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# Effectiveness Test of Biomass Stove Based on Fuel Mass Ratio of Biopellet and Betung Bamboo Chips

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**ABSTRACT**

*Biomass is one of the renewable energy sources where its abundant availability in nature is a great potential to be developed.. In this case, a study of the effectiveness of biomass stoves using biopellets and betung bamboo chips aims to obtain optimal operating conditions for temperature, flame duration, thermal efficiency, and specific fuel consumption values produced for comparison with reference to SNI 7926:2013 quality standards. The method used to test the biomass stove is the Water Boiling Test method. The fuel used was analyzed for proximate and ultimate content. In this study, it is known that biomass stoves using rice husk biopellets and betung bamboo chips operate optimally at a mass ratio of 50%:50% in terms of temperature, flame duration, thermal efficiency, and specific fuel consumption. While using rice husk biopellets and teak wood powder biopellets, the biomass stove operates optimally at a mass ratio of 75%:25% in terms of temperature and flame duration and a mass ratio of 50%:50% in terms of thermal efficiency and fuel consumption.*

***Keywords:*** *Biomass, Biopellets, Biomass Stove, Betung Bamboo*

## 1. INTRODUCTION

The diversity of energy in Indonesia has many energy sources that can be used, one of which is biomass. This is an important aspect of the country's development and sustainability. Biomass, also known as bio resource, is material obtained from plants either directly or indirectly and can be utilized as energy [1].

Various types of biomass sources that can be found both from agricultural products, plantations and forests in various provinces in Indonesia, including woody plants, grasses, agricultural waste, forest waste, including livestock manure that can be optimized for use as an alternative fuel [2]. Biomass energy sources have the advantage of being a renewable energy source that can provide a sustainable source of energy [3].

One of the new and renewable energies that is currently being developed and produced because it has very abundant biomass raw materials is biopellets [4]. Biopellets are pelletized biomass fuels that have uniform size, shape, moisture, and energy content [5]. Pellets are produced by a device with a mechanism of continuous material input and pushing the dried and compressed material through a steel circle with holes that have a certain size. Meanwhile, bamboo is a grass-type plant that has cavities and internodes in its stem. Indonesia is currently the third largest bamboo producing country in the world after China and Thailand [6]. Until now, bamboo biomass has been utilized for light construction, heavy construction, and handicrafts [7].

So far, solid biomass, especially wood, has been traditionally used for cooking in rural areas, either through traditional kitchens or direct combustion. However, poor combustion quality results in very low biomass combustion efficiency. In addition, combustion smoke causes air pollution that is harmful to health [8].

Biomass as fuel can be used in various ways and tools, one of which is burning biomass using a biomass stove. A biomass stove is a device used to convert the potential energy of biomass into thermal energy. Biomass stoves are one type of stove that has the potential to be developed because it can reduce the impact of environmental pollution due to smoke from direct combustion and reduce the impact of global warming [1]. Biomass stoves using pellet fuel usually have a simple design using a top-lit updraft system consisting of preheating, counter-flow, and co-firing combustion mechanisms.

Given the available opportunities and potential benefits, this research was conducted to develop a biomass-fueled stove with a renewable energy source that produces high thermal efficiency and is environmentally friendly or low gas emissions. The things that will be analyzed on the biomass stove are the combustion process that occurs in the stove, and the thermal efficiency of the stove.

## 2. MATERIAL AND METHODS

This research was conducted at the Energy Engineering Laboratory of Sriwijaya State Polytechnic and the fuel was tested for ultimate analysis at the PT Geoservices Coal Palembang Laboratory and proximate analysis at the Chemical Engineering Laboratory of Politeknik Negeri Sriwijaya.

### 2.1 Material

The fuels used in this research are rice husk biopellets, teak wood powder biopellets, and betung bamboo chips. The biopellets were tested for their characteristics based on SNI 8021:2014. The equipment used is a set of Top-Lit Up Draft type biomass stove equipped with primary and secondary air holes and a forced air system using a fan with a supply air speed of 2-10 m/s, thermogun, digital anemometer, mercury thermometer, and gas analyzer.

### 2.2 Methods

This research involves the following variables: Fixed Variable: Fuel mass 1kg, supply air flow velocity 4 m/s, primary air outlet valve open and secondary air outlet valve open. Free Variable: Fuel composition variations are: 100:0%, 75:25%, 50:50%, 25:75%, 0:100%.

The research procedure was carried out in several stages, as follows: Preparing the tools and fuel to be used, measuring the initial temperature of 2 liters of water to be boiled, Fully open the primary and secondary air outlet valves and the fuel is burned with the airflow velocity at 4 m/s, Record boiling time and flame duration. Measure final water mass, fuel mass used, flame temperature, and CO.

Testing the specific fuel consumption value aims to measure the efficiency of the use of fuel used to produce energy. The lower the specific fuel consumption value, the more efficient the use of fuel. The specific fuel consumption value uses the equation (SNI 7928:2013):

$$FCR = \frac{Mbt}{t} \qquad \ldots(1)$$

$$M_{bt} = m_a - m_{ak}$$

where:

| | | |
|---|---|---|
| FCR | : | *Fuel Consumption Rate* (gr/minutes) |
| $M_{bt}$ | : | Mass of fuel used (gr) |
| $M_a$ | : | Initial fuel mass (gr) |
| $M_a$ | : | Final fuel mass (gr) |
| t | : | Time (minutes) |

Thermal efficiency is the ratio of the heat produced by the fuel to the heat received by the water to raise its temperature and evaporate it. Calculations to determine the amount of thermal efficiency using the equation (SNI 7928:2013):

$$\eta T = \frac{Ma.Cp.\Delta T + \Delta Ma.L}{\Delta Mk.LHV} \times 100\% \qquad \ldots(2)$$

Where:

| | | |
|---|---|---|
| ηT | : | Thermal efficiency (%) |
| $M_a$ | : | Water mass (kg) |
| Cp | : | Specific heat of water (4,1866 kJ/kg°C) |
| ΔT | : | Water temperature difference (°C) |
| $\Delta M_a$ | : | Mass of evaporated water (kg) |
| L | : | Calor of evaporation of water (2268 kJ/kg) |
| $\Delta M_k$ | : | Mass of fuel used (kg) |
| LHV | : | Lower Heating Value (kJ/kg) |

## 3. RESULT AND DISCUSSIONS

This research was conducted using experimental to determine the best performance in the use of Top Lift Up Draft biomass stoves in terms of variations in the mass of biopelet fuel and betung bamboo chips. The fixed variable in this study is the airflow velocity of 4 m/s. While the free variable in this study is the mass ratio of the fuel mixture of biopelets and betung bamboo chips, where the variation of the fuel mass ratio can be seen in Table.1.

**Table 1**. Fuel Mass Ratio

| Sample Name | Rice Husk Biopellets: Betung Bamboo Chips | Rice Husk Biopelets: Teak Wood Powder Biopelets |
|---|---|---|
| | (%) | (%) |
| S.1 | 100 : 0 | 100 : 0 |
| S.2 | 75 : 25 | 75 : 25 |
| S.3 | 50 : 50 | 50 : 50 |
| S.4 | 25 : 75 | 25 : 75 |
| S.5 | 0 : 100 | 0 : 100 |

### 3.1 Biomass Fuel Content Analysis

Research conducted on the effectiveness test of Top Lift Up Draft type biomass stoves using biomass fuels, namely rice husk biopellets, teak wood powder biopellets, and betung bamboo chips. The content of biopellets and betung bamboo chips can be seen in Table 2 and 3.

**Table 2**. Fuel Proximate Analysis Results

| Component | Rice husk biopellets | Teak wood powder biopellets | Betung bamboo chips |
|---|---|---|---|
| | (%wt) | (%wt) | (%wt) |
| Moisture | 9,09 | 8,85 | 8,51 |
| Volatile Matter | 72,55 | 72,25 | 73,68 |
| Fix Carbon | 17,3 | 17,85 | 14,39 |
| Ash | 1,06 | 1,05 | 3,42 |
| **Total** | **100** | **100** | **100** |

*(Source: Sriwijaya State Polytechnic Chemical Engineering Laboratory Analysis, 2024)*

**Table 3**. Ultimate Fuel Analysis Results

| Component | Rice husk biopellets | Teak wood powder biopellets | Betung bamboo chips |
|---|---|---|---|
| | (%wt) | (%wt) | (%wt) |
| C | 46,54 | 46,69 | 44,78 |
| $H_2$ | 5,31 | 5,28 | 5,05 |
| $N_2$ | 0,64 | 0,32 | 0,51 |
| $O_2$ | 38,61 | 39,08 | 38,16 |
| $H_2O$ | 8,34 | 8,02 | 8,19 |
| S | 0,05 | 0,13 | 0,07 |
| Ash | 0,62 | 0,48 | 3,24 |
| **Total** | **100** | **100** | **100** |

*(Source: PT Geoservice Palembang Laboratory Analysis, 2024)*

Based on the table 2, namely proximate analysis (ASTM-D7582-10) on 10) on biopelet fuel has met the standards in SNI 8021-2014 and betung bamboo chips have also met the standards in SNI 9032: 2021.

## 3.2 Effect of Fuel Mass Ratio on Flame Temperature

In the research of effectiveness biomass stoves, the raw materials used are rice husk biopellets, teak wood powder biopellets and betung bamboo chips. The fixed variable used is the air flow rate, which is set at 4 m/s, while the independent variable used is the variation in fuel composition.

Based on the results of the biomass stove tests that have been carried out, it can be analyzed the effect of the fuel mass ratio on the resulting fire temperature, where the effect can be seen in Figure 2. Based on the figure 2, it can be seen that the highest temperature produced in combustion using a biomass stove with a mass ratio of mixed fuel of rice husk biopelets and betung bamboo chips is at a ratio of 50%:50%, which is 778.8°C, while the highest temperature produced from mixed fuel of rice husk biopelets and teak wood powder biopelets is at a ratio of 75%:25%, which is 777.4°C.

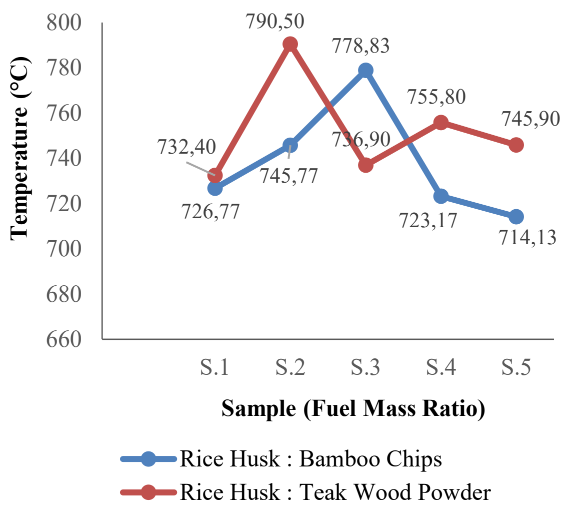


**Figure 2.** Effect of Fuel Mass Ratio on Flame Temperature

The difference in temperature produced is influenced by several factors, including differences in physical structure, moisture content, volatile matter, ash, and the heating value contained in the fuel used. Biopellets have a denser and more uniform structure that results in more even and consistent combustion in biomass stoves, thus producing more heat and higher temperatures. The lower the value of moisture, volatile matter, and ash content so as to produce a high calorific value, the higher the temperature produced in the combustion process [9].

## 3.3 Effect of Fuel Mass Ratio on Flame Duration

Measurements are taken using a stopwatch. Fuel that has been ignited into a fire will be measured until the fuel in the biomass stove burns out and the fire burns out. The effect of fuel mass ratio on flame duration can be seen in Figure 3.

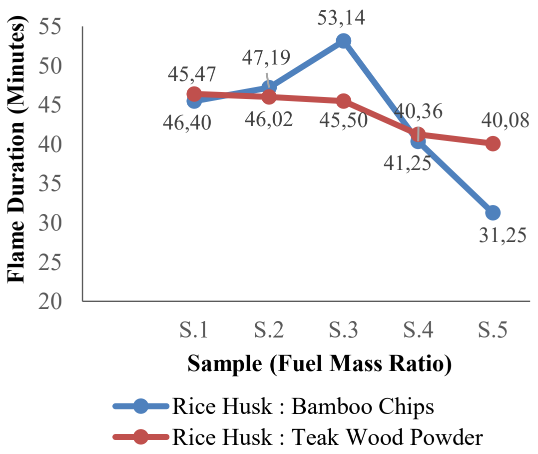


**Figure 3.** Effect of Fuel Mass Ratio on Flame Duration

Based on the figure 3, it can be seen that the longest flame duration in combustion using a biomass stove with a mixed fuel mass ratio of rice husk biopellets and betung bamboo chips is at a ratio of 50%:50%, which is 53.14 minutes, while the longest flame duration from a mixture of rice husk biopellets and teak wood powder biopellets is at a ratio of 100% rice husk biopellets, which is 46.4 minutes.

The difference in flame duration is due to differences in the physical and chemical properties of each fuel used. The flame duration is influenced by several factors, namely the physical structure such as density and size of the material, where biopellets have a higher density due to the compression process carried out during the manufacture of biopellet fuel. The high density of a fuel results in more energy that can be liberated during combustion. In addition, the moisture and volatile matter content contained in the fuel is also a factor that affects the flame duration. Fuels that have a high density and moisture content, as well as low volatile matter content result in a longer flame duration [10]. The high moisture content causes the fuel to be difficult to burn, while the high volatile matter content results in a faster flame.

### 3.4 Effect of Fuel Mass Ratio on Thermal Efficiency of Biomass Stove

The process of measuring and collecting data on biomass stoves is carried out using the Water Boiling Test (WBT) method, This is done to measure the thermal efficiency of the biomass stove used. The effect of fuel mass ratio on thermal efficiency can be seen in Figure 4.

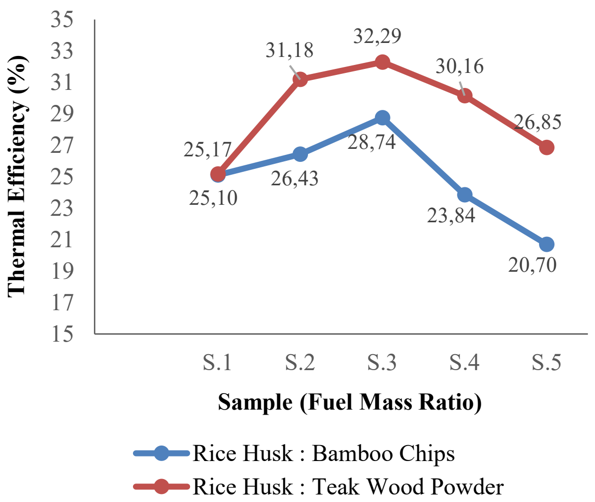


**Figure 4.** Effect of Fuel Mass Ratio on Thermal Efficiency

Based on the figure 4, it can be seen that the highest thermal efficiency of biomass stoves with a mixed fuel mass ratio of rice husk biopellets and betung bamboo chips is at a ratio of 50%:50%, which is 28.74%, while the highest thermal efficiency produced from a mixture of rice husk biopelets and teak wood powder biopelets is at a ratio of 50%:50%, which is 32.29%. However, all variations of the fuel mass ratio used in combustion using biomass stoves produce thermal efficiency that meets the standards of SNI 7926:2013 where the minimum value of thermal efficiency of biomass stoves is 20%.

The composition of each fuel mixture greatly affects the thermal efficiency. The fuels used have different combustion characteristics, so the right mix ratio needs to be determined to achieve optimal thermal efficiency. High energy content will result in large thermal efficiency. Biopellets have a higher energy content, this is because the biopellets have gone through a compaction process that increases the energy density. The moisture content of the fuel will also affect the combustion efficiency, high moisture in the fuel can reduce the thermal efficiency as more energy is required to evaporate the water before actual combustion occurs.

The mass of fuel used also affects the thermal efficiency value of the biomass stove, where the less mass of fuel used, the thermal efficiency of the biomass stove will increase. This is because much of the energy produced from these fuels can be utilized. The efficiency value is very influential on the temperature and heat contained in the biomass stove, therefore the higher the temperature, the higher the heat value and efficiency [11]. High calorific value and high temperatures result in more complete and efficient combustion. Complete combustion reduces the amount of fuel wasted as smoke or unburned residue, so more of the energy produced from the fuel can be utilized.

### 3.5 Effect of Fuel Mass Ratio on Specific Fuel Consumption

Testing the specific fuel consumption aims to determine the efficiency of fuel use used in testing biomass stoves. Testing the specific fuel consumption value using the Water Boiling Test (WBT) method. The effect of fuel mass ratio on the specific fuel consumption can be seen in Figure 5.

Based on the figure 5, it can be seen that the specific fuel consumption of the highest biomass stove with a mixed fuel mass ratio of rice husk biopellets and betung bamboo chips is at a ratio of 100% betung bamboo chips, which is 2.76 kg/hr, while the highest specific fuel consumption produced from a mixture of rice husk biopellets and teak wood powder biopellets is at a ratio of 100% teak wood powder biopellets, which is 2.42 kg/hr.

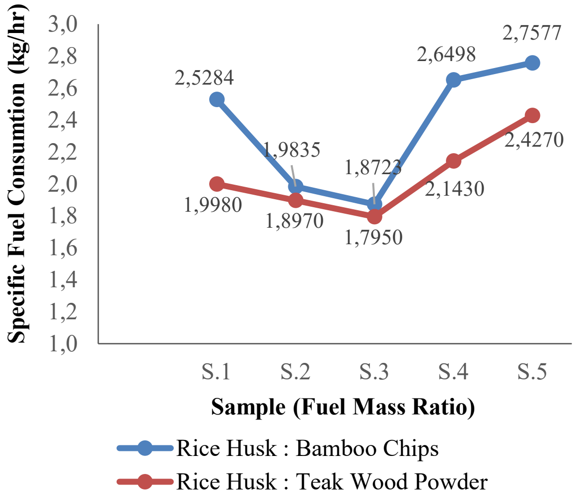


**Figure 5.** Effect of Fuel Mass Ratio on Specific Fuel Consumption

The specific fuel consumption is influenced by several factors related to fuel properties, operating conditions, and biomass stove appliance design. Fuels that have a higher energy content will result in a lower specific fuel consumption because less fuel is required to produce the same amount of energy.

Fuels that have a high moisture content will require more energy to evaporate the water, thus reducing combustion efficiency and increasing the specific fuel consumption. In addition, the particle size and density of fuel is one of the factors that affect the specific fuel consumption, fuel that has smaller particles and is denser will burn more efficiently so that it can reduce the specific fuel consumption. Therefore, the use of biopellets is more efficient than the use of unprocessed biomass.

From the research results that can be seen in Figure 4, the specific fuel consumption produced does not meet SNI 7926:2013, where based on SNI the maximum specific fuel consumption is only 1 kg/hr. This is because the biomass stove design used is not equipped with an insulator, where the insulator on the biomass stove has a significant impact on the specific fuel consumption produced. Insulators help reduce heat loss from the stove wall, so if the heat from the combustion process is not well isolated, a lot of energy is wasted to the surrounding environment [4]. In addition, the insulator helps optimize the combustion process in the combustion chamber. By reducing heat loss, the insulator can increase the combustion temperature, so that the fuel can burn more completely and reduce the formation of residues or toxic gases, and increase combustion efficiency, so that the specific fuel consumption can decrease because less fuel is needed to produce the same energy.

## 4. CONCLUSIONS

The optimal operating condition of the biomass stove with an air flow rate of 4 m/s using a mixture of rice husk biopellets and betung bamboo chips on the temperature and flame length produced is at a fuel mass ratio of 50%:50%, where the temperature produced at that ratio is 778.8°C and the flame duration is 53.14 minutes. While the optimal operating conditions for biomass stoves with mixed fuel of rice husk biopellets and teak wood powder biopellets are at a fuel mass ratio of 75:25%, where the temperature produced at this ratio is 777.4°C and the duration of the flame is 46.4 minutes.

The thermal efficiency produced in each variation of the mass of fuel used has met SNI 7926:2013. The highest thermal efficiency of the biomass stove with rice husk biopelet fuel and betung bamboo chips is at a 50:50% ratio of 28.74%. While with rice husk biopelets and teak wood powder biopelets also in the 50:50% ratio of 32.29%

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