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Analysis of Biomass Briquette Mixed Bagasse and Sugarcane Peel on the Performance of Forced Top-Lit Updraft Gasifier Stove

Intan Hardiatama*, Aron Enruico, Yuni Hermawan, Muhammad Trifiananto, Skriptyan N.H. Syuhri

Department of Mechanical Engineering, Faculty of Engineering, University of Jember, Jember, Indonesia, 68121
**Corresponding author:intan.hardiatama@unej.ac.id*

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ABSTRACT

The population growth in Indonesia from 270 million in 2020 to 279 million in 2024 has increased LPG consumption, potentially leading to future fuel shortages. The top-lit updraft (TLUD) gasifier stove using renewable biomass materials, offers a sustainable alternative. Biomass such as bagasse and sugarcane peel can be optimized into charcoal briquettes with high calorific value and low emissions. The calorific value of briquettes can be further enhanced by blending other high–calorific biomass materials. This experimental research focuses on testing the calorific value of raw bagasse and sugarcane peel before carbonization, as well as briquette mixtures (70:30, 50:50, 30:70) using a bomb calorimeter. The fuel briquettes are tested by operating the TLUD gasifier stove, measuring performance in terms of water boiling time (WBT) and flame characteristics. Results show that the 30:70 bagasse-to-sugarcane peel composition has the highest calorific value (6,242.292 cal/gram), followed by the 70:30 composition (6,094.753 cal/gram) and the 50:50 composition (5,657.935 cal/gram). The 30:70 ratio also achieved the longest flame duration (119 minutes 32 seconds), the highest combustion chamber temperature (570.2°C), and the greatest flame height (11.468 cm). The TLUD stove demonstrated an efficiency of 56.41%, with a char weight of 61 grams and a water temperature increase from 28.4°C to 90.4°C in 10 minutes 45 seconds. These briquettes met the SNI 01-6235-2000 standard, which requires a minimum calorific value of 5000 cal/g.

Keywords: *Biomass, briquettes, calorific, value gasifier*

I. Introduction

As time goes by, population growth in Indonesia continues to increase. This is supported by data from the Central Statistics Agency (BPS), which states that Indonesia's population in 2020-2024 will increase by 270 to 279 million people. Population growth is directly proportional to the consumption of fuel oil as the main energy for cooking, especially the use of LPG (liquefied petroleum gas) [1]. Fuel oil consumption is increasing every year and could lead to fuel shortages in the coming year. Therefore, it is necessary to develop technology regarding stoves that use alternative and renewable energy to replace oil.

The top-lit updraft (TLUD) gasification process, which produces both thermal energy and biochar, is a combustion technology recognized for its ecological benefits. When applied in heating or cooking equipment, it can contribute to environmental sustainability by reducing deforestation pressures, enhancing soil productivity, and promoting cleaner energy practices. This technology ensures effective environmental protection and fosters the development of sustainable energy systems [2]. The operating principle of this TLUD stove

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is to light the fire from the top so that the heat moves downwards. When this heat meets primary air, which moves upwards through the gasifier holes, gas from the biomass fuel is released and reacts imperfectly with the primary air. Gasification is the process by which solid fuels are converted into a synthetic fuel gas called syngas with limited air [3]. This shows that biomass gasification is incomplete combustion, producing a small amount of smoke which is considered more environmentally friendly [4]. One of the factors that influence the thermal efficiency of gasifier that can replace oil fuel is biomass energy [5]. Biomass is an organic material composed of cellulose and lignin [6]. Biomass originating from agricultural and plantation waste can be utilized optimally in the form of charcoal briquettes, thereby reducing environmental pollution [7]. Briquettes charcoal is a solid fuel that has a high calorific value, contains carbon, burns for a long time, and can be made from biocharcoal, namely carbonized biomass [8].

According to Njenga [9], the use of biomass in the form of briquettes can increase energy density, reduce deforestation, and have low emissions. Bagasse and sugar cane peel are biomass that can be used as the main ingredients for briquettes because they are abundant in quantity as sugar cane plantation areas in Indonesia expand from year to year. Increasing the energy content of briquettes can be done by adding other types of biomass with high calorific energy values [10].

Previous studies Sholeha [11] have shown that briquette fuel made from bagasse, where the composition of bagasse and its peel was not specified, affects the flame characteristics and efficiency due to differences in chemical composition and calorific value of each material. Additionally, bagasse and its peel have varying material densities, with the peel being harder than the bagasse. This results in difficulties during combustion and inconsistent flame characteristics. A controlled composition in briquettes allows for the optimization of calorific value and combustion efficiency, making it superior to raw bagasse material.

This research aims to make briquettes with variations in the composition of a mixture of bagasse and sugarcane peel as fuel for TLUD gasifier stove. The two biomasses have different material characteristics in terms of air content, hardness, and stiffness. This can affect the heating value and thus affect the performance of the TLUD gasifier in terms of flame duration, temperature, high flame, and thermal efficiency. The briquettes that have been produced are then subjected to bomb calorimeter testing and testing on the TLUD gasifier to determine the calorific value and characteristics of the briquettes as fuel.

II. Material and Methods

1. Materials

Bagasse and sugarcane peel are abundant biomass resources that can be utilized as primary materials for briquettes. In 2023, the area of sugarcane plantations in Indonesia reached approximately 504,000 hectares, providing a substantial supply of these raw materials. Bagasse is the inner part of sugarcane that contains a lot of water so that it is soft and elastic. The chemical composition of bagasse consists of 42% cellulose, 27,6% hemicellulose, and 21,5% lignin [12]. The low lignin content of bagasse compared to sugarcane peel causes bagasse to have a high water absorption capacity [13]. Sugarcane peel contains 7% cellulose, 27% hemicellulose, and 47% lignin has a high lignin content so that it can provide hard, stiff, and hydrophobic properties [14]. The biomass was sun-dried for four days until it turned yellowish-brown to reduce its moisture content. It was then stored in a sealed container made of aluminum to ensure it remained dry. The physical differences between bagasse and sugarcane peel can be seen in Figure 1.


(a) (b)
Fig. 1. (a) Bagasse and (b) Sugarcane peel

2. Process of Making Briquette

Bagasse and sugarcane skin biomass undergo carbonization process by placing each into a pyrolysis drum at a temperature of 300°-350° for 2-3 hours until it becomes charcoal [15]. Then, the charcoal is ground into powder and filtered using 60 mesh charcoal. Tapioca flour as much as 5% is used as a briquette adhesive then mixed with charcoal powder then stirred until homogeneous with a ratio of bagasse and sugarcane skin of 70:30, 50:50, and 30:70 from a mass of 600 grams [16]. The briquettes are compacted into a mold measuring 2 x 2 x 8 cm and molded using a hydraulic press with a pressure of 50 kg/cm^2. The briquettes are oven-dried at a temperature of 100° for 4 hours then stored in an airtight plastic container so that the briquettes remain dry and free from moisture.

3. Calorific Value Test

The calorific value of a fuel indicates the amount of energy produced from the combustion of a unit mass of the fuel. A fuel with a higher calorific value will be more efficient in generating energy [17]. In this study, samples of biomass briquettes mixed with bagasse and sugarcane peel were taken, each weighing 15 grams, to test their calorific value using a bomb calorimeter. This testing aimed to determine the initial calorific value of sugarcane bagasse and sugarcane peel before carbonization and after being processed into charcoal briquettes. The bomb calorimeter test yielded the Higher Heating Value (HHV), also known as Gross Calorific Value (GCV), which measures the total energy released during the complete combustion of the fuel, including the energy released from the condensation of water vapor formed during the combustion process [18].

4. Water Boiling Test and Fire Characteristic Test

This study used a TLUD gasifier stove: forced draft made of 3 mm thick iron in a cylindrical shape with a diameter of 250 mm, a height of 400 mm, and a blower installed as an air supplier. Each variation of biomass briquettes (70:30, 50:50, 30:70) was weighed up to 600 grams using a digital scale. The test was carried out at night with a temperature of 30 °C. Before conducting the water boiling test, the initial temperature of the water was measured, the result was 28.4 °C, then prepare 1 liter of water in a pan with a diameter of 20 cm and a height of 13.5 cm made of aluminum to be heated on the stove. The weighed briquettes are burned with a gas torch to start the combustion. Insert the partially lit briquettes into the TLUD gasifier reactor and maintain the flame until all the briquettes are burned out. Record the boiling time and water temperature every 2 minutes until the water reaches 90 °C which is measured using a mercury thermometer and measure the mass of the remaining char. For the flame characteristic test, the data taken including flame duration, combustion chamber temperature, and flame height. every 2 minutes using a thermocouple, with T1 positioned 80 mm from the top of the stove and T2 positioned 160 mm from T1. Perform each test and variation three times to ensure accurate data. Analyze the data and draw conclusions from the research results. The gasifier test scheme is shown in Figure 2.

	Component Name
1.	TLUD Gasifier Stove
2.	Combustion Chamber
3.	Thermocouple (T1)
4.	Thermocouple (T2)
5.	Blower
6.	Dimmer
7.	Anemometer
8.	Thermoreader
9.	Pan
10.	Mercury thermometer
11.	Ruler
12.	Digital scales

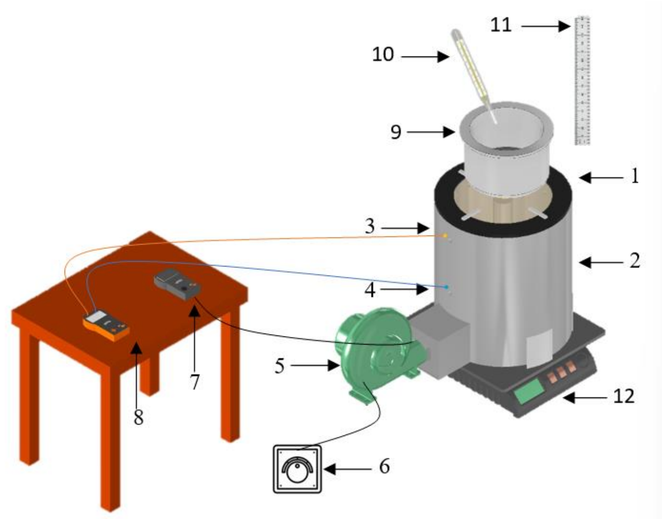

Fig. 2. TLUD gasifier stove scheme

III. Results and Discussions

1. *Caloric Value*

Bomb calorimeter testing was carried out to determine the initial heating value by testing bagasse powder and sugarcane peel. Testing of the calorific value of bagasse and sugarcane peel before the carbonization process is shown in Table 1.

Table 1. Calorific value results for bagasse and sugarcane peel

No	Material	Moisture (%)	Caloric Value (cal/gram)	Standard Benzoic Calibration
1.	*Bagasse*	9.23	4,299.6768	2,425.656
2.	Sugarcane Peel	6.76	4,590.8464	2,425.656

The bomb calorimeter test results indicated that the gross caloric value of the initial calorific value of bagasse was 4,299.676 cal/g, while that of sugarcane peel was 4,590.846 cal/g. These differences in calorific values can influence the mixture of bagasse and sugarcane peel in the briquette formulation. The bomb calorimeter analysis of the briquette samples for each variation is shown in Table 2.

The results of the research show that the calorific value of bagasse and sugarcane peel briquettes with a composition of (70:30) is 6,094.753 cal/gram, a composition of (50:50) is 5,657.935 cal/gram, and a composition of (30:70) has the highest heat produced was 6,242.292 cal/gram. The composition (50:50) experienced a decrease in calorific value, which could have occurred due to several factors, such as higher water content and a sample mixture that was not yet homogeneous. SNI 01-6235-2000 regarding wood charcoal briquettes states that the minimum heating value is 5,000 cal/gram. The results of bomb calorimeter testing show that the calorific value of the briquettes in this study meets quality standards. The composition of the raw material affects the calorific value, and the calorific value has an impact on the quality of the briquettes produced. The higher the heating value, the better the quality of the briquettes.

Table 2. Calorific value of briquettes mixed with bagasse and sugarcane peel

No	Variation	Moisture (%)	Caloric Value (cal/gram)	Standard Benzoic Calibration
1.	70 : 30	13.46	6,094.75312	2,425.656
2.	50 : 50	13.67	5,657.93504	2,425.656
3.	30 : 70	12.46	6,242.29248	2,425.656

2. Long Burning Time

The briquette flame duration test was carried out on a TLUD gasifier stove using a stopwatch. In this study, air was supplied using a blower at a speed of 2 m/s. Data collection begins when the briquettes are inserted into the stove, and the briquettes are partially burned until the briquette fuel runs out. The flame test results are shown in Figure 3.

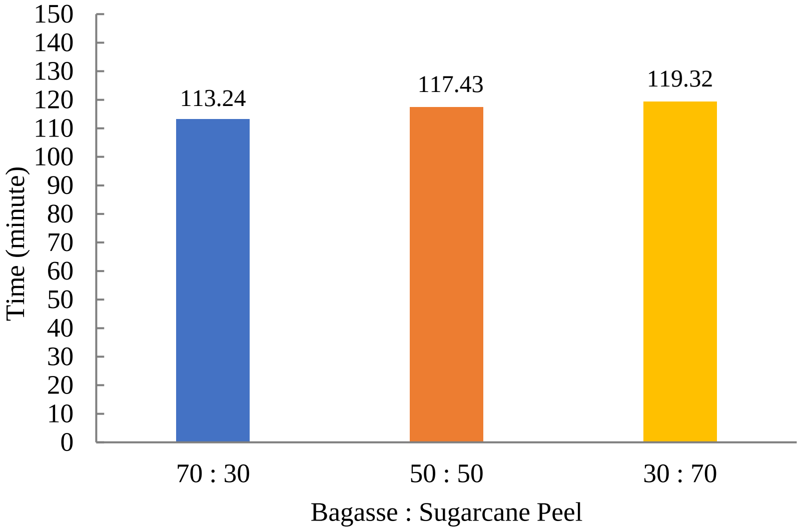

Fig. 3. Duration burning time test

Based on the average flame duration test results for variations in the composition of bagasse and sugarcane peel, 70:30, 113 minutes 32 seconds, variations in composition 50:50, 117 minutes 43 seconds, and variations in composition 30:70, 119 minutes 32 seconds, are shown in the graph Figure 3. The calorific value of briquettes has a significant influence on the duration of their burning. Briquettes with a high heating value tend to have a longer burning time [19].

3. Combustion chamber temperature

This test is carried out using a thermocouple, which is read by a digital thermometer at two points (T1 and T2) inside the gasifier. Then, temperature recording is continued at 2-minute intervals until the fire is completely extinguished. The data is processed and presented in the graph Figure 4.

Based on the test results, it show the comparison of combustion chamber temperatures (T1 and T2) with a composition of 70:30, 50:50, and 30:70. At T1, the resulting temperature is inconsistent because the position of the thermocouple is far from the fuel and close to the top end of the stove, allowing airflow into the combustion chamber to influence the temperature during testing. The highest T2 temperature point for the 70:30 briquette fuel composition is at the 10th minute with a temperature of 529.6℃, the 50:50 composition is at the 14th minute with a temperature of 529℃, and the 30:70 composition is at the 14th minute, with a temperature of 570.2℃. Based on these results, it is known that each variation has a different highest temperature point (peak), this is due to the different heating values in each variation. Variations of briquettes with higher heating values will produce higher combustion temperatures. The greater the energy released, the higher the temperature reached during the combustion process the greater the energy released, the higher the temperature reached during the combustion process [20].

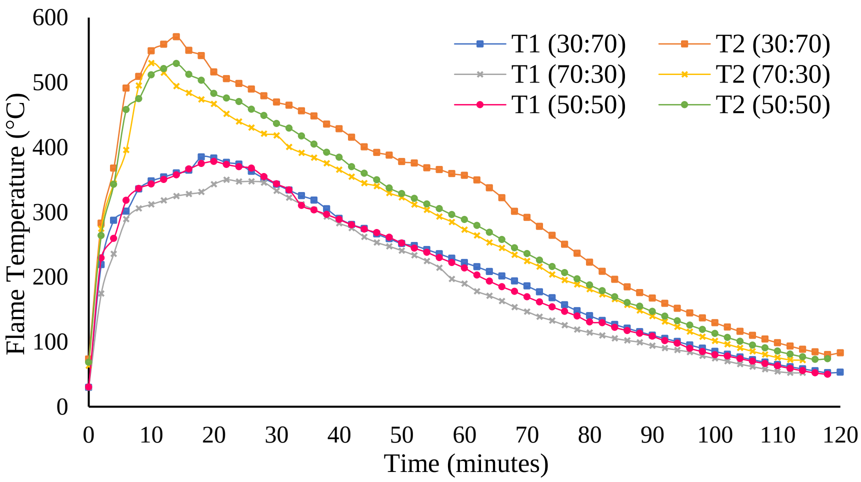

Fig. 4. Combustion chamber temperature test graph

4. *Fire Height*

Test documentation of fire height measured using ImageJ software. The maximum flame height test data is shown in Figure 5. Based on fire height data calculated using the ImageJ application with briquettes varying in composition, 70:30 was 7.515 cm, 50:50 composition was 8.384 cm, and composition 30:70 was 11.468 cm.

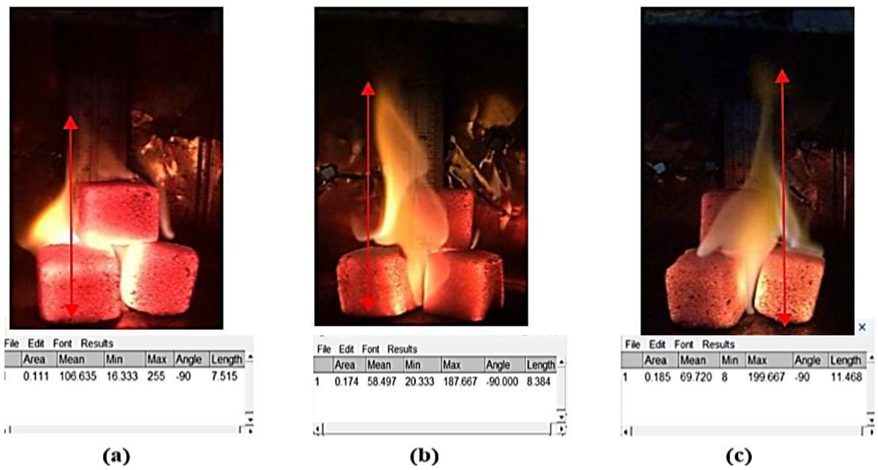

Fig. 5. Measurement of flame height using ImageJ software
(a) 70:30 (b) 50:50 (c) 30:70

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5. Water Boiling Test (WBT)

Figure 6 represents the water boiling time test showed that the 70:30 composition of bagasse and sugarcane peel had the longest boiling time at 12 minutes 59 seconds, followed by the 50:50 composition at 11 minutes 33 seconds, and the 30:70 composition with the shortest time at 10 minutes 45 seconds. The time difference between the longest and shortest boiling times was 2 minutes 14 seconds.

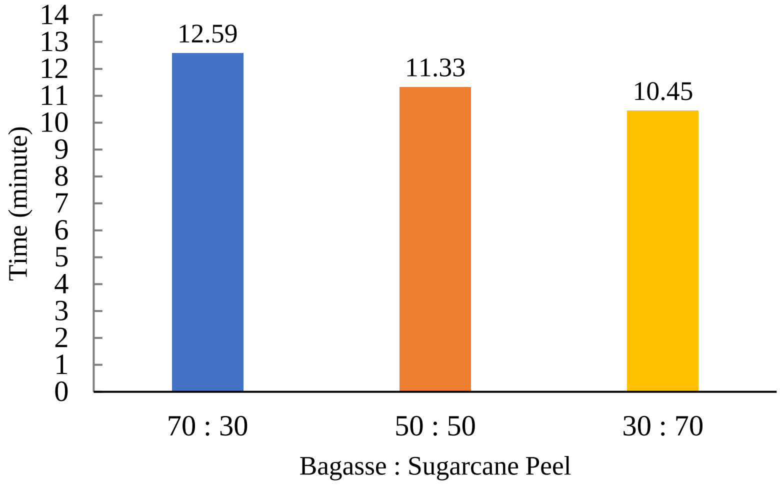

Fig. 6. Water boiling time test

It can be concluded that variations in the composition of bagasse and sugarcane peel significantly affect the water boiling duration, which in turn influences furnace efficiency. The test results show that each composition has a different peak temperature, with the average peak occurring around the 10th minute. The 30:70 composition reaches the highest temperature of 540 °C, contributing to a shorter boiling time. Combustion with higher calorific values requires less time to boil water, as more energy is released during combustion, allowing water to heat faster and reach its boiling point.

The test also produced unburned residue (charcoal) and ash. Combustion that results in lower charcoal residue typically indicates superior combustion performance, which can enhance the quality of the briquettes. The fuel briquettes with a 70:30 composition had a larger mass of charcoal and ash, weighing 72.3 grams, while the lowest mass of charcoal, 61 grams, was observed in the 30:70.

6. Thermal Efficiency

TLUD stove efficiency or thermal efficiency is the comparison between the heat produced by fuel briquettes and the heat absorbed by water to increase its temperature and evaporate it [21]. The results of the efficiency calculation using Eq. (1).

$$\eta = \frac{(m_a.C_p.\Delta T)+(\Delta m_a L)}{\Delta m_k.LHV} \times 100\ \% \quad \text{.......} \quad (1)$$

Where η thermal efficiency, m_a is mass of water, C_p is specific heat of water, ΔT is change in temperature, Δm_a is evaporated water mass, L is latent heat of evaporation, Δm_k is mass of charcoal (kg), LHV is lower heating value (net calorific value) of the briquette. A calculation of LHV using Eq. (2) and the result is shown in Figure 7.

$$LHV = HHV - 2.400\ (M + 9 \times H_2) \quad \text{(2)}$$

Where HHV is higher heating value (gross calorific value), M is the percentage water content in fuel.

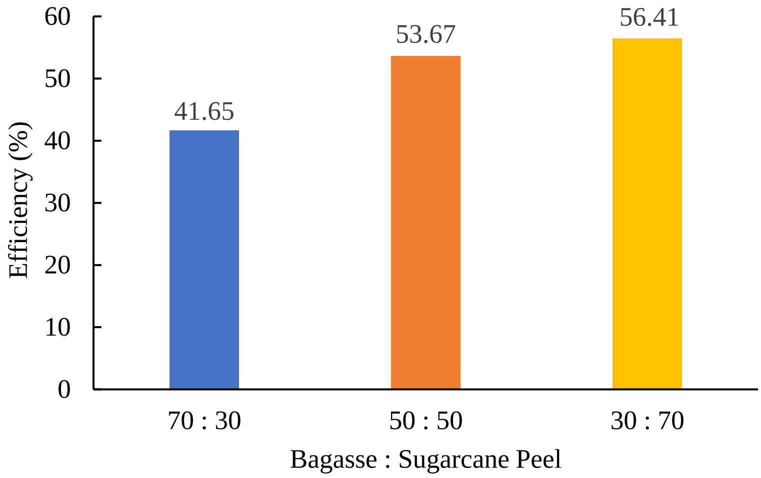

Fig. 7. Efficiency of the TLUD gasifier stove

Based on the research results, it was found that the fuel efficiency of mixed bagasse and sugarcane peel briquettes with a composition variation of 70:30 was 41.65%, 50:50 composition was 53.67%, and 30:70 composition was 56.41%. From testing each parameter on the TLUD stove, efficiency can be influenced by several things, such as temperature increase, char weight, and heating value. Compositions with a high calorific value increase the efficiency of the stove.

A high heating value of a fuel means more energy is available for the combustion process. This results in more efficient combustion, better heat transfer, and more effective fuel use. The high thermal efficiency of a gasifier is influenced by many things such as the design of the gasifier, type of stove, flow rate, and also the fuel used. Biomass with a carbonization process such as briquettes has a higher calorific value because the carbon content also increases when the carbonization process is carried out so that it can be used as alternative energy such as briquettes [22]. Carbonization of biomass in closed drums with good ventilation arrangements aims to minimize environmental impacts. Although this process still produces gas emissions, reductions in smoke and harmful particles can be achieved through proper control in the drum design. Studies have shown that pyrolysis under controlled conditions can reduce greenhouse gas emissions compared to direct combustion of biomass.

IV. Conclusions

This study aimed to develop biomass briquettes from a mixture of bagasse and sugarcane peel optimized for use in a top-lit updraft (TLUD) gasifier stove. By considering the differing characteristics of the two materials, the research sought to analyze the effects of briquette composition on calorific value, flame duration, temperature, flame height, and thermal efficiency of the TLUD stove. The experiments were conducted in a laboratory setting using a bomb calorimeter to determine the calorific value, and the TLUD stove was tested both with and without water boiling. The results indicate that briquettes with a 30:70 (bagasse peel) composition perform the best, achieving the highest calorific value of

6,242.292 cal/gram, followed by the 70:30 and 50:50 compositions. The 30:70 composition also exhibited the longest flame duration, the highest combustion chamber temperature, and. The stove's efficiency reached 56.41%. This efficiency was measured through the water boiling test, where the water temperature increased from 28.4°C to 90.4°C in 10 minutes 45 seconds. In the future, this research opens up the potential for further development by utilizing various types of biomass as alternative, environmentally friendly fuel sources. The application of this technology can contribute to energy sustainability by reducing dependence on LPG while also minimizing agricultural waste and emissions.

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