Evaluation of Thermal Efficiency of a Rotary-Type Paddy Dryer Using an LPG Gas Burner

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Abstract

This study aims to analyze the effect of varying drying temperatures on moisture reduction, energy consumption, and energy efficiency in rice drying using an LPG-fueled rotary dryer. The drying temperatures applied were 45°C, 55°C, and 65°C. The results showed that increasing the drying temperature accelerated the reduction of rice moisture content at each time interval. The highest drying rate occurred at 65°C, indicating that it took a shorter time to reach low moisture content compared to 55°C and 45°C. This increase in drying rate was due to a higher thermal gradient and a greater vapor pressure difference between the rice and the drying air, which increased heat and mass transfer. However, higher drying temperatures also resulted in greater total energy consumption, with the highest energy consumption occurring at 65°C. Nevertheless, energy efficiency tended to increase with increasing temperature, from approximately 25% at 45°C to almost 27% at 65°C, indicating more effective utilization of thermal energy for water evaporation.

Keywords: paddy, rotary dryer, LPG, energy efficiency

Abstrak

Penelitian ini bertujuan untuk menganalisis pengaruh variasi temperatur pengeringan terhadap penurunan kadar air, konsumsi energi, dan efisiensi energi pada pengeringan gabah menggunakan pengering tipe rotary berbahan bakar gas LPG. Variasi temperatur pengeringan yang diterapkan adalah 45°C, 55°C, dan 65°C. Hasil penelitian menunjukkan bahwa peningkatan temperatur pengeringan mempercepat penurunan kadar air gabah pada setiap interval waktu. Temperatur 65 °C menghasilkan laju pengeringan tertinggi sehingga waktu yang dibutuhkan untuk mencapai kadar air rendah menjadi lebih singkat dibandingkan temperatur 55°C dan 45°C. Peningkatan laju pengeringan ini disebabkan oleh meningkatnya gradien panas dan perbedaan tekanan uap air antara gabah dan udara pengering yang mempercepat perpindahan panas dan massa. Namun, peningkatan temperatur juga menyebabkan konsumsi energi total semakin besar, dengan konsumsi energi tertinggi terjadi pada temperatur 65 °C. Meskipun demikian, efisiensi energi cenderung meningkat seiring kenaikan temperatur, dari sekitar 25 % pada 45 °C menjadi mendekati 27 % pada 65 °C, yang menunjukkan pemanfaatan energi panas yang lebih efektif untuk proses penguapan air.

Kata kunci: gabah, pengering rotary,LPG, efisiensi energi

1. Introduction

Drying is a crucial step in the paddy industry as it helps to reduce moisture content in the grains (Jimoh Kabiru, 2023), preventing mold growth and ensuring proper storage [1]. Proper drying enhances rice quality by improving its cooking properties and flavor. Moreover, the drying process extends the shelf life of rice and minimizes post-harvest losses. [2]. Overall, the drying process plays a vital role in maintaining the quality and profitability of the paddy industry. By effectively drying the grains, farmers can ensure that their product meets market standards and commands higher prices. Additionally, using the right drying techniques can help prevent the development of aflatoxins, toxic substances produced by molds that can contaminate rice [3]. By investing in efficient drying methods, paddy farmers can not only improve the quality of their product but also increase their overall profitability in the long run. Some rice drying methods include sun-drying, mechanical drying, and parboiling. Sun-drying is a traditional method where harvested rice grains are spread out on mats or concrete surfaces to dry in the sun [4]. While this method is cost-effective, it is highly dependent on weather conditions and can be time-consuming.

An example of a mechanical rice dryer is a continuous-flow dryer, which utilizes heated air to rapidly and efficiently reduce the moisture content of rice grains. This method is more reliable than sun-drying and can help farmers

avoid losses due to unpredictable weather. Parboiling is another drying method that involves soaking rice in water before drying. This process enhances the texture and preserves the nutritional quality of rice, contributing to its widespread preference among consumers. Overall, investing in efficient drying methods can not only improve rice quality but also increase the market value of the product, ultimately benefiting rice farmers in the long run. Flat-Bed Dryers are another popular option for drying rice [5]. These dryers consist of a flat-bed where rice is spread out in a thin layer and hot air is blown through to remove moisture. This method is effective in evenly drying the rice and can be easily monitored and controlled to ensure optimal results. Furthermore, flat-bed dryers offer higher energy efficiency than conventional drying methods, making them an economical option for farmers seeking to optimize their drying operations. By using a flat-bed dryer, farmers can enhance productivity and ensure a consistent supply of high-quality rice to meet market demands.

Vertical dryers, on the other hand, are designed with a vertical chamber where rice is stacked in layers, and hot air is circulated from the bottom up [6]. This technique enables a greater quantity of rice to be dried simultaneously, making it ideal for large-scale operations. Vertical dryers also have the advantage of being more space-efficient, as they can be stacked vertically to save floor space. Overall, both flat-bed and vertical dryers offer significant benefits for farmers seeking to improve their drying operations. Flat-bed dryers are ideal for small-scale operations and support a consistent supply of high-quality rice, while vertical dryers are more appropriate for large-scale applications because of their greater drying capacity and more efficient use of space. Ultimately, the choice between the two types of dryers will depend on the specific needs and scale of the farm. Fluidized Bed Dryer, on the other hand, offers a different drying method that involves suspending the rice in a stream of hot air, allowing for even drying and preventing clumping [7]. This method is often preferred for delicate grains or products that require gentle handling during the drying process. Fluidized bed dryers are also known for their energy efficiency and ability to quickly dry large quantities of rice [8]. Additionally, they have the added benefit of producing a more uniform final product compared to traditional rotary dryers. This makes them ideal for farms that prioritize quality and consistency in their rice production. Moreover, fluidized bed dryers are simpler to clean and maintain, which minimizes downtime and enhances overall drying efficiency. Rotary dryers are another common option for drying rice, especially for smaller operations or farms with limited space [9]. These dryers work by tumbling the rice in a rotating drum, allowing for even drying. Although they are less energy efficient than fluidized bed dryers, they remain effective in removing moisture from rice grains. However, one drawback of rotary dryers is that they can sometimes lead to uneven drying, resulting in a less consistent final product. Additionally, they may require more frequent maintenance and cleaning compared to fluidized bed dryers. Despite these challenges, rotary dryers remain a popular choice for many farmers due to their simplicity and versatility in the drying process. Overall, rotary dryers are a reliable and cost-effective option for drying grains [10,11]. Their ability to evenly tumble and dry the rice makes them a popular choice among farmers looking for a straightforward and efficient drying method. While they may require more maintenance and cleaning, the benefits of using a rotary dryer often outweigh the drawbacks.

2. Research materials and methods

This experimental study aimed to assess the effect of varying drying temperatures on the performance of a rotary dryer in the grain drying process. Drying was conducted at three drying air temperatures: 45°C, 55°C, and 65°C, with other operating parameters such as grain mass, air flow rate, and drum rotation speed kept constant. Temperature variation was used as the primary treatment to determine the characteristics of the drying process at different temperature conditions.

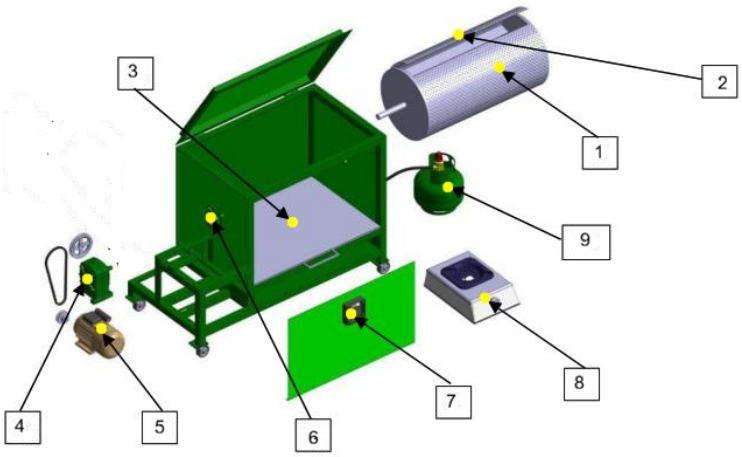


Figure 1. rotary dryer schematic. 1.rotary cylinder, 2.cylinder cover, 3.heating plate, 4.gearbox, 5.electric motor, 6.bearings, 7.exhaust fan, 8. gas stove, 9. LPG gas

The research materials and equipment included paddy grains, LPG, a household gas stove, a K-type thermocouple, a data logger, and a rotary dryer. The rotary dryer used iron plates, stainless steel plates, a steel axle, and a steel box. It was equipped with an exhaust fan, transmission system, rubber insulation, a gearbox, trolley wheels, a drying cylinder, and an electric motor. The rotary drying chamber had a cylinder inner diameter of 400 mm and a length of 800 mm. The research was conducted according to the dryer design shown in Figure 1.

The dryer's design is compact, meaning the dryer's components are integrated and housed in a single unit. A cylindrical drying chamber (circular cylinder) is located inside a non-circular cylinder. A non-circular fixed cylinder is located outside the rotary cylinder, equipped with an exhaust fan. Corn is dried inside the rotary cylinder chamber, and the corn rotates with the rotation of the rotary cylinder. The cylinder rotates using an electric motor through a gear transmission. The cover of the rotary cylinder serves to inlet and outlet of the food. The walls of the rotary cylinder are designed with small holes, resulting in a rough inner surface. The rough internal surface of the tube promotes a more effective heat exchanger and a better heat transfer rate than smooth tubes [12]. During the drying process, the mass and moisture content of the grain are periodically measured until it reaches a safe storage moisture content. The data obtained is used to determine the drying rate based on the change in water mass over time. Furthermore, energy consumption during the drying process is recorded to calculate drying energy efficiency, which is the ratio of the energy used to evaporate water to the total energy used by the drying system. The test data were analyzed quantitatively and comparatively to evaluate the effect of variations in grain mass on drying rate, moisture content reduction, and energy efficiency of the rotary dryer. The results were analyzed based on the theory of heat and mass transfer in the drying process of agricultural materials.

The total heat used in the drying process is Q (kJ), as in equation 1.

$$Q_{use} = Q_1 + Q_2 \quad (1)$$

Q_1 is the sensible heat of the material (kJ). Q_2 is the heat to evaporate the water of the material (kJ) [13]. Q_1 is obtained based on the mass, specific heat, and temperature of the material, as presented in equation 2.

$$Q_1 = m \cdot C_p \cdot \Delta T \quad (2)$$

m is the total mass of grain (kg), ΔT is the difference between the dryer temperature and the ambient temperature, and C_p is the specific heat of grain (kJ/kg °C) [14].

$$C_p = 1110 + 44{,}8\, M_w \quad (3)$$

M_w is the moisture content of the grain (%). The energy efficiency of the dryer is calculated based on equation 4

$$\eta = \frac{Q_{use}}{Q_{in}}\, x\, 100\% \quad (4)$$

3. Results and Discussion

The initial moisture content of the rice as sample in the LPG rotary dryer test in this study was 23%. The rice was dried to a maximum moisture content of 12.25%, based on guidelines from the National Standardization Agency of the Republic of Indonesia. The general quality requirement for maximum rice moisture content is 12%. Figure 2 shows that increasing the drying temperature from 45°C to 65°C accelerated the decrease in rice moisture content at each time interval. At 65°C, the moisture content decreased most rapidly, so the time required to reach low moisture content was shorter than at 55°C and 45°C. This indicates that higher temperatures increase the heat gradient and water vapor pressure between the rice and the drying air, thereby increasing the drying rate. This phenomenon is in accordance with the principles of heat and mass transfer and is in line with the results of paddy drying research which showed that increasing the drying air temperature reduces drying time due to an increase in the drying rate [15].

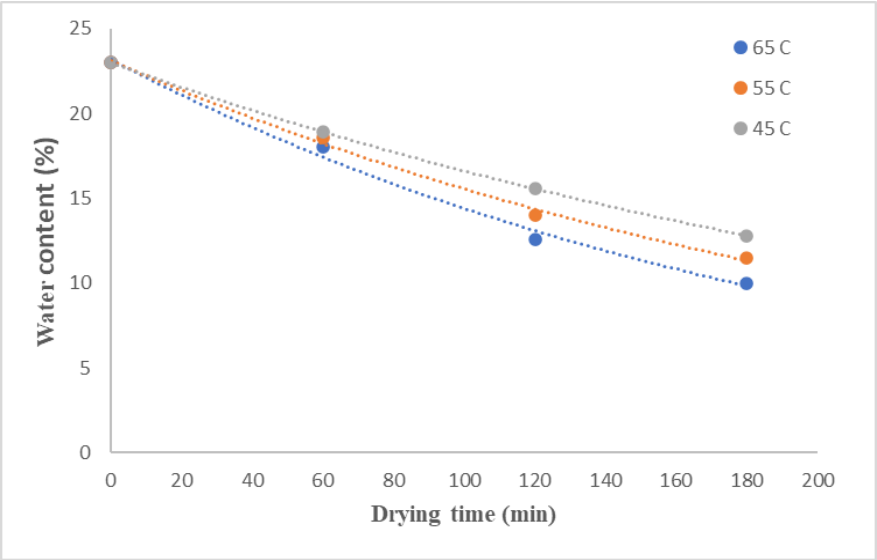


Figure 2. Paddy water content for 180 minutes drying time

Figure 3 shows the temperature profile during the drying process at a drying temperature of 55°C, where TP (plate temperature) is in the range of ±85–95°C, TR (drying chamber temperature), Tout (outlet air temperature), and TL (ambient temperature) are stable at around ±30°C for 180 minutes. At the beginning of drying, around 30 minutes there is an increase in temperature, because heat energy is used to heat the material and the drying chamber, after reaching stability, the temperature begins to remain constant. This pattern illustrates that the dryer heating system successfully maintains a plate temperature higher than the room temperature and the outlet air temperature, which means that heat energy is facilitated from the plate to the drying air to trigger the evaporation of grain moisture. The outlet air temperature tends to be close to room temperature, indicating a balance between heat supply and heat transfer to the dried material.

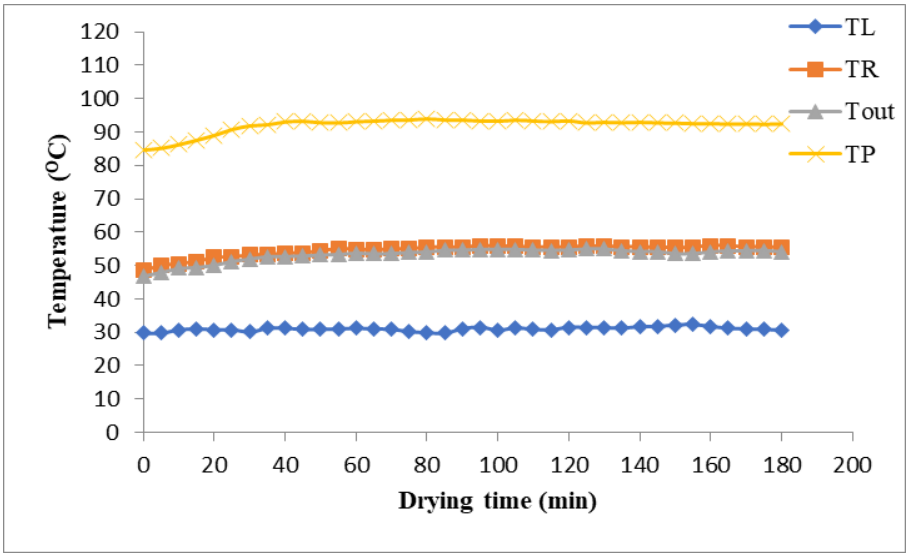


Figure 3. Temperature distribution of LPG energy rotary dryer

The longer the drying time, the greater the energy consumption. Figure 4 shows that increasing the drying temperature from 45°C to 65°C causes total energy consumption to increase with increasing drying time. At each time point, 65°C shows the highest energy consumption, followed by 55°C and 45°C. This occurs because at higher temperatures, the heating energy requirement increases to maintain the drying air temperature, even though the drying rate is generally faster. In other words, accelerated water evaporation is not always accompanied by a decrease in total energy consumption. A similar pattern has also been reported in grain drying, where increasing the drying air temperature accelerates moisture reduction but increases total energy consumption [16].

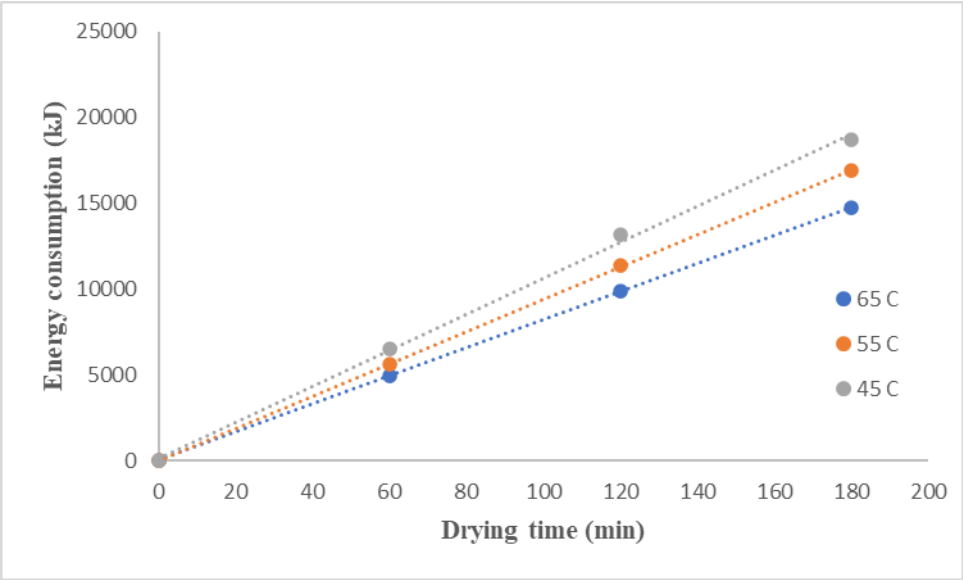


Figure 4. Energy consumption during the drying process

Increasing the drying temperature from 45°C to 65°C shows a trend towards increasing drying energy efficiency, marked by an increase in efficiency from approximately 25% at the lowest temperature to nearly 27% at the highest temperature. This condition indicates that at higher drying temperatures, the heat energy supplied to the system can be utilized more optimally for the process of evaporating water from paddy grains, so that the proportion of energy lost to the environment is relatively smaller. At 45°C, the drying process occurs at a slow rate, causing most of the heat energy to be absorbed to increase the temperature of the material and drying air without being followed by significant water evaporation. Conversely, at temperatures of 55°C and 65°C, the temperature difference and water vapor pressure between the paddy grains and the drying air become greater, so that the heat and mass transfer processes occur more intensively. This condition accelerates the release of free water and bound water in the material, which ultimately shortens the drying time. As a result, the ratio between the energy actually used to evaporate water to the total energy supplied becomes higher. This trend of increasing energy efficiency is in line with the research results of [17], who reported that increasing the drying air temperature in the range of 40–60 °C can increase the energy efficiency of rice drying due to shorter drying time and an increase in the ratio between useful energy and input energy.

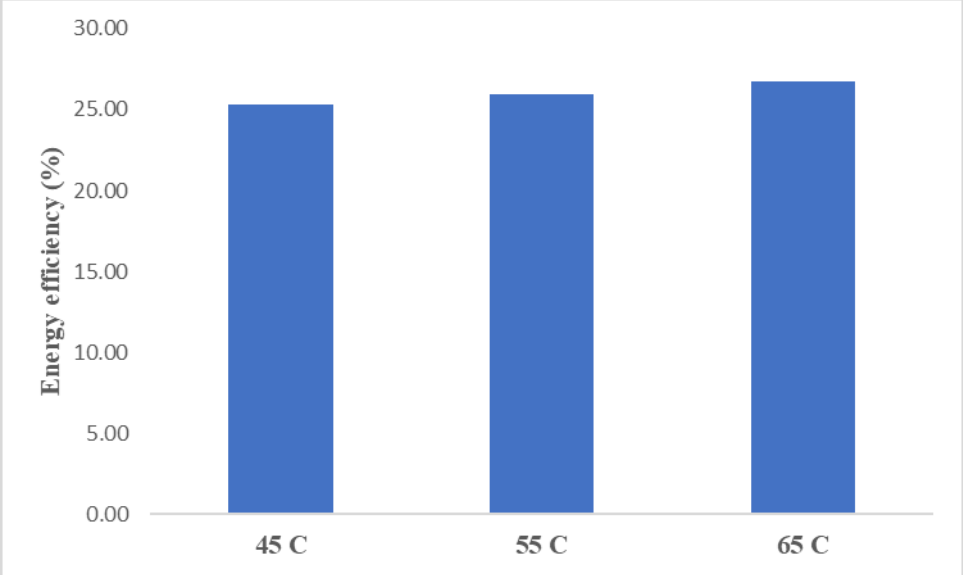


Figure 5. dryer energy efficiency at various drying temperatures

4. Conclusion

Based on the results of this study, it can be concluded that drying temperature has a significant effect on moisture reduction behavior, energy consumption, and energy efficiency in an LPG-fueled rotary paddy dryer. The initial paddy grain moisture content was 23% and was successfully reduced to a final moisture content of at least 12.25%, which is in accordance with the maximum moisture content recommended by the National Standardization Agency of the Republic

of Indonesia. Increasing the drying temperature from 45°C to 65°C was proven to accelerate the reduction of paddy moisture content at all observed time intervals. The fastest drying rate occurred at 65°C, resulting in a shorter drying time compared to 55°C and 45°C, due to the higher thermal gradient and the difference in water vapor pressure between the paddy grain and the drying air, which enhances the heat and mass transfer processes. Analysis of the temperature profile at 55°C showed stable operating conditions, where the plate temperature remained significantly higher than the drying chamber and outlet air temperatures, indicating effective heat transfer from the heating plate to the drying air and subsequently to the grains. However, increasing the drying temperature also leads to an increase in total energy consumption, as more heating energy is required to maintain the high drying air temperature, despite the faster drying rate. This confirms that accelerated moisture evaporation does not necessarily correlate with a reduction in total energy use. Nevertheless, drying energy efficiency showed an increasing trend with temperature, rising from approximately 25% at 45°C to nearly 27% at 65°C. This increase indicates that at higher temperatures, a greater proportion of the applied thermal energy is effectively utilized for moisture evaporation, while relative energy losses decrease. Overall, higher drying temperatures offer a compromise between faster drying rates and increased energy consumption, but with improved energy efficiency. These findings suggest that the optimal drying temperature should balance drying time, energy use, and efficiency to achieve effective and energy-efficient grain drying.

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