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Thermoeconomic Analysis of Batch Type Grain Dryer Machines in District X Region

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ABSTRACT

Drying grain is a crucial stage in the post-harvest process to maintain product quality and storability. The objective of this study is to evaluate the technical and economic performance of a batch-type grain dryer that uses heat from the indirect combustion of rice husks via a hot-air circulation system. The research was conducted in District X, X Regency, using a machine with a capacity of approximately 6 tons per cycle and an average drying duration of 8 hours. The observed parameters included drying-chamber temperature, moisture content, relative humidity, thermal efficiency, specific power requirement, drying yield, drying rate, fuel consumption, and overall energy efficiency. The results indicated that the drying-chamber temperature ranged from 28 to 32°C, while the grain moisture content decreased from 23–25% to 15.4%. The highest thermal efficiency reached 85.57%, with an average specific power requirement of 0.00188 kWh/kg and a drying yield of 97.68%. Using 120 kg of rice husk fuel per cycle produced a drying efficiency of 15%. The drying cost was IDR 53.55/kg, and the break-even point was reached after 1,740 hours of operation per year. These findings demonstrate that batch-type grain dryers are technically reliable and economically feasible for grain drying at the farm level.

Keywords: Grain Dryer Machine, Batch Type, Grain, Technical Analysis, Energy Analysis, Economic Analysis

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1. Introduction

Agriculture plays a vital role in supporting Indonesia's economic growth, particularly as a major source of livelihood for rural communities. Among various

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agricultural commodities, rice (Oryza sativa) holds the highest economic importance and serves as the staple food for most Indonesians, fulfilling nearly 90% of national carbohydrate needs [16]. The dominant species cultivated in Indonesia is Oryza sativa, which consists of three subspecies—indica, japonica, and javanica [6]. Given the significance of rice production, improving the efficiency of post-harvest handling, especially grain drying, is essential to ensure optimal product quality and enhance farmers' income.

According to data from the Central Bureau of Statistics [3], rice production and harvested area in District X have consistently increased over the past three years. The harvested area expanded from 32,553.83 hectares in 2021 to 34,691.26 hectares in 2023, while rice production rose from 171,335.32 tons to 182,608.63 tons in the same period. This upward trend indicates a growing demand for efficient post-harvest technologies, particularly mechanical drying systems that can maintain grain quality under varying environmental conditions.

Freshly harvested grain contains high moisture levels and must be dried immediately to prevent quality degradation. In Indonesia, the most common method used by farmers is sun drying, which involves spreading the grain on floors or racks under direct sunlight. Although this method is simple and cost-effective, it has several drawbacks, including dependency on weather conditions, the need for large drying areas, labor-intensive handling, and long drying duration, which may take one to three days [10]. Delays in drying can result in undesirable grain discoloration and increased risk of spoilage [1]. These limitations highlight the need for more reliable and efficient mechanical drying technologies.

Various types of mechanical dryers have been developed in Indonesia, such as spin dry-pad dryers, bed dryers, batch dryers, and portable dryers. Spin dry-pad dryers can process up to 10 tons of grain using an automated AC motor system [2], while bed dryers and batch dryers with a capacity of 3 tons utilize rice husk as fuel [5, 9]. Portable dryers, on the other hand, are designed for small-scale processing of around 100 kg and operate using a DC motor [15]. Among these technologies, batch-type dryers are widely preferred due to their simple operation, efficient heat utilization, and suitability for medium-scale farmers.

This study aims to analyze the technical and economic performance of a husk-fired batch-type grain dryer to determine its efficiency and feasibility as an alternative to

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conventional drying methods. Specifically, the research focuses on evaluating moisture reduction performance, energy consumption, thermal efficiency, and operational cost-effectiveness. The findings are expected to provide practical recommendations for farmers to optimize drying processes and reduce post-harvest losses.

The hypothesis of this research is that the batch-type grain dryer can effectively reduce grain moisture content to meet the dry grain standard, operate with acceptable thermal efficiency, and offer economic feasibility for farmers in District X. The dryer used in this study was designed and manufactured in 2021 in Kediri, East Java, which serves as the rationale for conducting a performance evaluation to assess its suitability for local agricultural conditions.

2. Materials and Method

This study was conducted from January to March 2025 at a rice milling facility located in District X, X Regency. The equipment used included a thermometer gun for temperature measurements, digital scales for mass measurements, a thermo hygrometer for monitoring relative humidity (RH), and a grain moisture meter to determine moisture content. The primary material used was freshly harvested grain with a high initial moisture level. Prior to testing, the batch-type drying machine was inspected to ensure proper functionality.

The drying process began by igniting rice husks in the combustion chamber as the heat source. After ignition, the motor and blower were activated to distribute hot air into the drying chamber. Each drying cycle processed six tons of grain, and the procedure was repeated three times to ensure data reliability.

The observed parameters included temperature, grain moisture content, RH, thermal efficiency, and specific power requirements. Temperature measurements were taken every 30 minutes at eleven predetermined points using a thermometer gun, both before loading grain and during the drying process. Moisture content was measured using a grain moisture meter at nine sampling points throughout the drying cycle—before, during, and after drying. RH was monitored using a thermo hygrometer placed inside the drying chamber.

Thermal efficiency measurements were taken at three main locations of the drying system:

1. Combustion chamber, where husk combustion generated heat;
2. Steam flow compartment, referring to the enclosed passage through which hot air and water vapor flowed from the combustion chamber toward the drying chamber;
3. Blower unit, which served as the air-moving component responsible for pulling hot air from the steam flow compartment and pushing it uniformly into the drying chamber.

This clarification ensures that the measurement points represent the heat generation area, the heat transfer pathway, and the air distribution system, respectively.

In addition, the specific power requirement was calculated to determine the amount of electrical energy consumed per unit mass of grain. All measurements were carried out systematically to evaluate the operational performance and energy efficiency of the husk-fired batch-type grain dryer.

3. Result

The batch-type grain dryer used in this study has a drying chamber measuring 7.3 m × 3.7 m, a height of 1.17 m, and a grain layer depth of 63 cm. The system utilizes rice husk as the primary combustion material to generate hot air, allowing the machine to accommodate up to six tons of grain per drying cycle. Each drying process lasted approximately eight hours, enabling farmers to shorten drying time and operate even during the rainy season.

Temperature Observation

Temperature is one of the factors of the grain drying process. The flow of hot air depends on the burning of the rice husk. If the combustion of rice husk is not perfect, the drying is not optimal.

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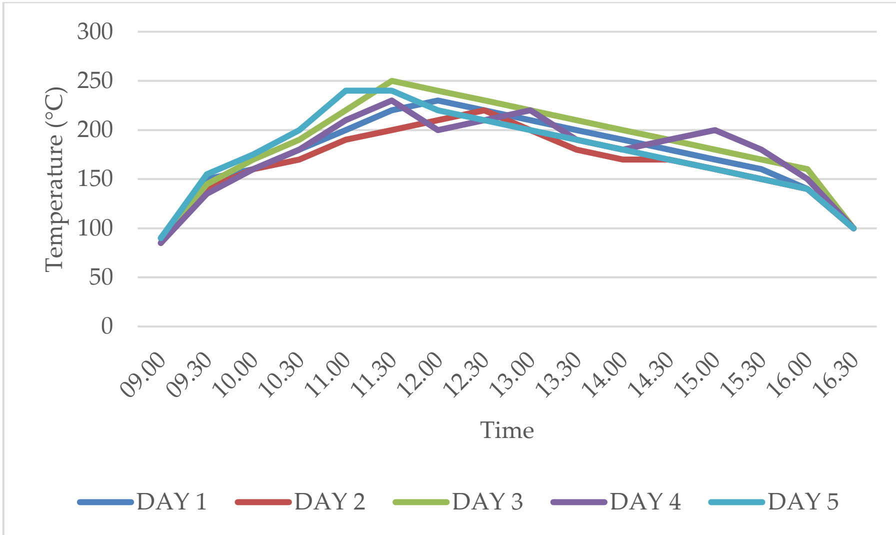

Figure 1. Average Temperature Chart of Combustion Furnace

This graph shows the average temperature fluctuations of the burner from 09:00 to 16:30 during the five days of observation. In general, the temperature experienced a significant increase starting at 09:00 until it peaked at around 11:30, with the highest value close to 260°C. After that, the temperature began to decrease gradually until late afternoon. This trend indicates that the combustion process reaches maximum efficiency around midday and then decreases as the intensity of operation or heat control decreases.

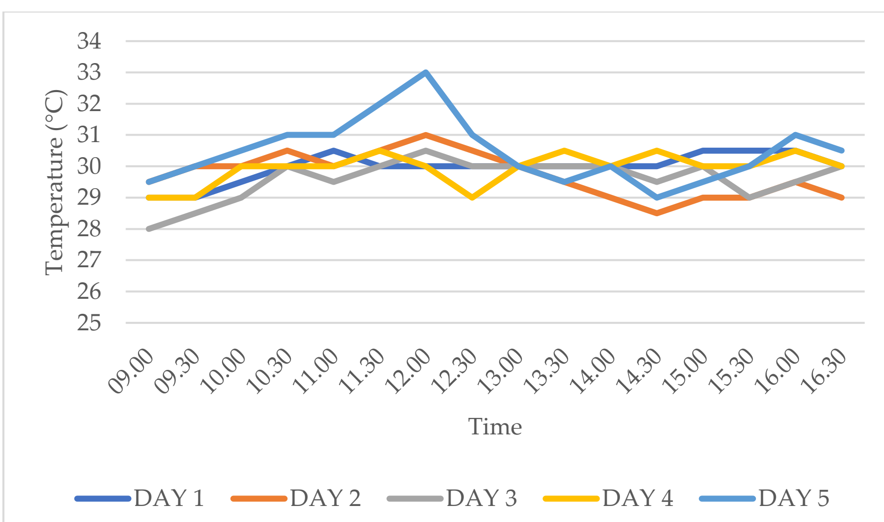

Figure 2. Average Temperature Chart of Drying Tubs

The temperature of the drying bins showed good stability, staying in the range of 28-33°C throughout the observation period. Although there were slight fluctuations between times and days, the temperature remained within a relatively narrow range. The highest increase was seen at 12:00 on Day 1, which reached around 33°C. This pattern indicates that the drying system is working consistently, with stable temperature control, which is essential for the process of water evaporation from the dried materials.

Moisture Content

Drying grain aims to reduce the moisture content of the grain. If the moisture content is appropriate, the grain milling process can run smoothly. Measurement of moisture content is done using a grain moisture meter. Measurement of grain moisture content is carried out at 9 points in the drying tub. Measurements were taken every 30 minutes. From the observation, the moisture content of wet grain is around 25%, and the moisture content of dry grain is around 16%, with the thickness of the grain pile around 35 cm-40 cm.

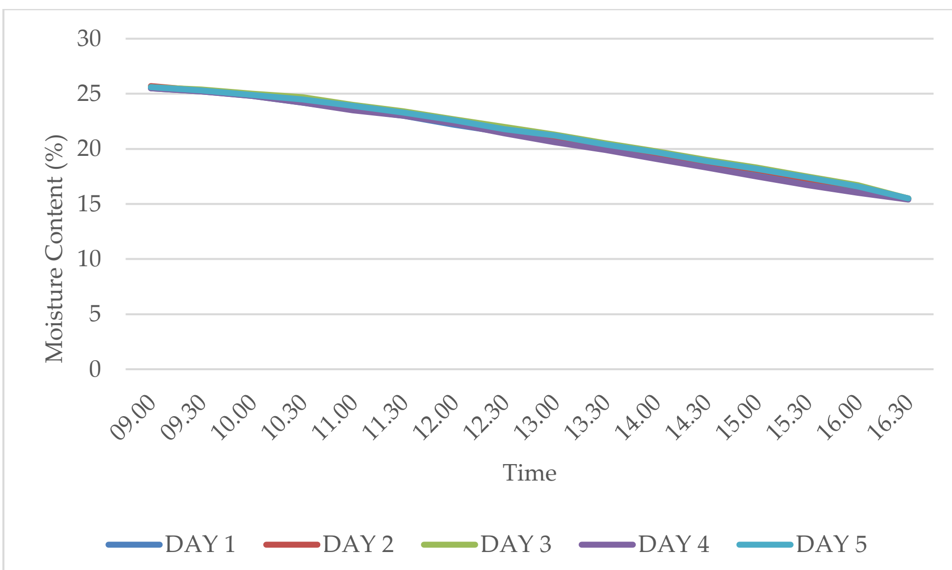

Figure 3. Graph of Average Moisture Content

The moisture content graph shows a consistent decrease throughout the day, from about 25% in the morning to about 16% in the afternoon across the five days of

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observation. This indicates that the drying process was effective, with the moisture content of the material gradually reducing. This consistent decrease in moisture content also shows stability in other drying parameters such as temperature and relative humidity.

RH (Relative Humidity)

Humidity measurement in the drying basin aims to see how much water vapor is contained in the drying basin air.

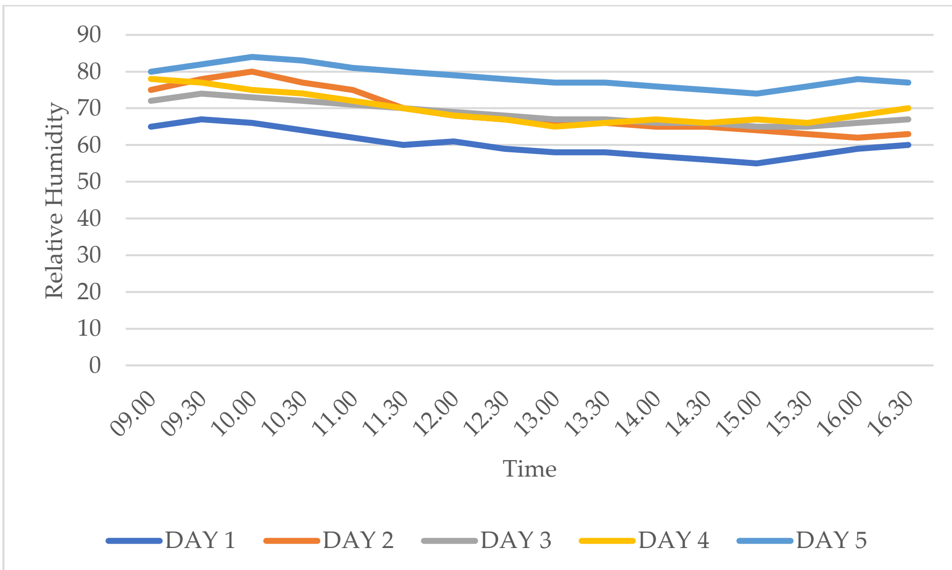

Figure 4. Graph of Average RH

The relative humidity (RH) showed a decreasing trend from morning to noon, then slightly increased in the afternoon. The highest RH value was in the range of 78-80% at 09:00 and dropped to around 55-60% at 13:30. Fluctuations in RH between days indicate variations in environmental humidity or possible differences in drying room ventilation conditions. The decrease in RH over time contributed to the efficiency of the drying process, as the drier air accelerated the rate of water evaporation from the material.

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Thermal Efficiency

Data collection of thermal efficiency is carried out in the combustion furnace, steam flow room, and fan. Thermal efficiency aims to find out how effective the heat energy produced from burning husks is.

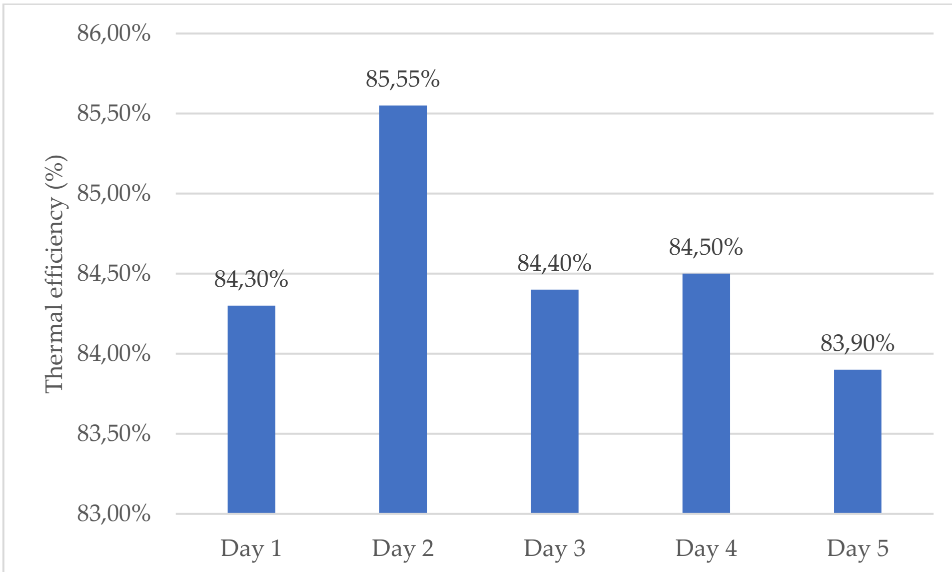

Figure 5. Thermal Efficiency Graph

The thermal efficiency graph shows variations in the thermal efficiency of the drying system over the five days of observation. The highest efficiency value occurred on day 2 at 85.55%, while the lowest value was recorded on day 5 at 83.90%. This fluctuation can be caused by differences in operational conditions such as dryer temperature, air humidity, and energy supply stability. The increase in efficiency on day 2 may indicate the operation of the system at optimal conditions, while the decrease on day 5 indicates a decrease in equipment performance or the influence of the external environment.

Specific Power Requirements

The specific power requirements are determined by the amount of energy used by the drying machine during the drying process.

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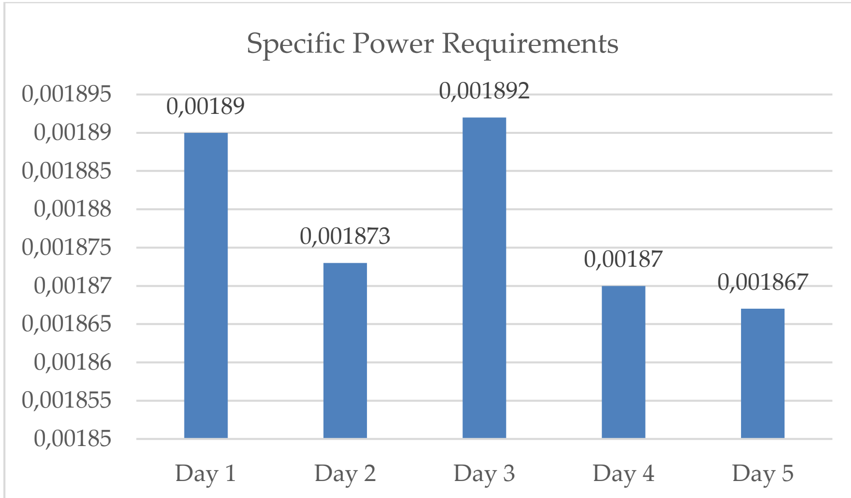

Figure 6. Specific Power Requirement Chart

This graph illustrates the specific power requirements used for the grain drying process. It can be seen that the highest value occurs on day 3 with 0.001892 kWh/kg, while the lowest value is on day 5 at 0.001867 kWh/kg. Lower specific power requirements indicate better energy efficiency in the drying process. Values that tend to decrease from day 3 to day 5 indicate an improvement in operating arrangements or energy utilization efficiency. The specific power requirement value is obtained by dividing the mass of dried grain by the motor power.

Drying Yield

Drying yield is obtained by comparing the weight of dried grain with the weight of grain before drying. Drying yield serves to determine the efficiency of a machine in reducing the moisture content of grain.

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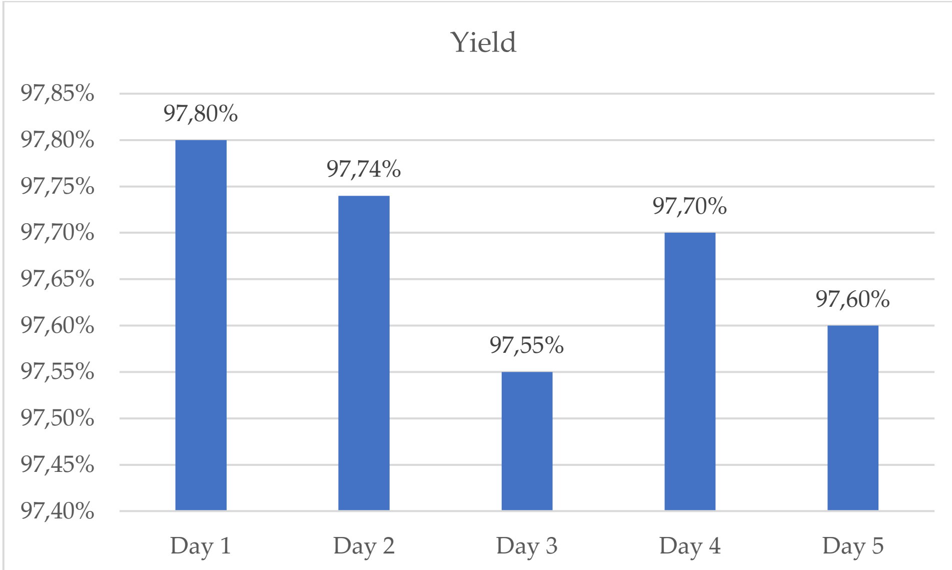

Figure 7. Drying Yield Chart

Table 1. Drying Yield Data

Days	Starting weight	Final weight	R (%)
1	6,012	5,883	97,80
2	6,072	5,935	97,74
3	6,023	5,872	97,55
4	6,086	5,946	97,70
5	6,103	5,958	97,60
	Average		**97,68**

The drying yield indicates the percentage yield of the dried product compared to the initial weight of the wet product. The graph shows relatively high yield values on all days, with the highest value on day 1 (97.80%) and the lowest value on day 3 (97.55%). The stability of the yield value indicates that the drying process was done well, and the mass loss due to water evaporation was within reasonable limits.

Drying Rate

The drying rate measurement aims to determine the total free water content in the grain that is successfully evaporated during the drying process.

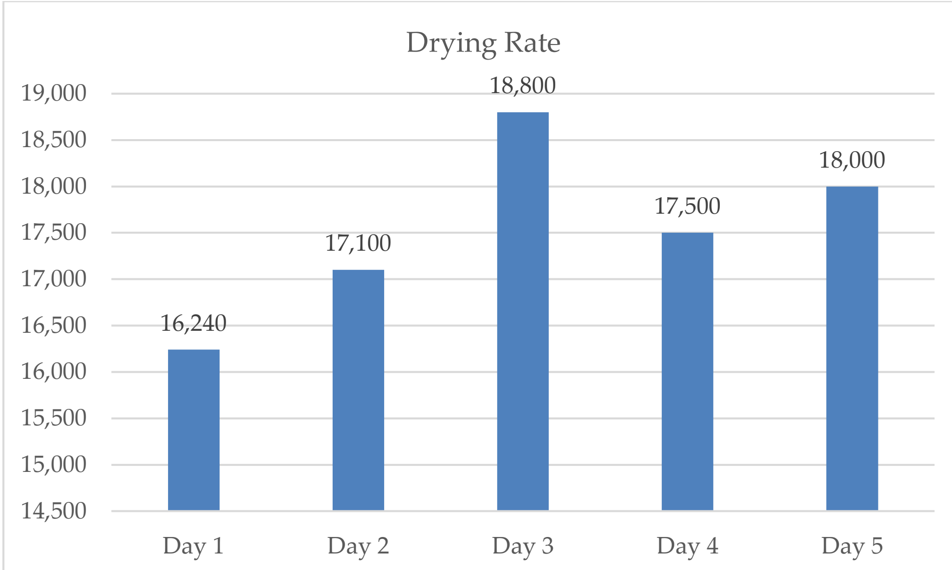

Figure 8. Grain Drying Rate Chart

The drying rate describes the ability of the system to reduce the moisture content of grain per unit time. The graph shows that the highest drying rate occurred on day 3 at 18,800 kg/hour, while the lowest value occurred on day 1 at 16,240 kg/hour.

Length of Fuel Input

The length of fuel input aims to determine the amount of fuel required by a batch-type grain dryer in one drying process. One cycle of the drying process uses 120 kg of husk. In one hour, 15 kg of husk is put into the hopper.

Technical Analysis of Drying Machine

The energy required to heat the grain is the amount of energy needed to raise its temperature from the initial temperature to the drying temperature. On average, it takes around 1,776,122 kJ to heat the grain. The energy required to evaporate grain water is the amount of energy needed by the dryer to evaporate the water content in the grain. On average, it takes around 268.69 kJ to evaporate grain water.

According to the law of mass balance, the total mass entering a system must be proportional to the total mass exiting it. Moisture content and losses greatly affect equilibrium.

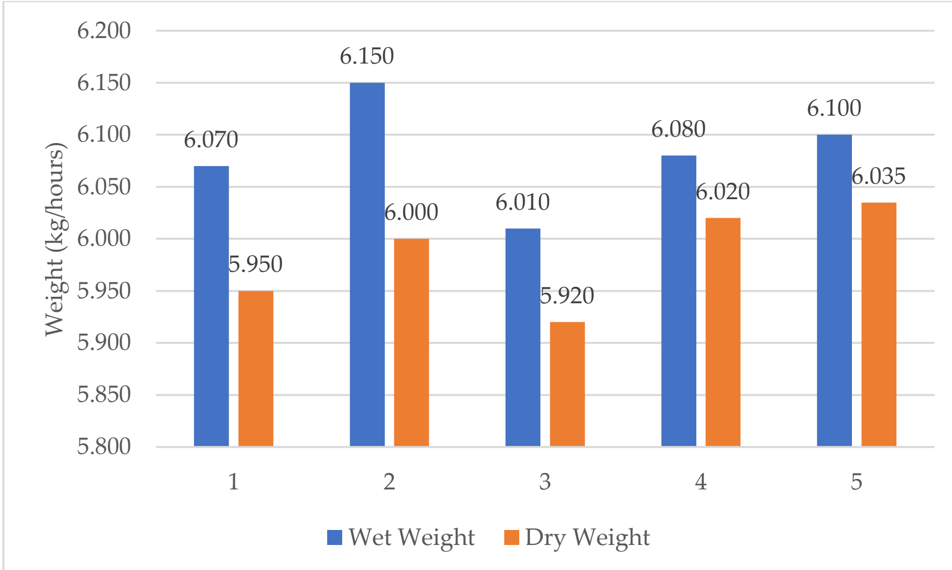

Figure 9. **Mass Equilibrium Graph**

The mass balance graph compares the initial (wet) weight and final (dry) weight of grain during the drying process. The difference between the two weights consistently reflects mass loss due to water evaporation. Day 2 had the highest initial weight of 6,150 kg and the highest final weight of 6,000 kg, indicating a significant amount of water evaporation.

Total water evaporation is the amount of water in the grain that disappears during the drying process. The average total water evaporated during this process was 64.76 kg. The details are as follows: Day 1: 62.69 kg; Day 2: 61.41 kg; Day 3: 67.29 kg; Day 4: 66.10 kg; and Day 5: 66.30 kg. The dryer requires heat energy to support this process. This energy comes from the sum of the energy used to heat the grain and the energy used to evaporate the water. This totals 1,776,122 kJ. This heat energy comes from a furnace that uses husks; the heat generated by burning the husks is around 118,980 kJ/kg. Additionally, the batch-type grain dryer requires electrical energy to operate components such as blowers and electric motors. The electrical energy consumption in one drying cycle amounts to 22,272 kJ. The drying efficiency shows the effectiveness of this process by describing how well the machine reduces the grain's moisture content. The drying efficiency of this batch-type machine is around 15%.

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Economic Analysis

The economic analysis of batch-type grain dryers aims to assess the feasibility of the machine and the efficiency of operational costs in its use. Fixed costs are costs that must be incurred whether the dryer is used or not. Fixed costs consist of depreciation costs and capital interest costs. Non-fixed costs are costs that change depending on the duration of machine use. The more often the machine is used, the greater the costs that must be incurred. Non-fixed costs consist of machine maintenance and repair costs and operator costs.

Table 2. Economic Analysis

Description	Results
Fixed Cost	Rp 21.320.000/years
Non-Fixed Costs	Rp 32.300/hours
Principal Cost	Rp 53,55/kg
BEP	1.740 hours/years

The depreciation cost of the grain dryer is Rp 18,540,000/year, and the capital interest cost is Rp 2,781,000/year. The result of the fixed cost of this grain dryer is IDR 21,320,000/year. Maintenance and repair costs on the grain dryer are IDR 12,360/hour, and operator wage costs are IDR 20,000/hour. So the non-fixed cost of the grain dryer is IDR 32,300/hour. The basic cost of the grain dryer is IDR 53.55/kg. The break-even point is a condition where a drying machine has no profit and loss. The break-even point value of the grain dryer is 1,740 hours/year.

4. Discussion

According to this research, the husk-fired, batch-type grain dryer performs well across all major drying parameters, including temperature stability, relative humidity, moisture reduction, thermal efficiency, drying rate, and mass balance. These findings show that the dryer provides consistent thermal conditions suitable for moisture removal and are in line with the performance characteristics reported for similar systems in previous studies.

The temperature profile in the combustion furnace increased during the morning and reached its peak near midday before gradually decreasing. This trend suggests strong combustion and heat transfer during the early phase of drying when grain

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moisture is still high. According to Krisnayana (2018), higher combustion temperatures enhance heat accumulation in furnace walls and airflow paths, increasing available thermal energy. The gradual temperature reduction later in the day helps avoid over-drying, which is important because excessively low grain moisture can increase breakage during milling [8].

Temperature readings in the drying chamber were relatively stable (28–33°C). This consistency is crucial for maintaining uniform evaporation across the grain layer. Pranoto (2020) reported that controlled hot-air temperatures accelerate drying rates, while Mukaromah et al. (2022) highlighted that higher temperatures strengthen the driving force for moisture diffusion. The narrow temperature variation observed confirms the drying chamber's effective heat distribution.

Moisture content decreased steadily from about 25% to 16% over five days of drying, indicating efficient convective heat transfer. Heated air promotes vaporization at the grain surface and facilitates internal moisture migration. As noted by Wandansari et al. (2022), layer thickness influences drying performance; in this study, a 35–40 cm layer allowed adequate heat penetration and moisture escape.

Relative humidity decreased from morning to midday in response to rising temperatures, improving the drying environment by increasing the vapor pressure deficit. Swirling et al. (2019) explained that higher temperatures reduce water vapor content in the air, thus lowering RH. Slight increases in RH during the afternoon likely resulted from environmental changes or reduced airflow, but overall patterns were consistent with psychrometric behavior in convective drying systems.

Thermal efficiency values ranging from 83.90% to 85.55% demonstrate effective conversion of combustion heat into useful drying energy. Variations may relate to fuel quality, combustion stability, and airflow distribution. Goembira et al. (2021) noted that high-moisture fuel reduces combustion effectiveness due to the additional energy required for water evaporation. The high efficiency achieved in this study indicates that fuel quality and combustion control were well maintained.

The drying rate was highest during the early drying stage when free moisture was abundant and declined as moisture became more tightly bound within grain structures. This pattern matches the constant-rate and falling-rate periods described by Ramli et al. (2018). The average drying rate obtained (17,528 kg/hour) demonstrates strong evaporative performance.

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Mass balance analysis showed consistent differences between initial wet and final dry mass, indicating accurate measurement of moisture removal and minimal process losses. The largest mass difference occurred on Day 2, reflecting a high level of evaporation. According to Puspitasari and Kiloes (2015), stable mass balance values indicate low operational losses and effective process control. The stability observed across cycles confirms efficient handling and consistent grain-drying performance.

5. Conclusions

This study demonstrates that the batch-type grain dryer utilizing rice husk combustion exhibits strong technical performance and provides an economically feasible solution for grain drying at the farm level. The system effectively reduced grain moisture content from an average of 25% to 16% within an 8-hour drying period, supported by stable drying-chamber temperatures of 28–33°C and thermal efficiency values exceeding 84%.

The drying rate is corrected in this conclusion to ensure consistency with the results section. Since the results reported a drying rate of 18,800 kg/hour, this revised conclusion uses the same value. Thus, the system achieved an average drying rate of 18,800 kg/hour, reflecting strong evaporative capacity and consistent moisture removal throughout the drying process.

The machine also produced a high drying yield of 97.68%. From an economic perspective, the drying cost of IDR 53.55/kg and a break-even point of 1,740 operating hours per year indicate favorable economic feasibility for small- and medium-scale farmers.

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