 70°C) along with drying time up to 360 minutes is shown in Figure 1. In general, all curves show a decreasing trend in mass with increasing drying time, which is consistent with the process of water evaporation from coffee beans; for example, at 0 hours the initial mass for all temperatures is around 5000 grams, then decreases gradually to the range of 3000–3900 grams at 360 minutes depending on the temperature (visible differences between temperature points at each time interval). The decrease in mass is faster at higher temperatures: at 70°C the mass is lower than at 40°C at each time point, indicating that the rate of mass loss increases with higher temperature this is in line with the thermodynamic principle that the evaporation rate increases at higher temperatures so that water is lost more quickly from coffee beans. The differences between the curves also indicate that drying temperature affects the drying kinetics; Higher temperatures produce a steeper curve in the initial phase so that water mass is lost more quickly, while lower temperatures maintain a higher mass for the same time. The results showed that drying temperature had a very significant effect on the rate of decrease in coffee bean moisture content. In all treatments, the decrease in water content occurred exponentially over time, which is a general characteristic of drying agricultural products with a dominant period of decreasing rate. This pattern occurs because initially, the evaporated water is free water on the surface, then the process is controlled by the diffusion of water from the inside of the bean to the surface [4].

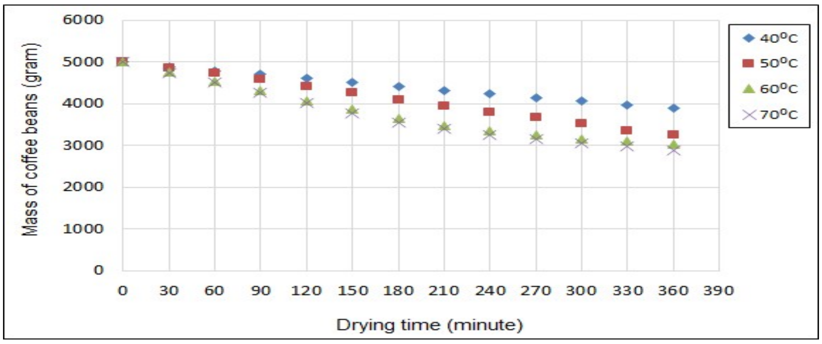

Figure 1. Graph of the relationship between drying time and coffee bean mass

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Figure 1 shows that the absolute drying rate (marked by the decrease in mass per time interval) at high temperatures is much greater. In the first 90 minutes, the mass of the sample at 70°C decreased by 900 grams (from 5,000 grams to 4,100 grams), while at 40°C it only decreased by 400 grams (to 4,600 grams). This means that the average drying rate at 70°C was more than double that at 40°C in the initial phase. This pattern was consistent throughout the process. After 360 minutes, the total mass of water evaporated at 70°C was 2,400 grams, while at 40°C it was only 1,400 grams. This behavior can be explained by the theory of heat and mass transfer. Increasing the drying air temperature increases the convective heat transfer coefficient to the seed surface and simultaneously increases the saturated vapor pressure at the surface, so that the vapor pressure gradient (causing mass transfer) becomes greater [5]. Additionally, in rotary dryers, constant stirring ensures that almost all parts of the beans are alternately exposed to the surface where heat and mass transfer are most intensive, thus utilizing this temperature increase more effectively than static drying.

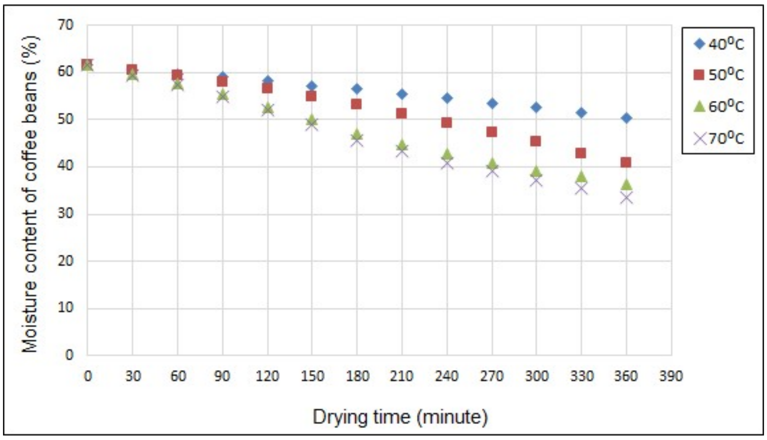

Figure 2. Graph of the relationship between drying time and coffee bean moisture content

The faster decrease in the moisture content of coffee beans at higher drying temperatures occurs because the increase in temperature increases the flow of heat energy into the beans, increases the vapor pressure gradient between the inside of the beans and the outside air so that water evaporates more quickly, and increases the internal water diffusivity in the bean tissue so that water molecules can move more quickly from the inside to the surface to be evaporated; at the beginning of drying, most of the water is free water so it evaporates easily, but over time the remaining water becomes bound water in the cell structure and can only be released through a diffusion mechanism, where higher temperatures thermodynamically and kinetically accelerate this mass transfer process, resulting in a higher rate of decrease in moisture content at temperatures of 60°C and 70°C compared to 40°C and 50°C, in accordance with the principles of drying kinetics of biomass materials that have been widely discussed in the drying technique literature.

Figure 2 reveals a sharp difference in performance. At 40°C and 50°C, the moisture loss curves show nearly identical trends, reaching 50% moisture content only after 360 minutes. This indicates that in this temperature range, a 10°C increase in heat energy is not enough to significantly overcome the water binding energy in the coffee beans or drastically increase the vapor pressure gradient. This may be near the limit of effectiveness of low temperatures for materials with complex cellular structures such as coffee. In contrast, increasing the temperature to 60°C and 70°C has a dramatic effect. At 60°C, the moisture content drops by 29% in the same time (360 minutes), while at 70°C it reaches 28%. This shows that after passing a temperature threshold (in this study above 50°C), the heat energy supplied is large enough to: 1. Significantly increase the water vapor pressure inside the cell, 2. Reduce the viscosity of the water, thus facilitating diffusion, and 3. Reduce the relative humidity of the outgoing air, thus increasing the driving force of evaporation [7]. The difference between 60°C and 70°C is relatively small at the end of the process, indicating that above 60°C, the drying mechanism may begin to be controlled by internal diffusion factors that are no longer linear with increasing temperature.

IV. Conclusion

Drying temperature significantly influences the performance of a horizontal cylindrical rotary dryer in drying coffee beans. Increasing the temperature from 40°C/50°C to 60°C/70°C dramatically increases the moisture reduction rate and drying rate. Temperatures of 60°C and 70°C show the best performance in terms of speed of achieving low moisture content, with 70°C being the fastest. Based on the process performance review, 60°C is recommended as the optimal operating condition because it provides a combination of a sufficiently high drying rate with a lower potential risk of thermal damage to the coffee beans compared to 70°C.

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