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The Effect of Hot Air Flow Velocity on The Drying Characteristics of Turmeric in A Rotary Dryer

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Abstract

Turmeric (Curcuma longa) is a rhizome plant widely used in the food, pharmaceutical, and cosmetic industries. This study aims to determine the characteristics of turmeric after the drying process and to analyze the effect of variations in hot air flow rate on moisture content reduction, drying rate, and thermal efficiency. Although various studies on turmeric drying have been conducted, most of these studies only tested one parameter, such as cylinder speed, drying temperature, and airflow rate, without considering the interaction of hot airflow rate in the rotary dryer system. The drying method in this study used a rotary dryer with a heat source from LPG combustion, at hot air flow rates of 5.2 m/s, 7.9 m/s, and 9.1 m/s with a drum rotation speed of 6 rpm for 360 minutes. The results showed that higher hot air flow rates accelerated the drying process. Optimal conditions were achieved at a speed of 9.1 m/s with a moisture content of 43.97%. Although drying was faster at higher speeds, the best thermal efficiency (23.36%) occurred at a speed of 7.9 m/s. Meanwhile, at a speed of 9.1 m/s, efficiency decreased to 22.39%.

Keywords: *air flow rate; rotary dryer; thermal efficiency; turmeric*

Abstrak

Kunyit (Curcuma longa) merupakan tanaman rimpang yang banyak dimanfaatkan dalam industri makanan, farmasi, dan kosmetik. Penelitian ini bertujuan untuk mengetahui karakteristik kunyit setelah proses pengeringan, serta menganalisis pengaruh variasi kecepatan aliran udaran panas terhadap penurunan kadar air, laju pengeringan, dan efisiensi termal. Meskipun berbagai penelitian tentang pengering kunyit telah dilakukan, namun sebagian besar studi tersebut hanya menguji salah satu parameter, seperti kecepatan silinder,suhu pengeringan, dan kecepatan aliran udara, tanpa mempertimbangkan interaksi kecepatan aliran udara panas pada sistem pengeringan rotary dryer. Metode pengeringan pada penelitian ini menggunakan rotary dryer dengan sumber panas dari pembakaran LPG, pada variasi kecepatan aliran udara panas 5,2 m/s, 7,9 m/s, dan 9,1 m/s dengan kecepatan putaran drum 6 rpm selama 360 menit. Hasil penelitian menunjukkan bahwa kecepatan aliran udara panas yang lebih tinggi mempercepat proses pengeringan. Kondisi optimal tercapai pada kecepatan 9,1 m/s dengan kadar air 43,97%. Meskipun pengeringan lebih cepat pada kecepatan tinggi, efisiensi termal terbaik (23,36%) justru terjadi pada kecepatan 7,9 m/s. Sementara itu pada kecepatan 9,1 m/s, efisiensi menurun menjadi 22,39%.

Kata kunci: efisiensi termal; kecepatan aliran udara; kunyit; rotary dryer

1. Introduction

Turmeric (*Curcuma longa* L.) is a rhizomatous plant widely utilized in the food, pharmaceutical, and cosmetic industries. In the food sector, turmeric serves as both a spice and a natural colorant [1]. Within the pharmaceutical industry, its curcuminoid content exhibits anti-inflammatory and antioxidant properties, which contribute to various health benefits [2]. Consequently, post-harvest processing, particularly drying, is essential to preserve quality and extend shelf life [3]. Fresh turmeric contains a high moisture content, approximately 80–82.5%, making it susceptible to deterioration if not promptly processed or dried [4]. International standards, including those set by the WHO, BSI, and ISO, stipulate a maximum moisture content of 10–12% for dried turmeric to ensure quality retention during storage [4]. International standards, including those set by the WHO, BSI, and ISO, stipulate a maximum moisture content of 10–12% for dried turmeric to ensure quality retention during storage Research conducted by Enjelina, E., and F. R. Siregar.

[5] demonstrated that an effective drying process can reduce turmeric's moisture content to 14.74%, as evidenced in their study employing an electric oven.

Traditionally, turmeric drying is conducted by sun exposure. Although this method is simple and cost-effective, it is highly dependent on weather conditions and requires prolonged drying durations. Furthermore, the process lacks hygiene, as the rhizomes are susceptible to environmental contamination, including dust and insects [6]. Consequently, conventional drying techniques are considered inefficient and fail to ensure optimal product quality [3]. As an alternative, mechanical drying systems such as electric ovens and tray-type dryers have been implemented to enhance efficiency and drying quality. These methods enable precise control of temperature and humidity, allowing for optimal moisture reduction in significantly shorter timeframes [7, 8, 9]. Suherman et al. [10] further demonstrated that mechanized dryers (e.g., rotary dryers) offer superior effectiveness compared to traditional sun-drying approaches.

The adoption of rotary dryers as a modern drying method offers significant advantages in terms of efficiency and product uniformity compared to conventional techniques. Rotary dryers facilitate continuous tumbling of agricultural commodities, ensuring homogeneous heat distribution across the material surface [11]. Studies indicate that variations in hot airflow patterns within rotary dryers can substantially influence thermal efficiency and final drying outcomes [12]. Suherman et al. demonstrated that rotary drying achieves a notably reduced moisture content of 9.68% within 5 hours, starting from an initial moisture level of 40%. Furthermore, Effendy et al. [12] emphasized that optimizing cylinder rotation speed and temperature settings enhances thermal efficiency, with recorded improvements up to 45.48% at 60°C and a rotational speed of 3 rpm.

Multiple studies have confirmed the superiority of rotary dryers as an efficient drying technology that accelerates processing while preserving material quality. Research Susanto et al. [6] further concluded that optimal cylinder rotation speed significantly influences thermal efficiency and overall drying duration. However, most of these studies focused on commodities other than turmeric, such as corn kernels or coffee beans, which exhibit distinct physical characteristics and initial moisture contents. Additionally, many experiments examined only isolated parameters (e.g., cylinder speed, drying temperature, or airflow velocity) without analyzing their combined interactions, particularly concerning hot airflow dynamics in rotary drying systems. This limitation restricts the understanding of optimal operational conditions, specifically for turmeric drying, particularly in achieving targeted moisture reduction, drying rates, and thermal efficiency.

2. Material dan Method

This study employed an experimental approach investigating the effects of varying hot airflow velocities in a rotary dryer system. The drying process was conducted at a fixed temperature of 70°C with a constant drum rotation speed of 6 rpm. Three distinct hot airflow velocities were examined: 5.2 m/s, 7.9 m/s, and 9.1 m/s. Airflow regulation was achieved through controlled adjustment of the blower inlet aperture, enabling precise modulation of the hot air velocity throughout the experiments. This research was conducted at the Production Laboratory of the Mechanical Engineering Department, University of Mataram.

This study was conducted to analyze the drying characteristics of turmeric using a rotary dryer with a constant drying time of 360 minutes, measuring moisture content every 30 minutes, where 5 kg of turmeric samples were used for each experimental variation, while recording ambient temperature, drying chamber inlet temperature, internal drying chamber temperature, outlet drying chamber temperature, as well as total mass and dry mass of the turmeric throughout the drying process. The tools and materials used include turmeric, blower, LPG gas, stove, heat exchanger, stainless steel plate, stainless steel pipe, 1 HP dynamo, gearbox, vanbelt, drying chamber, type K thermocouple, anemometer, thermostat, and digital scales.

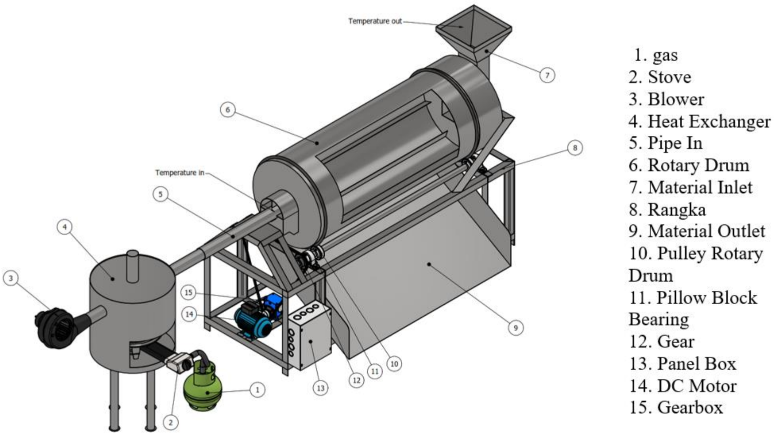


Figure 1. Design rotary drying machine

The experimental procedure began with the preparation of fresh turmeric rhizomes, which were thoroughly washed and then sliced into uniform pieces of approximately 3–5 mm thickness to ensure consistent drying. The sliced samples were weighed using a digital balance to obtain their initial mass prior to the drying process. Once the materials were ready, the drying system was operated by activating the blower to generate airflow, while thermal energy was supplied by burning LPG on a stove and transferred to the air through a heat exchanger. The heated air was then directed into the drying chamber, where airflow velocity was measured with an anemometer and the temperature was continuously monitored using a type-K thermocouple. To maintain stable drying conditions, the temperature inside the chamber was regulated by a thermostat.

Simultaneously, a 1 HP motor connected to a gearbox and belt drive was engaged to rotate the drying chamber, ensuring that the turmeric slices were evenly mixed and exposed to the hot air. The drying process continued either for the predetermined duration or until the moisture content of the samples approached equilibrium. At specific time intervals, the samples were removed and reweighed using a digital balance to track mass reduction. These measurements were then used to calculate the moisture content and drying rate of turmeric under the applied experimental conditions.

2.1 Moisture content and drying rate

The moisture content ($K_{(a)}$) was quantified relative to the total mass of the turmeric. An initial determination of the material's moisture content was conducted by heating the sample until a constant weight was achieved, signifying the complete evaporation of water. The moisture analysis of the turmeric was performed by subjecting a 1 kg sample to a temperature of 110˚C for 12 hours to obtain its dry mass (m_k). The following equation was employed to calculate the moisture content on a wet basis [13].

$$Ka = \frac{m_t}{m_t - m_k} \times 100\% \quad (1)$$

The drying rate in this study was calculated at 30-minute intervals throughout the experimental process. $\dot{m}_p$ (kg/s) The drying rate was calculated by comparing the mass of evaporated water to the total drying time, m_w (kg) [13].

$$\dot{m}_p = \frac{m_w}{t} \quad (2)$$

The mass of evaporated water, m_w (kg), was calculated as the difference between the initial mass of turmeric, m_t (kg), and its dried mass, m_p (kg) [13].

$$m_w = m_t - m_p \quad (3)$$

2.2 Thermal efficiency

The drying efficiency was calculated as the ratio of the energy utilized for drying Q (kJ) to the total energy transferred from the air to the material q (kJ) [14].

$$\eta = \frac{Q_{out}}{Q_{in}} \times 100\% \quad (4)$$

Q_{out} (kJ) The heat energy utilized for the drying process was calculated using the following equation [13].

$$Q_{out} = Q_1 + Q_2 \quad (5)$$

Q_1 represents the sensible heat required to raise the temperature of the moisture present in the material (kJ), while Q_2 denotes the latent heat necessary for moisture evaporation from the material (kJ) [13].

$$Q_1 = m_t . C_{pb}(T_{aw} - T_{ak}) \quad (6)$$

$$Q_2 = m_w \; x \; h_{fg} \quad (7)$$

The specific heat capacity of turmeric C_{pb} was determined as 3,488 kJ/kg°C [15]. The following temperature parameters were established T_{ak} represents the final temperature of turmeric after drying, T_{aw} indicates the initial temperature before drying (°C), while h_{fg} denotes the latent heat of water vaporization (kJ/kg).

Q_{in} (kJ) represents the net energy transfer from the drying air to the material, calculated using the following thermodynamic equations 8, 9, and 10.

$$Q_{in} = Q_{in1} + Q_{in2} \quad (8)$$

Q_{in1} represents the total energy released from the LPG combustion (kJ), while Q_{in2} denotes the thermal energy contribution from the blower system during the drying operation. The energy balance was calculated using the following equations [16].

$$Q_{in1} = \dot{m} \, . NK_{BB} \quad (9)$$

The mass flow rate of LPG ($\dot{m}$) was measured in kg, while the net calorific value (NK_{BB}) represents the energy content per unit fuel mass (kJ/kg). For the LPG used in this study, the (NK_{BB}) was determined to be 47,089 kJ/kg. [16].

$$Q_{in2} = P_{blower} \, . t \quad (10)$$

P_{blower} represents the total active power consumption of the blower (W), while t denotes the total drying duration (s) [17].

3. Results and Discussion

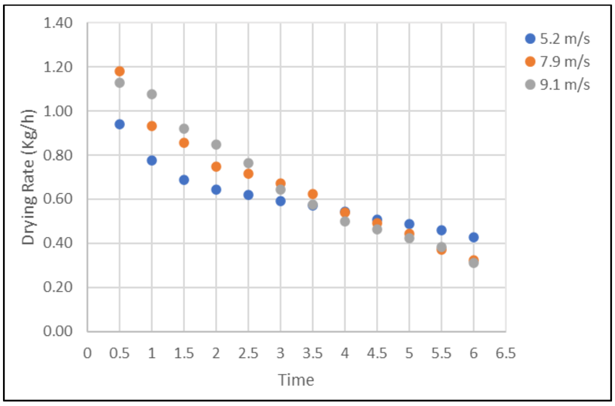
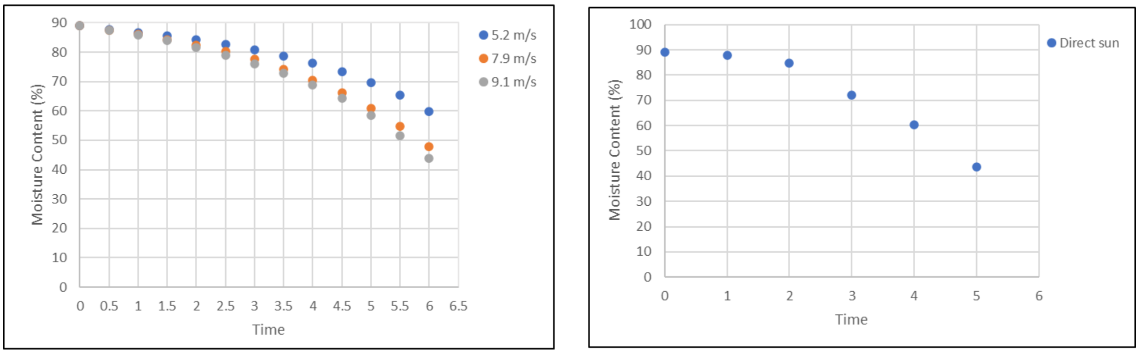


Figure 2. Drying rate versus drying time

Based on Figure 2 above, shows that the drying rate at the beginning of drying is faster than the drying rate at the end of drying, which slows down and is called the falling rate period. This condition occurs in every variation of hot air flow velocity. Higher air speeds result in a higher drying rate, such as at a speed of 9.1 m/s, where the initial drying rate reaches 1.13 kg/h, thereby shortening the overall drying time. At a speed of 5.2 m/s, the drying rate obtained is only 0.94 kg/h. This finding aligns with the research by Ibrahim et al. [18]. which states that increasing air velocity can significantly accelerate initial evaporation. However, at the end of the process, the lowest drying rate was observed at a speed of 9.1 m/s with a value of 0.31 kg/h, indicating a lower moisture content in the material compared to a speed of 7.9 m/s with a drying rate of 0.32 m/s, and at a speed of 5.2 m/s, the drying rate reached 0.43 m/s. Additionally, after reaching a drying time of 4.5 hours, the effect of air speed decreases, and the drying process is controlled by internal diffusion. As shown in Figure 2, at a drying time of 4.5 hours, the graphs intersect, and the subsequent decrease in drying rate is not significant. This condition indicates that external factors, such as airflow velocity, no longer significantly affect the drying rate because the surface moisture content of the material has been depleted and the process is now controlled by internal mechanisms [19].



(a) (b)

Figure 3. Rate of moisture reduction in (a) rotary dryer and (b) direct sunlight

Figure 3 shows the reduction in moisture content when using a rotary dryer for mechanical drying compared to conventional drying in direct sunlight. The rotary dryer can achieve a moisture content of up to 43.97% in only 6 hours, whereas conventional drying requires 5 days to achieve nearly identical levels. Conventional drying using direct sunlight, on the other hand, requires a much longer duration of 5 days to achieve nearly identical levels of moisture content at 43.66%. These results align with recent literature confirming that convective mechanical drying significantly accelerates the reduction of moisture content in materials such as turmeric, especially during the initial phase of high humidity [20]. These results demonstrate that the drying process through forced convection in a mechanical system yields faster results than conventional drying using direct sunlight. Additionally, Figure 3 (a) shows how the hot air flow rate affects the reduction in turmeric's moisture content percentage with the same drying time. The lowest moisture content of 43.97% was consistently achieved at a hot air flow rate of 9.1 m/s at the end of drying. The moisture content percentages were 47.91% at 7.9 m/s and 59.93% at 5.2 m/s.

Figure 4 shows the relationship between the drying rate and the moisture content of the material under three different hot air flow rates. The graph indicates that at each flow rate with similar moisture content levels, the drying rate exhibits a strong positive correlation with the hot air flow rate, as seen in the graph: the higher the moisture content of the material, the higher the drying rate. At a speed of 5.2 m/s, the drying rate is 0.94 kg/h with a moisture content of 87.83%, which is lower compared to speeds of 7.9 m/s and 9.1 m/s. Meanwhile, at a speed of 7.9 m/s, the drying rate was 1.18 kg/h with a moisture content of 87.50%, which is the highest drying rate value. When compared to the hot air flow speed of 9.1 m/s, which is the highest speed, the drying rate value was 1.13 kg/h with a moisture content of 87.58%.

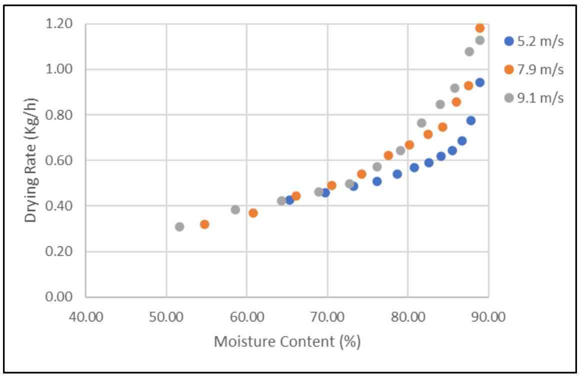


Figure 4. Relationship of drying rate and moisture content

This is due to surface hardening (case hardening) at a speed of 9.1 m/s. Excessively high air speeds can cause evaporation on the material surface to occur very quickly, forming a hard, low-permeability dry layer that subsequently hinders the mass transfer rate of water vapor from the interior of the material to the surface. However, this occurs only at the beginning of drying, so that by the end of drying, the moisture content and drying rate decrease progressively as the moisture content decreases [21]. At a speed of 9.1 m/s, the moisture content was 43.97% with a drying rate of 0.31 kg/h, followed by a speed of 7.9 m/s with a moisture content of 47.91% and a drying rate of 0.32 kg/h, and at a speed of 5.2 m/s, a moisture content of 59.93% was obtained with a drying rate of 0.43 kg/h. This phenomenon is consistent with the research by Maulana et al. [22], who stated that the speed of hot air flow can significantly influence the moisture content of the material.

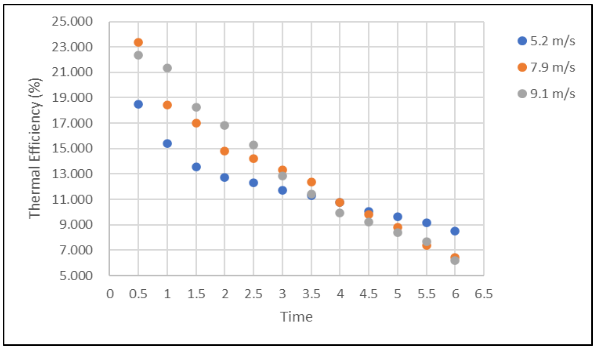


Figure 5. Relationship of thermal efficiency and drying time

Figure 5 above shows a graph of the relationship between efficiency and drying time with variations in hot air flow velocity. The highest efficiency is consistently achieved at an intermediate air velocity of 7.9 m/s, yielding a value of 23.359%. The lowest efficiency is recorded at a velocity of 5.2 m/s, yielding a value of 18.504%. Anomalously, the highest hot air flow velocity of 9.1 m/s yields an efficiency value of 22.379%, lower than the value at 7.9 m/s. This phenomenon can occur due to case hardening, which arises from the extremely rapid evaporation of the surface layer's water. This evaporation is induced by an air velocity that exceeds the rate of water diffusion from the material's interior. The result is a hard, impermeable surface layer that causes the material's surface to dry very quickly. Hasibuan et al. [23] support this phenomenon in the drying of temulawak, finding that the optimal air speed does not occur at the highest speed. This indicates that excessively high air speeds do not always provide better efficiency, as they can induce quality loss.

Figure 4 shows that, at a drying time of 4.5 hours, the graphs for each hot air flow rate converge. This indicates that, during the initial drying process (between 0 and 4.5 hours), external factors, such as the hot air flow rate, significantly affect drying efficiency. After 4.5 hours, however, the graphs change, running almost parallel with minimal separation.

This indicates that the influence of external factors, such as the hot air flow rate, has significantly decreased. At this stage, the rate of water molecule movement from the material's core toward the surface becomes more important than the air's ability to carry water vapor from the surface. Thus, the three flow rates become nearly identical in efficiency.

4. Conclusion

The drying of turmeric utilizing a rotary dryer demonstrated superior performance compared to conventional sun drying. At an initial moisture content of 88.98% (wet basis), sun drying required approximately five consecutive days of exposure to direct solar radiation to reduce the moisture content to 43.66%. In comparison, the rotary dryer exhibited a markedly higher drying efficiency, achieving a comparable final moisture content of 43.97% within only 360 minutes for a sample mass of 5 kg. These findings indicate that the rotary drying method not only accelerates the drying process but also provides better control over drying conditions, thereby enhancing the overall effectiveness of moisture reduction in turmeric. Variations in hot air flow velocity significantly affect the drying characteristics of turmeric in a rotary dryer. Increasing the airflow velocity from 5.2 to 7.9 to 9.1 m/s directly accelerates the reduction in moisture content and shortens the total drying time. This is due to an increase in the heat and mass transfer coefficients between the air and the turmeric surface, which makes the water evaporation process more efficient. Therefore, an airflow velocity of 9.1 m/s is the optimal condition for drying turmeric to a final moisture content of 43.97%.

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