

Study on the Utilization of Banana Stem and Rice Bran Waste as a Biogas Source for Electric Power Generation

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Abstract – The increasing amount of agricultural waste, especially banana stem and rice bran waste, causes environmental problems due to improper disposal and low utilization. This study aims to overcome these problems by utilizing these two wastes as alternative raw materials in biogas production through an anaerobic fermentation process for 25 days. Three variations of substrates were used, namely 100% banana stem, 100% rice bran, and a 50:50 mixture. The parameters observed included methane gas (CH_4) content, pH, temperature, biogas pressure, flame quality, and electrical energy conversion. The results showed that the 50:50 mixture produced the highest methane content of 101.07 ppm, a maximum pressure of 104,266.99 Pa, and a stable blue flame for 16 minutes 25 seconds. The pH value was in the optimal range of 6.5–7.1 with a mesophilic temperature of 30–36.5°C. The highest electrical energy produced reached 0.112493 kWh. These results demonstrate that the mixture of banana stem waste and rice bran is more efficient in producing biogas and has the potential to be an environmentally friendly renewable energy source.

Keywords – Biogas; banana stem waste; rice bran; anaerobic fermentation; electricity conversion.

I. INTRODUCTION

RENEWABLE energy has become a major focus in global efforts to reduce dependence on fossil fuels and address climate change. One form of renewable energy that has great potential is biogas. Biogas is a gas produced from the anaerobic fermentation process of organic matter by microorganisms [1]. According to the latest report from the Ministry of Energy and Mineral Resources (ESDM) in 2024, the amount of biogas energy consumption in Indonesia reached 0.70 million BOE (Barrel Oil Equivalent) from the total consumption of 1,237.43 million BOE, indicating that there are still many opportunities that can be optimized in increasing the use of biogas energy [2].

Indonesia as an agricultural country produces various types of agricultural waste in large quantities, including banana stem waste and rice bran every year. Based on data from the Central Statistics Agency (BPS), banana production in Indonesia will reach around 9.34 million tons in 2023 and 9.26 million tons in 2024, with

banana stem waste producing around 30% of the total crop weight. Similarly, rice production in 2023 will reach around 53.98 million tons and 53.14 million tons in 2024, with rice bran as a byproduct accounting for around 10% of the total weight of milled rice [3].

Banana stems, which are usually discarded and left to rot in the field after harvesting the fruit, have a structure rich in cellulose and hemicellulose reaching 19–35% and 4.9–18.7% dry weight, as well as 3–9.2% lignin content [4]. This structure is generally the raw material needed for biogas production. Likewise, rice bran, which is usually used as animal feed, is a byproduct of the rice milling process, has a high nutritional content, including crude fiber of around 29.43%, which can also be further processed into biogas energy [5].

Based on field conditions, this organic waste is usually left to rot or burned around the land along with leaf waste and other waste without proper management. If this waste is left to rot and burned, it will certainly produce greenhouse gas emissions such as carbon dioxide and methane. Although methane itself is not a direct threat to human health, its accumulation in the atmosphere contributes to climate change through global warming. This can certainly worsen health conditions by increasing the frequency and intensity of heat waves,

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floods, and infectious diseases. Therefore, researchers are motivated to conduct research on the use of banana stem waste and rice bran as a source of biogas for power generation. The aim is to reduce this waste and address the problems that arise.

Several previous researchers have reviewed research on the utilization of waste, both agricultural waste, livestock waste, and industrial by-product waste, which the author uses as a source of literature in this study. Research conducted by [6] has reviewed the utilization of banana peel waste and water spinach for biogas using an anaerobic bioreactor, showing that the effect of a 2:1 variable ratio with banana peel waste substrate contains more gas with a total of 119,554 liters and a more homogeneous flame test.

Research [7] examines the effect of adding liquid tofu waste and banana peel to cow dung from differences in biogas quality, showing that a mixture of cow dung and water produces 4 liters of biogas in 7 days with a methane content of 48.96%. Meanwhile, a mixture of cow dung, liquid tofu waste, banana peel waste, and water produces 4 liters of biogas in 4 days with a methane content of 67.59%. Likewise, research [8], which examines the effect of adding banana stem waste and rice straw on biogas production, shows that the best results according to observations for 7 days—namely the addition of 100 grams of rice straw and 100 grams of banana stems for 3 repetitions—have an average volume of 2143.15 mm³.

Research [9] examines the utilization of water hyacinth biomass from Limboto Lake using a TAK reactor (Without Acidification with Cow Dung Biostarter) and a TAB reactor (Without Acidification with Bakicot Intestine Biostarter) as biogas producers, showing that the TAK reactor produces 50 mL of biogas while the TAB reactor also produces 50 mL of biogas. Meanwhile, in the advanced stage with the addition of acid and the addition of 1:1 biostarter, the results obtained were 102 mL in the KS reactor (Cow Dung) and 5 mL in the SD reactor (Substrate Without Addition of 1:1 Cow Dung). Research [10], which examined the potential for electrical energy from biogas mixed with ketapang leaf waste and buffalo feces, found that the biogas produced from a mixture of non-starter materials was 0.00465 m³, while biogas with a starter was 0.0028 m³. The potential for electrical energy produced from non-starter biogas production was 0.022 kWh and with a starter was 0.013 kWh.

Biogas formation occurs through several stages, starting from hydrolysis, which is the breakdown of complex organic elements such as carbohydrates, proteins, and fats into simple molecules. This is followed by acidogenesis and acetogenesis, which is the con-

version of simple molecules into organic acids, hydrogen, and CO₂; then complex organic acids such as propionate and butyrate are converted into acetic acid as the main substrate for the next stage. Then the final stage (methanogenesis) is the conversion of acetic acid into CH₄ by methanogenic bacteria and CO₂ which is formed due to the reaction of hydrogen with CO₂ [11, 12]. This process is highly dependent on the balance of hydrolytic, acidogenic, and methanogenic bacteria, as well as optimum conditions such as a temperature of 25–35°C and a pH of 6.8–7.5 to maintain the stability of biogas production which generally contains 54–70% CH₄ and 27–45% CO₂ [13].

This research differs from previous studies that often use materials such as banana peels, straw, water hyacinth, tofu waste, or ketapang leaves without considering the balance of the mixture ratio of the materials used. Meanwhile, this study combines banana stem waste and rice bran, which are chemically complementary. Banana stems are high in cellulose, while rice bran is rich in protein and fat, resulting in a more optimal fermentation substrate in producing methane gas (CH₄). In addition, this study uses Arduino-based MQ-9 and MQ-135 digital gas sensors and a U-manometer to measure gas levels and pressure more accurately, which differs from previous studies that were still manual.

II. RESEARCH METHODS

This research used an experimental method and tool design with a descriptive quantitative approach. The objectives of this study were to determine the methane gas value, pH value, and temperature produced from the biogas production process using banana stem waste and rice bran; to determine the effect of HRT (Hydraulic Retention Time) on biogas pressure and flame test resulting from the anaerobic process; and to determine the electrical energy that can be generated from the pressure of the fermented biogas. This research was conducted in Tumbihe Village, Kabila District, Bone Bolango Regency, Gorontalo Province. The study period was from September 2024 to May 2025, from the design stage to the analysis of fermentation results.

i. Materials and Tools

The main materials used in this study were finely chopped banana stem waste for easy decomposition, rice bran as organic material with high carbohydrate and protein content, starter in the form of cow dung mixed with EM4 as a source of methanogenic bacteria, and water which functions to dissolve organic materials and maintain fermentation humidity. All materials were

obtained from the environment around the research location.

The tools used in this research included: a fixed-dome type biogas digester made of fiberglass with a total capacity of 120 liters (0.128 m³); a U-manometer for measuring gas pressure produced in the digester; MQ-9 and MQ-135 gas sensors connected to an Arduino Uno microcontroller for detecting CH₄, CO, and CO₂; a digital pH meter; a digital thermometer; digital scales; a banana stem shredder; and a gas storage balloon used to store gas before the flame quality test.

ii. Reactor Design and Preparation

The reactor was constructed from a 120 L fiberglass drum and equipped with three main valves: an inlet valve for feeding materials, an outlet valve for removing residue, and a gas valve for conveying gas to the storage balloon. The reactor was also equipped with a chopper connected to the inlet, gas sensors, a U-shaped manometer, a digital pH meter, and a digital thermometer to monitor fermentation parameters in real time.

iii. Preparation and Determination of Material Composition

The operating volume of the digester was set to 60% of the total capacity (0.128 m³). Three material composition variations were used as shown in Table 1.

Table 1: Variations in Material Composition

Variation	Banana Stem	Rice Bran	Starter (cow manure + EM4)
V1	100%	0%	7%
V2	0%	100%	7%
V3	50%	50%	7%

The total material entering the digester was approximately 77 L, consisting of 20 kg of organic material, 52 L of water, and 5 kg of starter, using a ratio of 1:2 between organic material and water. The banana stem waste was chopped using a shredder to accelerate the decomposition process.

iv. Digester Filling and Fermentation Process

After all ingredients were mixed homogeneously, the mixture was fed into the digester until it reached 60% of total capacity. Initial pH and temperature values were measured before sealing the digester to create anaerobic conditions. The fermentation process lasted for 25 days (HRT = 25 days) with daily monitoring of the following parameters: fermentation temperature (°C), substrate pH, gas pressure (cm), and CH₄, CO₂, and CO concentrations.

v. Data Collection

The data collection process was carried out daily using the following procedures:

1. Gas content (CH₄, CO₂, CO) was measured using MQ-9 and MQ-135 sensors connected to an Arduino Uno microcontroller. The measurement results were monitored through the Arduino IDE Serial Monitor.
2. Digester pressure was measured using a U-manometer by calculating the difference in water height (Δh) between the two columns, which was then converted into absolute pressure (P_{abs}) in Pascal units.
3. The pH value was measured using a digital pH meter calibrated with standard buffer solutions (pH 4, 6, and 9).
4. Fermentation temperature (°C) was monitored using a digital thermometer mounted at the upper section of the digester.

The collected data were then analyzed to observe the relationship between fermentation parameters and to compare outcomes among the different material variations.

vi. Data Analysis

The analysis was conducted descriptively and quantitatively, focusing on the changes in each parameter during the fermentation process and on comparing results across treatments.

1. Methane Gas Analysis (CH₄)

CH₄ data obtained from the sensors were analyzed to observe the pattern of daily gas concentration increase and to determine which substrate variation produced the highest methane levels.

2. pH and Temperature Analysis

The pH and temperature values were examined to determine the optimal fermentation phase for each substrate and to assess process stability under mesophilic conditions (25–44°C).

3. Pressure Analysis and HRT

Gas pressure measured from the U-manometer was converted into absolute pressure using the following equation:

$$P_{abs} = P_{atm} + \rho_{H_2O} \times g \times \Delta h \quad (1)$$

4. Flame Test Analysis

The biogas flame test was carried out by igniting the gas and observing the flame color and duration as indicators of gas quality. According to [14], a blue flame indicates a higher CH₄ content, while a yellow flame indicates a higher CO₂ concentration.

5. Energy Conversion to Electrical from Biogas

The potential electrical energy was calculated based on the volume of biogas produced during fermentation using the following equation:

$$E_{\text{elect.}} = V_2 \times \text{Energy proportionality} \times \eta_{\text{gen}} \quad (2)$$

Before calculating electrical energy, the pressure (in Pascal) must first be converted into gas volume using:

$$V_2 = \frac{P_{\text{abs}} \times V_{\text{rg}}}{P_1} \quad (3)$$

After the volume for each sample was obtained, the potential electrical energy could be determined using Equation (2). Based on [15], the efficiency of converting biogas to electrical energy using a generator ranges between 0.30–0.40, or approximately 30–40% for small-scale biogas power plants.

III. RESULTS AND DISCUSSION

This research began with the design and manufacture of a biogas reactor equipped with a chopping machine and an Arduino-based gas measuring instrument using MQ-9, MQ-135 sensors, and a U-manometer, as shown in Figure 1.



Figure 1: Reactor equipped with a chopping machine and measuring instruments

i. Methane Gas (CH_4) Analysis

Observations on methane gas (CH_4) content during the fermentation process for three treatments (100% banana stems, 100% rice bran, and a 50%:50% mixture) showed significant variations in both total gas produced and the daily rate of increase. The development of methane gas for each treatment is presented in Figure 2.

Based on Figure 2, the 100% banana stem treatment produced the highest methane concentration of

76.37 ppm on day 25, with the highest daily increase of 14.8 ppm on day 24 and the largest decrease of -8.92 ppm on day 7. The 100% rice bran treatment produced the highest methane content of 85.01 ppm on day 23, with a daily increase of 10.92 ppm on day 16 and a decrease of -11.23 ppm on day 7.

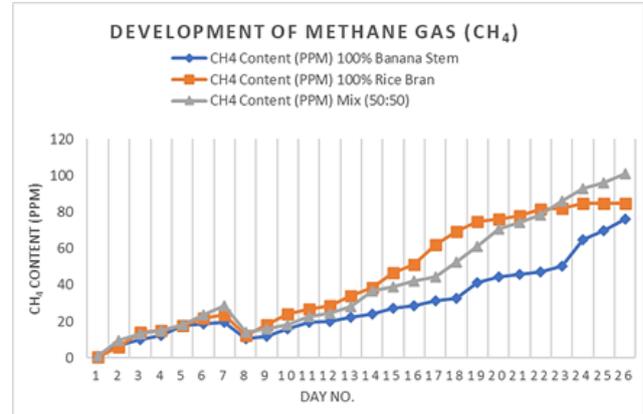


Figure 2: Development of Methane Gas (CH_4)

The 50%:50% mixture treatment produced the highest methane content overall, reaching 101.07 ppm on day 25, with the largest daily increase of 9.5 ppm on day 19 and the biggest decrease of -14.72 ppm on day 7. The decrease in all treatments on day 7 occurred because gases collected on the previous day still contained oxygen, requiring venting to maintain anaerobic conditions.

These results indicate that the combined substrate provides the highest and most stable methane production, in line with findings from [16], which state that substrate combinations increase fermentation efficiency and methane output.

ii. pH Analysis of Each Sample

pH analysis was carried out to determine the acidity or alkalinity of each sample throughout the fermentation process. pH is a critical parameter because it affects microorganism activity and the stability of fermentation. The recorded pH values for 25 days are presented in Figure 3.

Based on Figure 3, initial pH values were slightly different across treatments: 6.51 (banana stems), 6.77 (rice bran), and 6.68 (mixture). During the first week, pH decreased due to organic acid formation by acidogenic bacteria. The lowest pH occurred on day 7: 6.41 for banana stems, 4.79 for rice bran, and 4.6 for the mixture.

Following the acidogenesis phase, pH gradually increased until the end of fermentation (day 25), reaching 6.86 (banana stems), 7.02 (rice bran), and 7.10 (mixture). The rise in pH indicates the onset of the

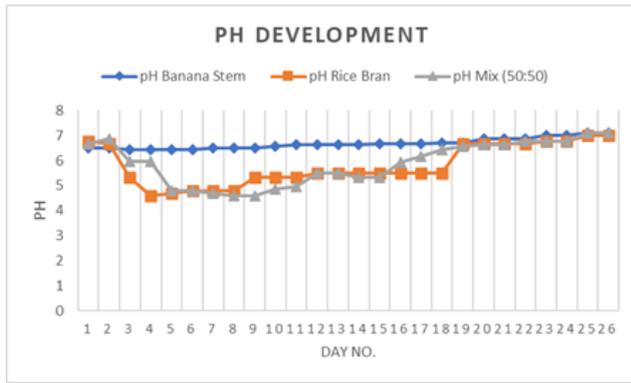


Figure 3: pH Development of Each Substrate

methanogenesis phase, where organic acids are converted into methane.

According to [17], the optimal pH for biogas production ranges from 6.5–8.0, while pH below 6.5 may inhibit methanogenic activity. This aligns with [18], which states that methane formation is most effective at pH 5.5–8.5. Thus, the pH conditions in all treatments were within the ideal range for effective methane production.

iii. Fermentation Temperature Analysis

Temperature monitoring during the 25-day fermentation process was conducted using a digital thermometer installed in the digester. The temperature development for each variation is shown in Figure 4.

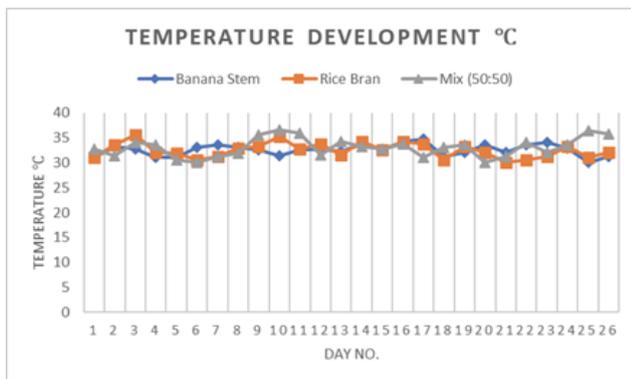


Figure 4: Temperature Development (°C)

Based on Figure 4, the banana stem treatment recorded temperatures ranging from 30°C to 34.8°C. The rice bran treatment showed wider fluctuations from 30°C to 35.5°C. The mixture treatment showed the highest and most varied temperature range of 30°C to 36.5°C.

Research conducted by [19] states that methane production occurs under mesophilic (25–44°C) and thermophilic (50–65°C) conditions, with most practical biogas systems operating in the mesophilic range. In this study, temperatures for all treatments remained

within mesophilic conditions, with peak methane production occurring at 32.9°C (mixture), 33.4°C (rice bran), and 34.8°C (banana stems).

Temperature variations were also influenced by environmental conditions surrounding the digester.

iv. Pressure Analysis and HRT

Biogas pressure was measured using a U-manometer and converted to Pascal (Pa) units using:

$$P_{\text{abs}} = P_{\text{atm}} + \rho_{\text{H}_2\text{O}} \times g \times \Delta h \quad (4)$$

with the following definitions: where P_{abs} is the absolute pressure (N/m^2), $\rho_{\text{H}_2\text{O}}$ is the density of water (1000 kg/m^3), g is the gravitational acceleration (9.80665 m/s^2), Δh is the height difference of the water column (m), and P_{atm} is the atmospheric pressure (101325 N/m^2).

The calculated biogas pressure results for the three samples are shown in Figure 5.

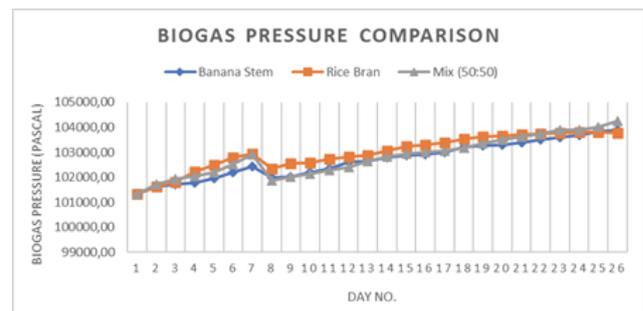


Figure 5: Biogas Pressure Comparison (Pascals)

Based on Figure 5, biogas pressure increased with fermentation time (HRT). The 50:50 mixture produced the highest pressure of 104266.99 Pa on day 25, followed by rice bran (103776.66 Pa) and banana stems (103884.54 Pa). This pressure increase reflects the increased gas volume produced by methanogenic microbial activity.

The pressure drop on day 7 occurred because early-stage gas still contained oxygen, which was released to maintain anaerobic conditions. Afterward, pressure continued to rise, reaching a peak at the end of fermentation. The 50:50 mixture performed best due to nutrient balance that supported microbial growth.

These findings agree with [7], which stated that mixed substrates produce higher pressure and gas volume than single-material substrates. Thus, the optimal HRT was achieved on day 25.

v. Flame Test Analysis

Flame tests were used to determine biogas quality based on flame color and burning duration. The flame test results for each sample are shown in Figure 6.

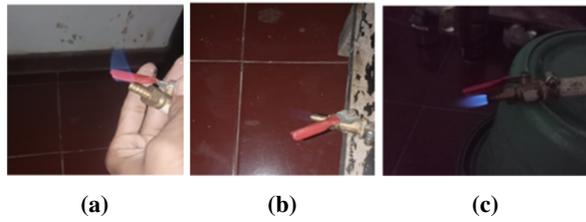


Figure 6: Flame Test of Each Sample (a) Banana Stem Waste (b) Rice Bran (c) Mixture (50:50)

Based on Figure 6, the banana stem biogas produced a flame lasting 8 minutes 34 seconds, blue in color but easily extinguished under high pressure, indicating that CO_2 was still dominant. Rice bran produced a flame lasting 8 minutes 56 seconds with a less blue color but more stable, influenced by gas humidity and mixed compositions.

The 50:50 mixture produced the best results with a bright blue flame lasting 16 minutes 25 seconds, indicating a higher CH_4 content. These results confirm that substrate combinations provide better methane composition and biogas quality.

vi. Biogas Energy Conversion Analysis

Biogas pressure was converted into gas volume using the digester gas chamber volume of 0.0512 m^3 (40% of 0.128 m^3). Gas volume was calculated using:

$$V_2 = \frac{P_{\text{abs}} \times V_{\text{rg}}}{P_1} \quad (5)$$

where V_2 is the final gas volume (m^3), P_1 is the initial gas pressure (1 atm), P_{abs} is the final gas pressure (Pa), and V_{rg} is the digester gas space volume (m^3).

The resulting gas volumes were 0.05249 m^3 (banana stem), 0.05244 m^3 (rice bran), and 0.05269 m^3 (mixture). According to [20], 1 m^3 of biogas equals 6.1 kWh of electrical energy. Thus, electrical energy was computed using:

$$E_{\text{electricity}} = V_2 \times 6.1 \times \eta_{\text{gen}} \quad (6)$$

with a generator efficiency of 30–40% (0.30–0.40). Using 35% efficiency:

$$E_{\text{electricity}} = 0.05249 \times 6.1 \times 0.35 = 0.11207 \text{ kWh}$$

The total electrical energy produced was:

1. Banana stem: 0.11207 kWh
2. Rice bran: 0.1119594 kWh
3. Mixture: 0.112493 kWh

The mixture produced the highest electrical energy, confirming synergistic substrate performance.

IV. CONCLUSION

The 25-day fermentation process produced methane gas concentrations of 76.37 ppm (banana stem), 85.01 ppm (rice bran), and 101.07 ppm (50:50 mixture). pH decreased early and increased toward day 25, indicating optimal fermentation. Temperatures stayed within 30°C – 36.5°C (mesophilic zone) with highest methane production at 32.9°C – 34.8°C .

The 50:50 mixture produced the highest biogas pressure (104266.995 Pa), the longest flame time (16 minutes 25 seconds), and the most stable blue flame, indicating superior combustion quality. Electrical energy production reached 0.112493 kWh, higher than single-substrate samples.

Overall, the 50:50 mixture proved most effective, showing strong potential as an environmentally friendly renewable energy source.

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