

## Experimental study on energy performance of a mobile biomass-fueled drying furnace using sawdust

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### Abstract

The development of energy-efficient, mobile dryers using biomass fuel remains a challenge, particularly for rural agricultural applications. This study experimentally evaluates the energy performance of a mobile drying furnace fueled by sawdust, focusing on the effects of fuel feeder rotational speed (25, 30, and 35 rpm). Key performance metrics include temperature distribution, fuel consumption rate, thermal efficiency, and energy balance. The furnace is equipped with a screw conveyor, combustion chamber, and heat exchanger, with temperature monitored via IR thermometers. The highest thermal efficiency of 37.64% was achieved at 25 rpm, with a fuel consumption rate of 4.25 kg/h and total energy output of 110,144 kJ. At 35 rpm, energy output peaked at 188,369.12 kJ, but efficiency declined to 22.41% due to incomplete combustion. All settings-maintained outlet air temperatures between 43.08–46.08°C, suitable for grain drying. Energy balance analysis revealed that 80.92% of total input energy was transferred to the drying chamber at 35 rpm. These findings suggest that moderate feeding speeds (25–30 rpm) offer the best trade-off between efficiency and energy delivery, confirming the potential of mobile, sawdust-fueled systems for sustainable drying in off-grid settings.

### Keywords:

Biomass, efficiency, feeder rotating speed, fuel consumption, and fuel feeder

### 1 Introduction

Good product quality is obtained by developing modern drying technology. The development of energy-efficient dryers remains a challenge. Given the limitations of fossil raw materials, innovative, efficient dryers with renewable energy are highly recommended. The total amount of natural resources that can be utilized in the form of energy is called biomass. The biomass category includes wood, grass, rice husk, marine algae, microalgae, agricultural, forestry, and household waste [1]. The only organic or carbonaceous material among renewable energy sources is biomass, which allows biomass to be stored as fuel/biofuel [2]. A highly efficient alternative solution based on local wisdom in Indonesia, an agrarian country with most of the population being farmers, is a biomass-fueled stove. In rural areas, a lot of biomass waste is used as an alternative energy [3].

Firewood is a biomass energy with a caloric value of 4,320 kcal/kg. Firewood can be found in all corners of Indonesia and is easily obtained. The study conducted by the Ministry of Energy and Mineral Resources reported that the use of biomass stoves in Indonesia was as high as 24.6 million (40%). Wood has cellulose and hemicellulose. In these two factors, chemical energy is stored, which is potential energy that, when burned, can produce heat energy that can be utilized for household activities and other mechanical endeavors such as biomass-powered power generation machines [4].

In a biomass combustion furnace, combustion and chemical energy change reactions occur to produce heat. In agricultural countries such as Indonesia, Thailand, and the Philippines, simple biomass kilns have been employed to address drying issues. For a clean and hot flame, grain drying stoves make the air natural [5]. A good furnace design is to create perfect combustion; the combustion chamber in the furnace must pay attention to the flow pattern formed when the fluid (air, gas, and combustion products) passes through the bed of firewood [6]

The use of compacted biomass in combustion engines can significantly improve engine performance. Particles with a high surface area to volume ratio, commonly involved in dust explosion incidents, can be utilized as more efficient fuels for external combustion engines [7]. Well-controlled combustion experiments have shown that smaller biomass can accelerate combustion [8]. In addition, compacted biomass reduces the material's weight, increases the calorific value and energy efficiency, and helps minimize emissions during the energy conversion process [9].

Several researchers have conducted several studies of biomass-fueled and researched the performance of the furnace with coconut shell fuel sizes 2-4 cm and 5-10 cm [7]. Another variation is the distance of air holes from the bottom of the furnace, ranging from 10, 20, 30, and 40 cm. The performance of a biomass furnace with fuel in the form of palm oil waste, including shells, fronds, and fibers [10]. Previous research used a fixed-bed type furnace, so its use was less effective. The researchers designed a sawdust-fueled mobile drying furnace. Currently, a mobile drying furnace has been designed. The mobile drying furnace is designed to move wheels under the furnace from one place to another. Farmer group members can also use it to make the drying furnace effective. Testing the energy performance of mobile drying furnaces has not been carried out. This study aims to evaluate the energy performance of mobile drying furnaces fueled by sawdust.

## 2 Research methods

### 2.1 Materials

In this research, the tools used are an anemometer, a camera, a stopwatch, a tachometer, an IR thermometer, an analog scale, and a unit of mobile drying furnace. The drying furnace process is shown in Fig. 1. The material used in this research is sawdust biomass.

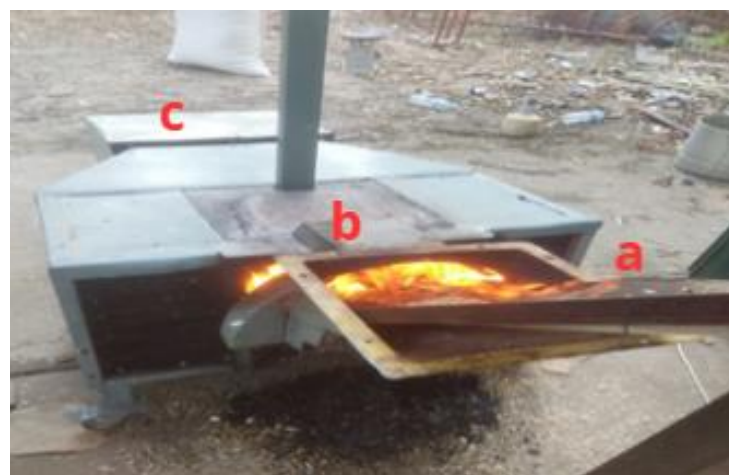


Fig. 1. Drying furnace process (a: fuel input, b: drying process furnace, c: outlet fun)

### 2.2 Implementation method

This research employs experimental methods and presents descriptive data. The treatment factors used are the rotating speed of the fuel feeder at 25, 30, and 35 rpm. Data is presented in the form of tables and graphs. The design of the mobile drying furnace and temperature measurement points can be seen in Fig. 2. The description in Fig. 2 are, 1. Screw conveyor, 2. Material dispensing channel, 3. Combustion chamber, 4. Heat exchanger, 5. Chimney, 6. Screw conveyor frame, 7. Furnace outlet channel, and 8. Mobilization wheel.

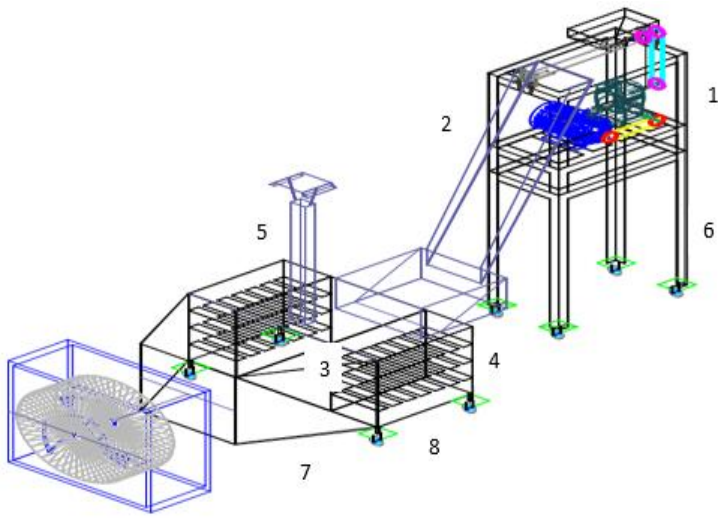


Fig. 2. Design of the mobile drying furnace

### 2.3 Method of work

The work stages used in this research are as follows:

1. Sawdust biomass to be burned is prepared and weighed, with a maximum of 2.5 kg per entry into the hopper.
2. Sawdust biomass is fed into the combustion chamber using a screw conveyor.
3. Sawdust biomass is burned to obtain heat.
4. During the combustion process, data were collected, including temperature at each measurement point, air flow velocity, fuel mass, and ash mass produced.
5. The combustion process for each treatment was conducted for 2 hours.
6. The hot air from burning sawdust biomass flows into the drying room.
7. Data analysis was conducted.

### 2.4 Observation parameters

The observation parameters in this study consist of temperature distribution, fuel consumption rate, furnace efficiency, and energy balance.

#### 1. Temperature distribution

Temperature distribution observations were made using an IR thermometer to determine the temperature distribution at the observation points. The temperature points observed in this study are the temperature in the feeder, the temperature in the combustion chamber, the temperature in the heat exchanger room, the temperature in the chimney, the temperature of the outlet furnace, and the temperature of the outlet fan.

#### 2. Fuel consumption rate

The fuel consumption rate is obtained by Eq. (1), where  $FCR$  is the sawdust fuel consumption rate (kg/h),  $w$  is the mass of sawdust fuel used (kg), and  $t$  is the combustion time (hours) [11]

$$FCR = \frac{w}{t} \quad (1)$$

#### 3. Furnace efficiency

The furnace efficiency is obtained by Eq. (2), where  $\eta_r$  is furnace efficiency (%),  $ma$  is mixed flow rate of fresh air and flue gas (kg/h),  $C_p$  is specific heat of air (kJ/kg.°C),  $T_1$  is ambient air temperature (°C),  $T_2$  is temperature of fresh air and flue gas mixture (°C),  $mf$  is sawdust feed rate (kg/h) [11]

$$\eta_r = \left[ \frac{ma C_p (T_2 - T_1)}{mf HHV} \right] \times 100 \quad (2)$$

#### 4. Energy balance

Energy balance is the equilibrium of energy in a system. Based on the first law of thermodynamics, which states that energy cannot be destroyed or created, it can only change its form. The formula for finding the energy balance is total energy = lost energy + accumulated energy [7]. The energy balance formula can be obtained from Eq. (3).

$$Q_t = Q_L + Q_a + Q_{net} \quad (3)$$

where  $Q_t$  is sawdust combustion energy (kJ),  $Q_L$  is Energy loss (kJ)  $Q_a$  is the energy absorbed by the furnace (kJ), and  $Q_{net}$  is the net energy generated by the stove that enters the drying chamber (kJ). Energy loss can be calculated using Eq. (4), where  $Q_L$  is energy loss (kJ),  $Q_1$  is heat loss through furnace walls,  $Q_2$  is heat lost in the chimney, and  $Q_3$  is Heat lost at the outlet.

$$Q_L = Q_1 + Q_2 + Q_3 \quad (4)$$

## 3 Results and discussion

### 3.1 Temperature distribution

The temperature distribution at each measurement point during the two-hour operation of the mobile drying furnace looks up and down or fluctuates, as presented in Figs. 3, 4, and 5. The amount of material fed causes this, and the amount of oxygen produced by each treatment has not been in the right proportion, which causes incomplete combustion; this shows there is still sawdust fuel that does not burn after the combustion process is complete. The temperature in the combustion chamber is high because the combustion process occurs well where sawdust has a high calorific value, resulting in a high-temperature range in the combustion chamber. The temperature is transferred to the heat exchanger room on the left and right of the combustion chamber, and the hot air is drawn by a fan, which becomes the output temperature, which can later be used for drying [12]. Placement of temperature measuring devices is carried out at the feeder point, heat exchanger, combustion chamber, chimney, temperature outlet fan, and furnace outlet temperature. Accurate temperature monitoring enhances energy efficiency and optimizes the performance of the mobile drying furnace, ensuring a more sustainable and cost-effective drying process.

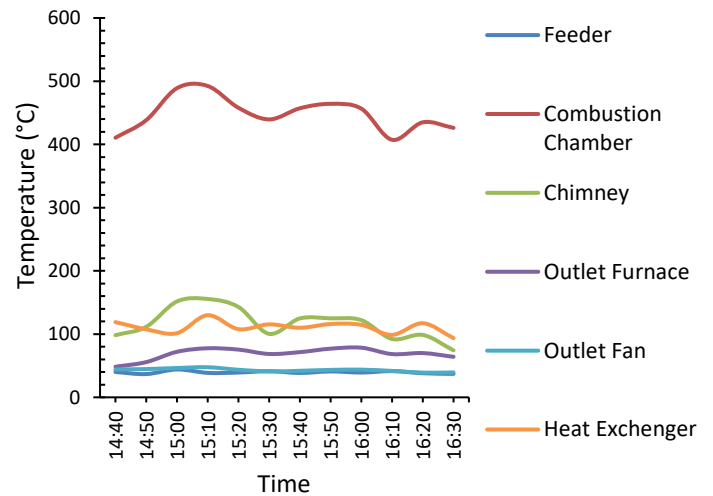


Fig. 3. Temperature distribution at 25 rpm feeder rotational speed

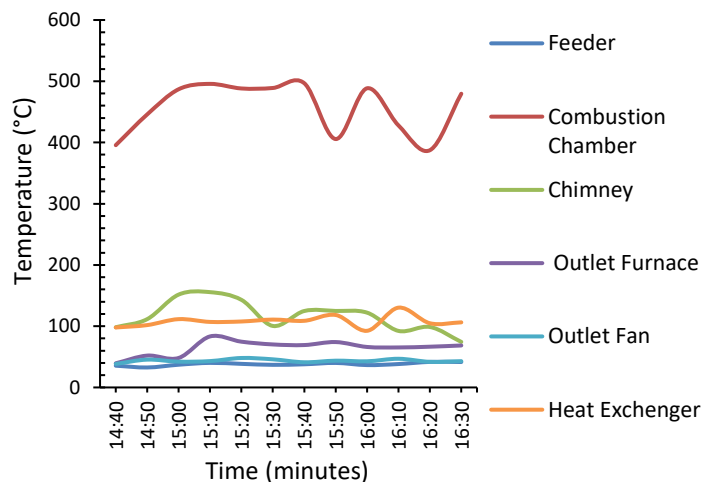


Fig. 4. Temperature distribution at 30 rpm feeder rotational speed

The airflow rate also affects the burning of sawdust. As the air supply increases, the amount of oxygen used for combustion in the oxidation area also increases [13]. The greater the air flow rate, the greater the temperature of the resulting fire, increasing the amount of combustible gas. The increase in the amount of combustible gas will increase the amount of heat released during combustion. The final output temperature, or the temperature passing through the fan, is suitable for drying grain. After passing through the fan, the resulting temperature is 43.08 - 46.08 °C; this temperature is suitable for drying grain so as not to cause grain damage [14].

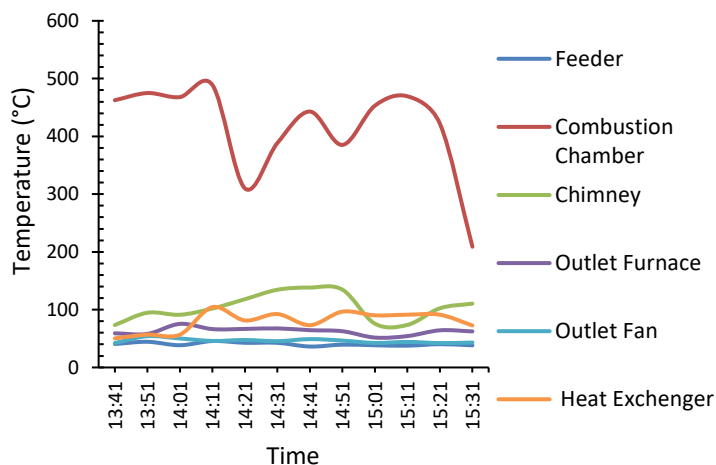


Fig. 5. Temperature distribution at 35 rpm feeder rotational speed

### 3.2 Fuel consumption

The fuel consumption rate is obtained by calculating the amount of fuel burned (consumed) divided by the combustion time. The amount of fuel consumed was obtained by weighing the sawdust fuel with an analog scale and putting it into a sack before the combustion process. When the combustion process was completed within two hours, the remaining sawdust fuel was weighed again. The initial weighing result is subtracted from the final weighing result, and the fuel consumed during the combustion process is obtained. The fuel consumption rate at feeder rotational speeds of 25, 30, and 35 rpm can be seen in Table 1.

Table 1. Fuel consumption rate at different feeder rotating speeds

Treatment	Fuel consumption rate (kg/h)
25 rpm	4.25
30 rpm	4.35
35 rpm	5.15

Table 1 explained that fuel consumption for 2 hours at feeder rotational speeds of 25, 30, and 35 rpm was 8.5, 8.7, and 10.3 kg, respectively. Table 1 shows that the highest fuel consumption rate was 5.15 kg/hour, and the lowest was 4.25 kg/hour. Table 1 shows that the greater the rotational speed of the feeder, the greater the amount of sawdust fuel consumed, and vice versa. This is because the high rotational speed of the fuel feeder causes the fuel flow to the combustion chamber to be rapid, ensuring an ample amount of fuel is burned. Enhancing biomass quality is crucial for maintaining efficient combustion performance [3]

### 3.3 Fuel efficiency

The energy conversion aspect is reflected in the dryer efficiency. In contrast, the mass transfer aspect is indicated by the rate of water mass release from the product to the heating air. Furnace efficiency is a value in units of percent obtained from calculating the values obtained from the mobile drying furnace test results using the equation [11]. Furnace efficiency at various feeder rotational speeds is presented in Table 2.

Table 2. Furnace efficiency at different feeder rotating speeds

Treatment	Furnace efficiency (%)
25 rpm	37.64
30 rpm	37.59
35 rpm	22.41

Table 2 explains the furnace's efficiency using sawdust fuel with three different rotating speeds of the sawdust fuel feeder. The furnace efficiency at 25 rpm feeder rotating speed is 37.64 %, the furnace efficiency at 30 rpm feeder rotating speed is 37.59 %, and the furnace efficiency at 35 rpm feeder rotating speed is 22.41 %. The highest furnace efficiency is achieved at a feeder rotational speed of 25 rpm. This is because a feeder rotational speed of 25 rpm is suitable for feeding sawdust fuel. A low feeder rotational speed causes the amount of fuel fed and burned to be adjusted accordingly, ensuring that combustion takes place efficiently with minimal heat loss. The combustion of wood biomass, in this case, sawdust, is strongly influenced by the ratio of air and fuel in the furnace [8]. The proper comparison will produce perfect combustion with a fast combustion rate. Furthermore, it accelerates combustion in the furnace, leading to an increase in the radiant energy generated by combustion [3], [15].

Combustion sawdust is the combustion of solid materials. Fuel-air mixing is much more complex in solid fuels, so much ash is produced. Ash or residue from solid fuel combustion is not only due to incomplete combustion, but also due to the composition of fuel, containing various materials that cannot burn [16]. Optimal drying is determined by efficient energy utilization, process efficiency level, and expected final product quality. These efficiency factors depend on drying conditions and parameters, such as temperature, air flow rate, drying duration, and product characteristics, which directly affect dryer performance.[17].

### 3.4 Energy balance

Energy balance refers to the energy balance within a system [18]. Based on the first law of thermodynamics, which states that energy cannot be destroyed or created, it can only change its form. The equation for finding the energy balance is total energy = energy lost + energy accumulated. The total energy value is obtained from the mass of sawdust biomass used multiplied by the highest heat value of sawdust, where the highest heat value is 18,288 kJ/kg. The value of lost energy is obtained from the calculation of any energy coming out of the mobile drying machine, and the accumulated energy value is the value of energy stored in the system or mobile dryer; the value is obtained from reducing the total energy minus the total energy lost, and the accumulated energy [15], [19]The energy balance calculated in this study obtained a value that can be seen in Table 3.

Table 3. Energy balance at different feeding rotational speeds

Energy balance	Energy (kJ/kg)		
	25 rpm	30 rpm	35 rpm
Total Energy/Qt (kJ)	155,448	159,105.60	188,369.12
Loss Energy/QL (kJ)	44,400	42,393	35,194
Energy consumed furnace /Qa (kJ)	903.58	856.27	739.93
The energy input to the drying chamber/Qnet (kJ)	110,144	115,856	152,435
Percentage (%)	70.86	72.82	80.92

3 explains the energy balance of each feeder rotational speed of 25, 30, and 35 rpm. The highest total energy is obtained from the 35-rpm feeder rotational speed experiment because, with a high fuel feeder rotational speed, the fuel fed into the combustion chamber is more than at the other fuel feeder rotational speeds. The highest lost energy was obtained at a rotating speed of 25 rpm of 44,400 kJ/kg, and the lowest was at a feeder rotating speed of 35 rpm of 35,194 kJ/kg. The highest furnace absorbed energy was obtained at a rotating speed of 25 rpm of 903.58 kJ/kg. This shows that the feeder rotating speed of 25 rpm absorbs much energy from the furnace. Energy into the highest drying room is obtained at a rotating feeder speed of 35 rpm, amounting to 152,435 kJ/kg. This shows the amount of energy that can be used for extensive drying [20].

### 4 Conclusion

This experimental study confirms the effectiveness of a mobile sawdust-fueled drying furnace in achieving stable temperatures suitable for grain drying. Among the three feeder speeds tested (25,

30, and 35 rpm), the 25-rpm setting demonstrated the best thermal efficiency (37.64%) and lowest fuel consumption (4.25 kg/h), producing an energy output of 110,144 kJ. Although the highest energy output was recorded at 35 rpm (188,369.12 kJ), efficiency dropped to 22.41% due to incomplete combustion. Across all variations, the outlet air temperature remained consistent between 43.08–46.08°C—optimal for preserving crop quality. The energy balance at 35 rpm showed that 80.92% of input energy was transferred to the drying chamber, indicating strong potential for biomass utilization despite lower efficiency. These results highlight a trade-off between thermal output and fuel efficiency, with 25–30 rpm representing an optimal operational range. Overall, the system supports sustainable energy use in mobile agricultural drying, especially in rural areas with abundant wood waste.

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