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Analysis of the Effect of the Mass Ratio of Mixed Fuel Rice Husk-Betung Bamboo Biopellets on a Biomass Gasification Stove

Naddya Anastasya Zahra[1], Zurohaina[*2], Lety Trisnaliani[3]

[1 2 3] Chemical Engineering Department, Politeknik Negeri Sriwijaya, Jl. Srijaya Negara Bukit Besar, Palembang, 30139, South Sumatera, Indonesia

Corresponding Author's e-mail : zurohaina@polsri.ac.id

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ABSTRACT

The utilization of biomass energy offers a promising approach to addressing the global energy crisis and reducing greenhouse gas emissions. This study examines the effect of rice husk and Betung bamboo bio-pellet mass ratios on the performance of a Top-Lit Up Draft (TLUD) biomass gasification stove. Performance indicators observed include thermal efficiency, combustion temperature, flame duration, boiling time, specific fuel consumption, and CO and CO_2 emissions. The Water Boiling Test (WBT) was applied to assess thermal performance, while proximate and ultimate analyses were conducted to characterize the fuel. Fuel compositions tested were 100% rice husk, 75% rice husk–25% Betung bamboo, 50%–50%, 25%–75%, and 100% Betung bamboo. The 75% rice husk–25% Betung bamboo blend achieved the best results, with a thermal efficiency of 61.10%, combustion temperature of 728 °C, flame duration of 65.21 min, boiling time of 732 s, lowest CO emission of 23 ppm, CO_2 emission of 388 ppm, and a specific fuel consumption of 0.30 kg h^{-1}. This composition is optimal because the high volatile matter content of rice husk accelerates gasification, while the stable fixed carbon of Betung bamboo supports sustained combustion.

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

1. INTRODUCTION

The global energy crisis and the impacts of climate change necessitate a transition towards renewable energy sources. Biomass, as a renewable energy alternative, holds significant potential in Indonesia, particularly from agricultural waste such as rice husk and Betung bamboo. Utilizing these wastes not only reduces environmental pollution but also creates added economic value [1], [2].

Top-Lit Up Draft (TLUD) biomass gasification stoves offer an efficient and environmentally friendly solution for converting biomass into heat energy. An optimally designed stove can increase energy efficiency by up to 30% and significantly reduce CO_2 emissions [3]. The precise airflow rate is crucial for optimizing stove performance, ensuring complete combustion and producing cleaner pyrolysis gas [4].

Biopellets, as a form of solid biomass, are gaining popularity due to their ease of storage and use. Combining rice husk and Betung bamboo as bio-pellet raw materials can yield high calorific values and reduce greenhouse gas emissions [5], [6]. Nevertheless, the utilization of bamboo has been limited to construction and handicrafts [7], thus innovation in processing bamboo into bio-pellets opens new opportunities in the renewable energy sector [8].

Previous research has investigated the effect of air hole size and airflow velocity on gasification stove performance [9], [10]. Melinda et al. [11] found that a 50:50% blend of rice husk and Betung bamboo shavings resulted in a temperature of 778.8°C, a flame duration of 53.14 minutes, and a thermal efficiency of 28.74%. However, further innovation is needed in gasification stove design to allow direct use of rice husk and Betung bamboo bio-pellets without additional processing.

This study aims to analyze the effect of the mass ratio of rice husk and Betung bamboo bio-pellet blends on the performance of a biomass gasification stove, and to determine the most optimal fuel composition. The performance evaluation includes key operational parameters such as thermal efficiency, flame characteristics, fuel consumption rate, and CO level emission.The findings of this research are expected to provide an appropriate technology solution for household energy needs in rural areas and complement previous findings with a new approach to biomass fuel utilization.

2. MATERIAL AND METHODS

This research was conducted from April to July 2025 at the Chemical Engineering Laboratory of Politeknik Negeri Sriwijaya. This experimental study investigated the effect of varying bio-pellet compositions of rice husk and Betung bamboo on biomass stove performance.

2.1. Materials

The biomass fuels used were rice husk bio-pellets (obtained from an e-commerce biomass energy supplier) and Betung bamboo waste (obtained from PALI Regency, processed into bamboo chips). Two liters of water were used as the testing medium. The main equipment used was a set of Top-Lit Up Draft (TLUD) biomass gasification stove.

2.2 Methods

The fuels used were biopellets derived from rice husk and betung bamboo, each formed into uniform cylindrical shapes using a pelletizing machine. Five fuel mixture ratios were tested:100% rice husk (P100), 75% rice husk + 25% bamboo (P75B25), 50% rice husk + 50% bamboo (P50B50), 25% rice husk + 75% bamboo (P25B75), and 100% bamboo (B100). Prior to performance testing, the biopellets were analyzed using proximate and ultimate analysis according to ASTM D7582 and ASTM D5373 methods to determine moisture, volatile matter, ash, fixed carbon, and elemental composition.

Performance evaluation of the stove was conducted using the Water Boiling Test (WBT), a standardized method that simulates typical stove use conditions by boiling 2 liters of water. During testing, the initial water temperature was measured, the fuel was ignited with both air inlets fully opened, and the flame was sustained under controlled air flow. Key performance indicators recorded included flame temperature, combustion duration, water boiling time, thermal efficiency, fuel consumption rate, and exhaust emissions (CO and CO_2 levels).The specific consumption (SC) was calculated using the equation:

$$S_C = \frac{\Delta mk}{\Delta t}$$

Where :

Δ_{mk} = Mass of fuel consumed (kg)

Δ_t = Total testing time (hours)

In accordance with SNI 7928:2013, thermal efficiency was evaluated by comparing the total heat absorbed by water with the heat released from the fuel during combustion, including both sensible and latent heat contributions.

$$\eta_T = \frac{maCp\Delta T + \Delta maL}{\Delta mkLHV}$$

Where:

M_a = mass of water (kg)

Cp = specific heat of water (4180 J/kg °C)

ΔT = Water temperature difference (°C)

ΔM_a = Mass of evaporated water (kg)

L = Calor of evaporation of water (J/kg)

ΔM_k = Mass of fuel used (kg)

LHV = Lower Heating Value (J/kg)

3. RESULTS AND DISCUSSIONS

This section presents the findings on the performance of the biomass gasification stove using various blends of rice husk and Betung bamboo bio-pellets. The results are analyzed in terms of fuel characterization, flame duration, thermal efficiency, specific fuel consumption, combustion efficiency, and emissions, highlighting the impact of different bio-pellet compositions on stove performance can be seen in Table.1

Table 1. Fuel Mass Ratio

Sample Name	Rice Husk Biopellets: Betung Bamboo (%)
S.1	100:0
S.2	75:25
S.3	50:50
S.4	25:75
S.5	0:100

3.1. Fuel Biomass Characterization

Before presenting the performance test results, it is necessary to first describe the physical and chemical characteristics of the biomass fuels used. The proximate analysis provides essential information on moisture, volatile matter, fixed carbon, and ash content, which directly influence combustion behavior and stove performance. Table 2 shows the proximate analysis results of rice husk and Betung bamboo bio-pellets used in this study.

Table 2. Fuel Proximate Analysis Results

Component	Rice Husk (%wt)	Betung Bamboo (%wt)
Moisture	4,74	4,19
Volatile Matter	45,55	48,38
Fix Carbon	35,25	33,94
Ash	14,45	13,49
Total	**100**	**100**

(Source: Sriwijaya State Polytechnic Chemical Engineering Laboratory Analysis, 2025)

The proximate analysis revealed that both rice husk bio-pellets and Betung bamboo have moisture contents within acceptable SNI standards (4.74% and 4.19% respectively). However, their ash contents (14.45% for rice husk and 13.49% for Betung bamboo) significantly exceed the standard limits for premium and high-quality bio-pellets [12], [15]. High ash content can negatively impact combustion efficiency and increase residue formation [13], [17]. Betung bamboo exhibits a slightly higher volatile matter content (48.38%) compared to rice husk (45.55%), while rice husk has a higher fixed carbon content (35.25%) than Betung bamboo (33.94%). These characteristics play crucial roles in the combustion behavior of the blends.

3.2 Effect of Bio-pellet Composition on Flame Duration

Flame duration indicates how long the stove can sustain combustion with each fuel blend. Variations in rice husk and Betung bamboo composition influence this parameter, as shown in the figure 1.

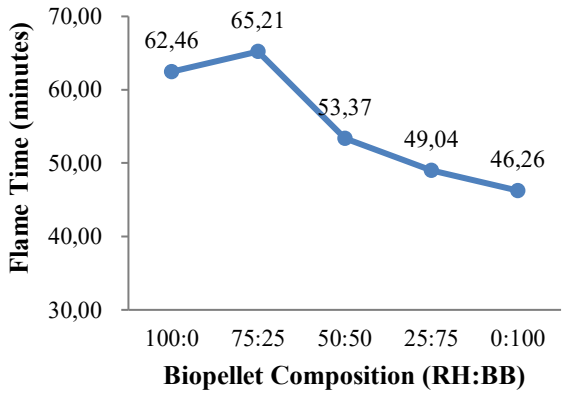


Figure 1. Flame duration of the TLUD biomass gasification stove using various rice husk–Betung bamboo bio-pellet compositions.

The flame duration was significantly influenced by the composition of the bio-pellet blends. As shown in Table 2, the blend of 75% rice husk and 25% Betung bamboo achieved the longest flame duration of 65.21 minutes. This is attributed to the synergistic effect of the high volatile matter in rice husk, which facilitates rapid ignition, and the stable fixed carbon in Betung bamboo, which supports sustained combustion. In contrast, higher proportions of Betung bamboo resulted in shorter flame durations due to its denser structure and higher ash content, which hinder efficient combustion.

3.3 Effect of Bio-pellet Composition on Thermal Efficiency

Thermal efficiency is a key indicator of how effectively a stove converts the energy stored in fuel into useful heat. Variations in the composition of rice husk and Betung bamboo bio-pellets are expected to influence this parameter because of differences in volatile matter, fixed carbon, and ash content between the two biomass types. Understanding these differences helps explain the performance trends observed in the figure 2.

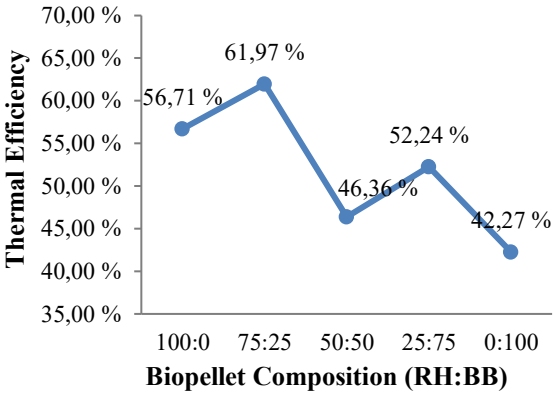


Figure 2. Thermal efficiency of the TLUD biomass gasification stove using various rice husk–Betung bamboo bio-pellet compositions.

Thermal efficiency was also affected by the bio-pellet composition. The 75% rice husk and 25% Betung bamboo blend exhibited the highest thermal efficiency of 61.10%, significantly exceeding the SNI minimum standard of 20%. This blend's efficiency can be attributed to the optimal balance of volatile matter and fixed carbon, which enhances gas quality and energy transfer during combustion. These findings are consistent with Melinda et al. [11], who reported that a mixture of rice husk and Betung bamboo shavings increased combustion temperature and extended flame duration, thereby improving thermal efficiency. Similarly, Lubwama et al. [14] and Kipngetich et al. [23] highlighted that biomass blending can significantly enhance energy conversion efficiency by optimizing fuel properties. Conversely, blends with higher Betung bamboo content showed lower thermal efficiencies, indicating that the higher ash content negatively impacted combustion performance, in line with the observations of Pratik Chaudhuri et al. [20] and Widodo et al. [24] that excessive ash content reduces the heat transfer capability and hinders complete combustion.

3.4 Effect of Bio-pellet Composition on Specific Fuel Consumption

Specific fuel consumption reflects the amount of fuel needed to produce a certain energy output. Differences in rice husk and Betung bamboo ratios affect this parameter, as shown in the following results.

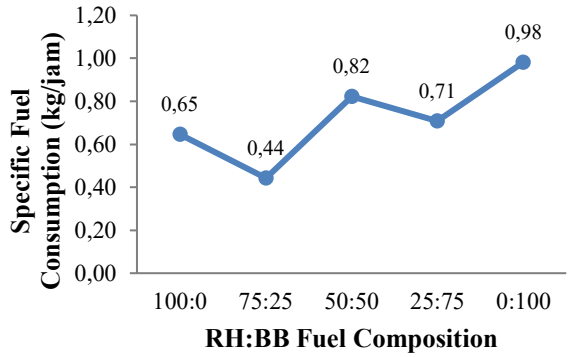


Figure 3. Specific fuel consumption of the TLUD biomass gasification stove using rice husk–Betung bamboo bio-pellet compositions.

Specific fuel consumption (SFC) was lowest for the 75% rice husk and 25% Betung bamboo blend at 0.30 kg/hour, indicating superior fuel utilization efficiency. This blend's composition allows for better combustion characteristics, leading to reduced fuel consumption. In contrast, the pure Betung bamboo blend had the highest SFC of 0.98 kg/hour, highlighting the inefficiencies associated with its denser structure and higher ash content.

3.5 Combustion Efficiency and Emission Characteristics

Combustion efficiency and emission levels indicate how completely the fuel burns and the environmental impact of the process. The effect of different rice husk and Betung bamboo ratios on these parameters is shown in the figure 4.

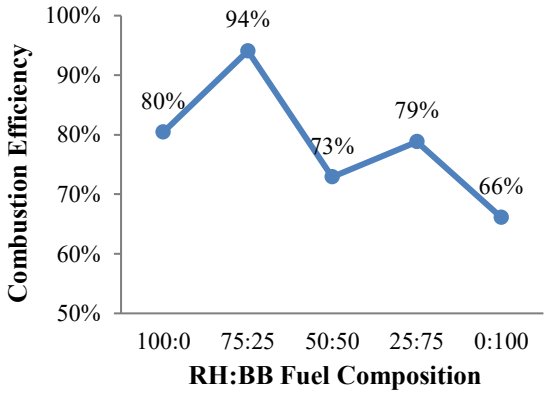


Figure 4. Combustion efficiency of the TLUD biomass gasification stove using rice husk–Betung bamboo bio-pellet compositions.

Combustion efficiency was highest for the 75% rice husk and 25% Betung bamboo blend at 94%, indicating nearly complete combustion and effective conversion of CO to CO_2. This blend's efficiency is a result of the optimal fuel–air mixing and combustion conditions. In contrast, the 100% Betung bamboo blend showed a combustion efficiency of only 66%, primarily due to incomplete combustion and higher CO emissions.

Emissions of carbon monoxide (CO) and carbon dioxide (CO_2) are crucial indicators of combustion completeness and environmental impact. CO is a product of incomplete combustion, while CO_2 results from complete combustion. The study found that the 75% rice husk and 25% Betung bamboo mixture produced the lowest CO emission at 23 ppm, alongside a CO_2 emission of 388 ppm. This low CO level signifies a highly efficient and complete combustion process for this specific fuel blend, minimizing harmful emissions. The balanced CO_2 emission indicates effective carbon conversion, making this mixture environmentally favorable compared to other compositions that might produce higher CO due to less efficient burning.

Table 3. CO Level Emission of Combustion

Air Flow Velocity (m/s)	Fuel Composition RH:BB (%W/W)	CO Emission Level CO(ppm)	CO_2 Emission Level CO_2 (ppm)
4,5	100:0	56	286
	75:25	23	388
	50:50	73	269
	25:75	70	331
	0:100	84	248

(Source: Sriwijaya State Polytechnic Chemical Engineering Laboratory Analysis, 2025)

These findings align with previous research by Osei et al. [17] and Yan Cao et al. [18], who reported that co-firing or blending different biomass feedstocks improves combustion completeness and reduces CO emissions. Similar results were also observed by Kipngetich et al. [23], showing that optimal blending ratios can significantly lower harmful emissions and improve energy conversion efficiency. The results of this study therefore reinforce the conclusion that the synergistic combination of rice husk's high volatile matter and Betung bamboo's stable fixed carbon contributes to both higher combustion efficiency and cleaner emission profiles.

4. CONCLUSIONS

This study successfully analyzed the impact of rice husk and betung bamboo biopellet mass ratios on TLUD biomass gasification stove performance. The research confirmed that fuel composition significantly influences key parameters, with the 75% rice husk and 25% betung bamboo mixture yielding optimal results. This blend achieved the highest thermal efficiency of 61.10%, a flame duration of 65.21 minutes, and the lowest specific fuel consumption at 0.30 kg/hour. Furthermore, it produced the lowest CO emissions at 23 ppm and controlled CO_2 emissions at 388 ppm. These superior outcomes are attributed to the synergistic balance between rice husk's high volatile matter for rapid gasification and betung bamboo's stable fixed carbon for sustained combustion. This optimal fuel composition presents an efficient and environmentally sound solution for biomass energy utilization in household applications.

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