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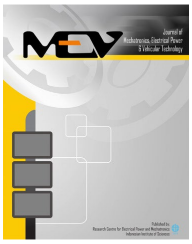

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Sustainable energy production: Performance evaluation of a generator-set using cow dung-based biogas

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Abstract

Interest in utilizing new and renewable energy sources, commonly known as bioenergy, has significantly grown in the past decade due to the mounting environmental concerns, such as air pollution, global warming, and ozone layer depletion, resulting from the accelerated consumption of fossil fuels. Biogas, derived from the anaerobic decomposition of organic materials like cow dung, presents a viable solution due to its high methane content and calorific value. This study aims to assess the performance of biogas-fueled generator sets utilizing cow dung as the raw material for biogas production. The generator set employed has a power capacity of 2,500 Watts, and various load variations ranging from 150 to 350 Watts were applied. The parameters measured include voltage, current, biogas discharge, and efficiency. The findings indicate that the generator's output power for the five load variations of 150, 200, 250, 300, and 350 Watts are 150, 226.7, 266, 298.3, and 372.3 Watts, respectively. Moreover, the fuel consumption rates range from 0.013 to 0.009 kg/minute for the 150 to 350 Watts load, respectively. Notably, the 350 Watts loading exhibits the highest efficiency compared to other load variations, with an efficiency percentage of 14.51 %. This research advances our knowledge of the useful uses of biogas in generating systems, where its use is growing.

Keywords: biogas consumption; generator sets; efficiency optimization.

I. Introduction

The increasing energy demand year by year is not matched by an adequate corresponding increase in energy sources, resulting in escalating fuel prices, particularly for fossil fuels [1]. This trend is likely to be more pronounced in the near-term future as conventional oil and gas are depleted and difficult-to-extract unconventional oil and gas become a larger part of the fossil-fuel supply [2].

To address future energy needs, it is crucial to seek efficient and economical alternative energy sources. The transition to renewable energy systems is technically feasible and economically viable, offering substantial benefits such as energy savings and low-cost energy supply [3]. However, there are barriers hindering investment in clean energy production, including the affordability and availability of fossil fuels in certain regions [4]. Despite the potential of renewable energy sources like solar, wind, and

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hydropower, investment in them has fluctuated [5]. A comprehensive energy transition requires a sufficient rate of capital growth, progress in energy efficiency, and control of energy demand [6]. Therefore, exploring renewable energy alternatives is crucial, especially as fossil fuel resources decline and their use contributes to global warming [7].

Indonesia has vast potential for renewable energy sources such as solar photovoltaic (PV) energy, ocean currents, and biogas. Solar PV has the largest potential, exceeding all other renewable energy resources combined and can meet future energy needs at a competitive cost [8]. The energy of ocean currents is also a stable and predictable source that can be developed especially in coastal areas and small islands [9]. Additionally, biogas from animal manure can serve as an alternative energy source beyond fossil fuels [10].

Biogas, produced through the anaerobic decomposition of organic matter, primarily consists of methane (CH_4) and carbon dioxide (CO_2) gases. It exhibits considerable potential as a renewable energy source due to its high methane content and calorific value. The removal of impurities from biogas enhances its calorific value. Biogas can be utilized as a fuel for vehicles, household electricity, and generator sets [11][12].

A study evaluated a gasoline-powered motor generator adapted to biogas, achieving a generator power of 501 Watts with an efficiency of 7.53 % when using a resistive load of 510 Watts. The average volumetric flow was 1.97 m^3/h, indicating the feasibility of biogas as a fuel source in such systems [13].

The examination of exhaust emissions from gasoline and biogas-fueled generators at different loads reveals significant differences in emission profiles and efficiency [14]. Gasoline generators typically emit higher levels of carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbons (HC) [15][16] compared to biogas-fueled generators [17][18]. The studies highlight the potential of biogas as a cleaner alternative, with variations in emissions depending on the type of biogas and the load applied to the generator. The results showed that the generator produced higher levels of CO_2 when using gasoline (2.54 %) compared to biogas (2.40 %) [19]. Additionally, gasoline - fueled operations had higher O_2 content (18.66 %) compared to biogas-fueled operations (15.60 %) [2]. On the other hand, CO emissions were significantly higher in gasoline-fueled operations (5.06 %) than in biogas-fueled operations (0.20 %) [20].

Despite the increasing recognition of biogas as a viable renewable energy source, there exists a noticeable gap in comprehensive studies evaluating its performance in generator sets. This study utilized cow dung as the raw material for biogas production, employing a generator with a maximum output power of 2,500 Watts. The tests were conducted to determine the generator's performance with varying load levels of 150, 200, 250, 300, and 350 Watts. This research objective is to evaluate the performance of a biogas-fueled generator, utilizing cow dung as the feedstock, under different load conditions (150 – 350 Watts). The study aims to provide insights into the optimal utilization of biogas as a sustainable fuel source for generator sets, contributing to the broader discourse on renewable energy utilization in the Indonesian context.

II. Materials and Methods

The testing material utilized in this study is biogas derived from cow dung, which serves as the generator fuel. The equipment employed for the research includes the Firman FPG3800E1 generator with a capacity of 2,500 Watts. The biogas composition was measured using a Geotech GA5000 gas analyzer, while voltage/potential difference and electric current were measured using a voltmeter and an ammeter, respectively. For the generator, with a power of 100 Watts per bulb and five lamps with a power of 200 Watts per bulb was used.

The collected test data focused on voltage, electric current, generator output power, and biogas flow rate. Then to determine the input power parameters and generator efficiency, equations (1), (2), and (3) were used. The mass of methane (m) in biogas can be calculated using equation (1), where ρCH_4 is the density of methane and Q_{biogas} is the volumetric flow rate of biogas.

$$m = \rho CH_4 \, x \, Q_{biogas} \tag{1}$$

The system input energy (Q_{in}) was calculated using equation (2) where $\dot{m}CH_4$ is the mass flow rate of methane and LHV_{CH_4} is the low calorific value of methane.

$$Q_{in} = \dot{m}CH_4 \, x \, LHV_{CH_4} \tag{2}$$

Furthermore, as written in equation (3), the thermal efficiency of the system (η) was determined using the relationship between equations (1) and (2), where W_{net} is the net power produced by the system, and Q_{in} is the calculated input energy.

$$\eta = \frac{W_{net}}{Q_{in}} x 100\% \tag{3}$$

Data recording occurred at each loading level (150, 200, 250, 300, and 350 Watts). Biogas discharge was quantified using a Siargo MF5700 flow meter. The entire testing process was conducted twice at each loading level to ensure data accuracy and consistency.

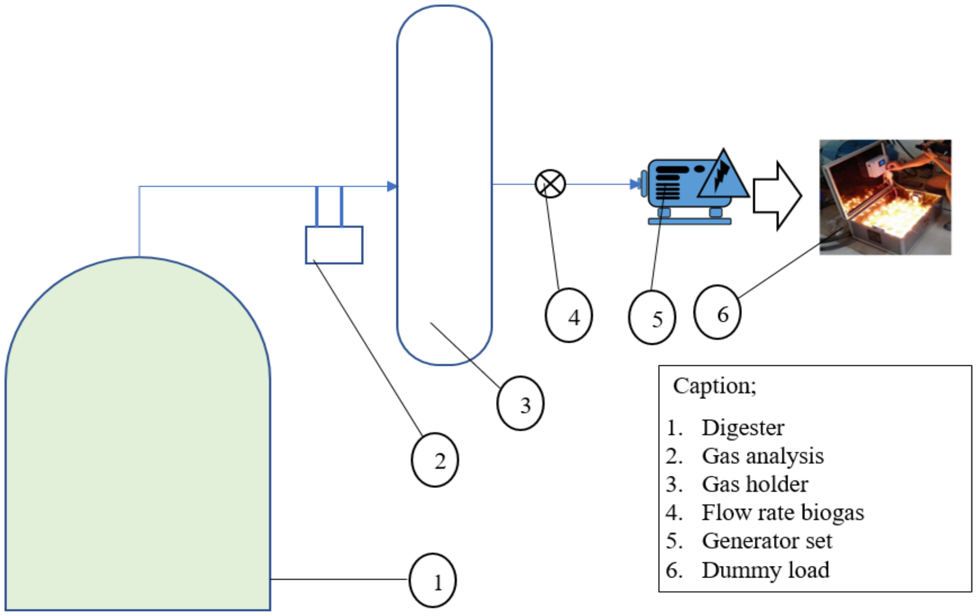

Figure 1. Test scheme for a biogas generator.

The illustration in Figure 1 provides an overview of the testing process. The initial step involves the preparation of the gas fuel source, represented by the digester (1), in which a hose is attached to the biogas channel to measure the biogas content using gas analyzer (2) before utilization as fuel. Once the biogas content is determined, it is directed through the channel towards the gas holder (3) to be stored as pressurized gas adjusted according to requirements. Following the preparation, a flowmeter rate for biogas (4) is installed in the biogas fuel line leading to the generator set (5). The generator set, connected to the biogas fuel, is then activated to generate electrical power. A dummy load device is employed to measure the output power.

This study recognizes certain limitations that warrant consideration. Firstly, due to constrained resources, our research is restricted to measuring detailed parameters such as brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC). These parameters are undeniably crucial in a comprehensive analysis of engine performance. However, the unavailability of specialized equipment and financial constraints hindered our ability to delve into these aspects. Consequently, this research primarily focuses on the generator's output power and the biogas fuel consumption rate to provide valuable insights within the scope of our available resources. Future research endeavors with more extensive resources could undertake broader analyses, incorporating parameters like BTE and BSFC, for a more comprehensive performance evaluation of biogas generators.

III. Results and Discussions

The results of biogas composition measurements before being utilized as generator fuel are presented in Table 1. The experiment involved operating the biogas-fueled generator under a range of loading powers, spanning from 150 to 350 Watts. The generated voltage values were recorded and analyzed during these varying loading conditions. The analysis of Figure 2 reveals a noteworthy relationship between the level of load and the voltage value in the biogas-fueled generator. As the load increases, there is a discernible decline in the voltage output. This phenomenon can be attributed to the additional load, which in turn results in an increase in the electric current flowing through the generator. Consequently, the generator's output voltage experiences a decrease, indicating that the system is subjected to greater demand as the load grows.

It is crucial to emphasize that the standard electric voltage set by the State Electricity Company in Indonesia (PLN) is fixed at 220 Volts, with a permissible tolerance of +5 % and -10 %. Thus, this prescribed voltage range provides an acceptable and safe threshold for electrical devices in the country.

Table 1.
Biogas composition.

No.	Gas component	Total
1	CH_4	57.40 (%)
2	CO_2	44.30 (%)
3	H_2S	1760 (ppm)
4	O_2	0.30 (%)

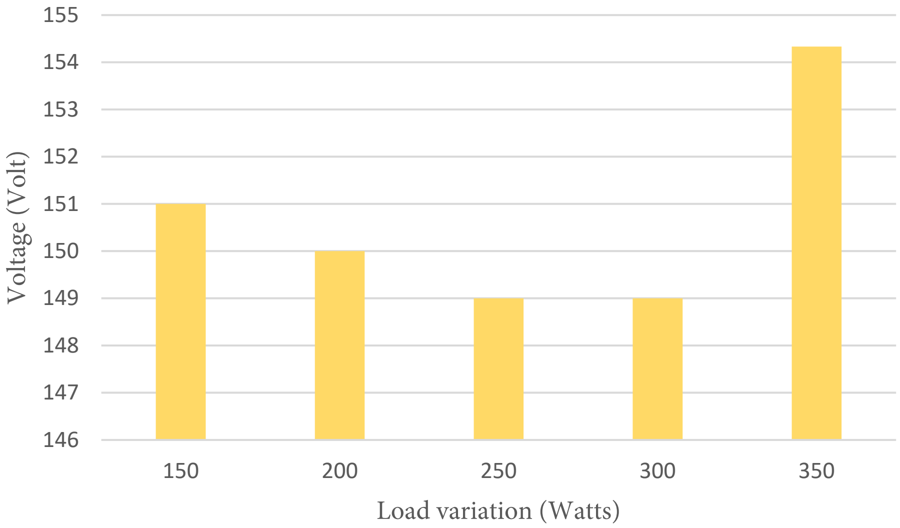

Figure 2. Biogas-fueled generator set voltage.

However, the analysis highlights a concerning observation regarding the generator's performance at loads of 150 to 350 Watts. At all load levels, the generator's output voltage is outside the acceptable range set by the State Electricity Company of Indonesia. Consequently, the generator failed to meet these specified voltage standards due to sudden changes in load during testing, potentially causing suboptimal function and possible risk of damage to electrical devices connected to the generator.

The voltage output data during the generator set testing, as shown in Figure 2, reveals a relatively stable performance across various load conditions, with minor fluctuations observed. At lower loads of 150 Watts and 200 Watts, the voltage output was recorded at 151 V and 150 V, respectively, indicating consistent voltage delivery close to the nominal value. As the load increased to 250 Watts and 300 Watts, the voltage slightly decreased to 149 V, suggesting a marginal drop in generator output under these load conditions. This could be attributed to the increased electrical demand affecting the generator's ability to maintain steady voltage levels.

At the highest tested load of 350 Watts, the voltage increased to 154.33 V, representing a notable deviation compared to the preceding load levels. This increase could be due to the generator's automatic voltage regulation mechanism, compensating for higher loads by slightly overcompensating the output voltage [21]. Alternatively, it may indicate that the generator operates more efficiently at higher loads within the tested range [22].

The overall voltage output, as depicted in Figure 2, demonstrates the generator's capability to provide a stable power supply under varying load conditions with minor deviations likely within acceptable limits for practical applications. Future investigations could focus on assessing the impact of these voltage variations on connected devices, especially at higher loads, and on optimizing the generator's voltage regulation system to minimize fluctuations.

Based on the test results of the biogas-fueled generator presented in Figure 3, the performance shows a linear relationship between the load given and the output power generated. For load variations ranging from 150 Watts to 350 Watts, the output power increases proportionally to the load, starting from around 150 Watts to 350 Watts. Based on previous research, it is actually inversely proportional, which suggests that the relationship is influenced by various factors such as biogas composition, engine efficiency, and load conditions [22]. This indicates that further testing is still needed to achieve its maximum load.

The testing of a biogas generator set at loads up to 350 Watts, despite not reaching its maximum capacity of 2500 Watts, provides valuable insights into the system's stability and performance under varying loads. This limitation in testing was primarily due to the insufficient availability of biogas, which is a common challenge in biogas systems. The results from these tests can still offer significant information about the generator's efficiency, adaptability, and potential for rural electrification, as well as highlight areas for improvement in biogas supply and system design.

For future studies, additional testing with an adequate biogas supply is necessary to evaluate the generator set's maximum capacity. Testing at higher loads will help assess the performance limits of the generator and the system's efficiency under operating conditions closer to its maximum capacity. These additional data will also strengthen the discussion

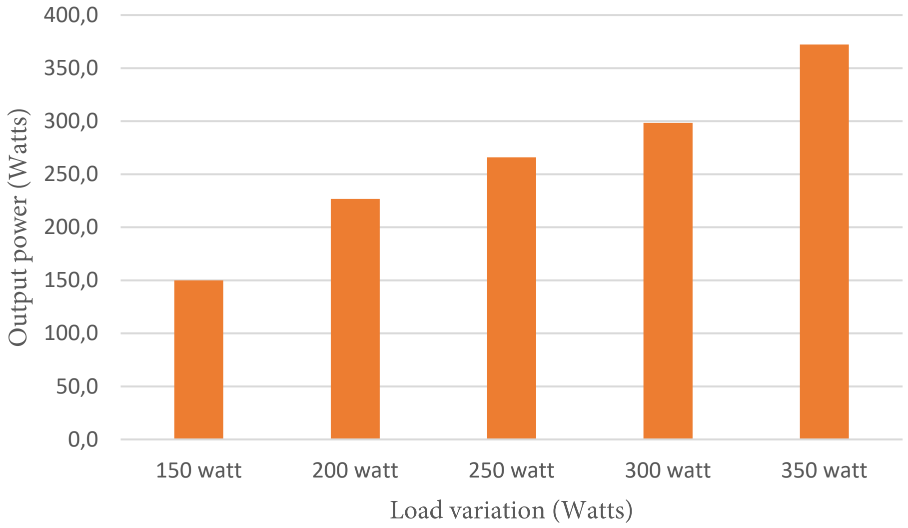

Figure 3. Generator set output power during testing.

regarding biogas's potential as a competitive fuel compared to fossil fuels.

The obtained data on the generator's efficiency is visually presented in Figure 4. For load variations ranging from 150 Watts to 350 Watts, the output power increased proportionally with the load, starting from approximately 150 Watts and reaching 350 Watts. This indicates that the generator system is capable of operating stably and efficiently within this load range, supported by an optimal biogas combustion process. These findings highlight the potential of biogas as a reliable alternative energy source for generator set applications.

The energy efficiency of the biogas-fueled generator set is influenced by two key factors: The actual output power and the input power. The output power represents the electrical power generated by the generator set, while the input power is related to the energy contained in the biogas used as fuel. The calculation of input power involves the multiplication of the methane mass flow rate, representing the amount of biogas consumed, by the lower heating value (LHV) of methane gas, which is measured to be 50.048 MJ/kg [23].

The generator's performance examination reveals that its energy efficiency is rather low; at a load of 350 Watts, the greatest figure was 14.51 %. The efficiency value of 14.51 % for a biogas generator is a significant improvement compared to some previous studies on biogas generators. This efficiency is higher than the 7.53 % efficiency reported in a study where a motor generator was adapted to biogas, which used a 4-

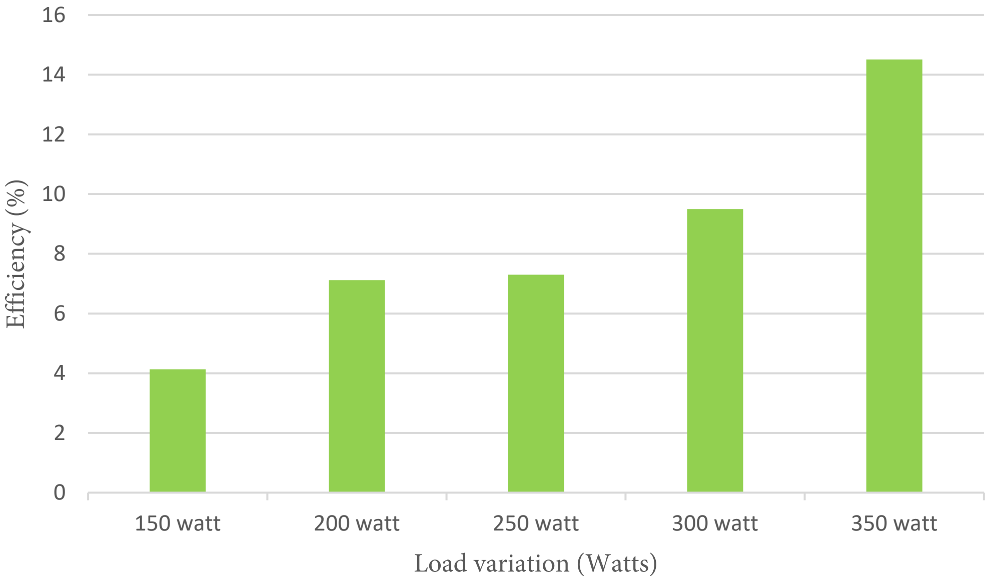

Figure 4. Generator set efficiency.

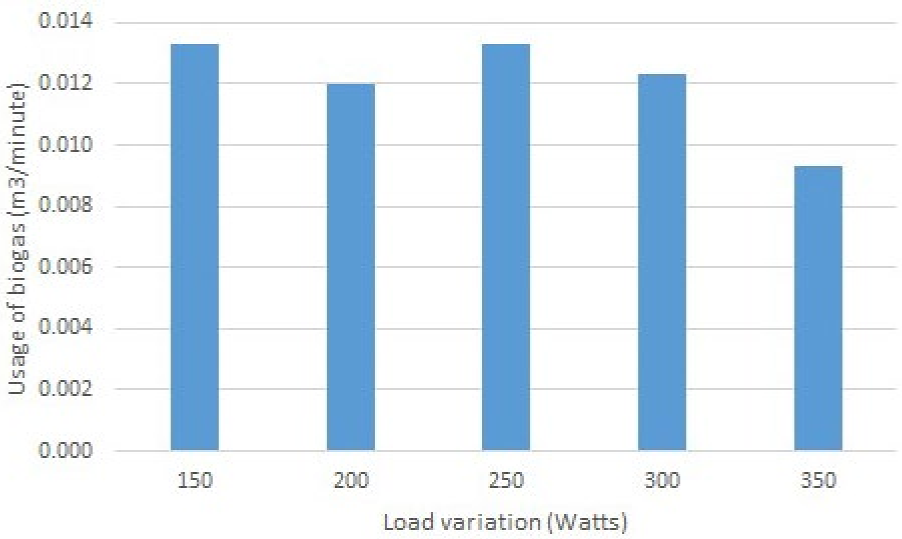

Figure 5. Use of biogas fuel in generator set.

stroke, single-cylinder gasoline-powered motor generator with a nominal power of 6.5 HP [13]. However, it is lower than the efficiencies reported in other contexts, such as a micro gas turbine achieving up to 23.4 % efficiency [23]. This indicates that the generator's overall performance and efficiency can still be greatly enhanced by employing a number of techniques, including engine parameter optimization and fuel blending. It has been demonstrated that blending biogas with biohydrogen increases combustion efficiency. Due to its faster flame speed, biohydrogen causes less ignition delay, which leads to more thorough combustion and improved brake thermal efficiency. Additionally, by lowering emissions of unburned hydrocarbons and carbon monoxide, this blend enhances engine performance overall [24].

Another factor influencing the generator set's performance is the impact of the biogas converter on its operation. The biogas converter is responsible for transforming the raw biogas into a usable form for the generator. Any inefficiencies or limitations in the converter's design or operation may hinder the generator set's performance, affecting its energy efficiency. Furthermore, the presence of impurities in the biogas fuel, such as sulfur and carbon dioxide, poses a significant challenge. These impurities can interfere with the combustion process, leading to incomplete combustion and reduced energy output. Proper purification of the biogas fuel would be essential to improve the combustion efficiency and subsequently enhance the generator set's performance [25][26]. The pressure and flow rate of biogas are critical for maintaining stable engine operation. Inconsistent pressure can lead to fluctuations in engine speed and power output, as observed in experiments where biogas consumption and engine speed varied with load changes [22].

The results of the biogas consumption test, as presented in Figure 5, indicate a distinct relationship between load variation and biogas usage in the generator set. At lower loads of 150 Watts and 250 Watts, the biogas consumption was recorded at 0.013 m^3/minute, representing the highest consumption values in the study. For intermediate loads of 200 Watts and 300 Watts, the consumption slightly decreased to 0.012 m^3/minute, indicating improved efficiency as the load increased. Notably, at the highest tested load of 350 Watts, the biogas consumption significantly dropped to 0.009 m^3/minute, reflecting the lowest fuel consumption across all load variations. This trend underscores the generator set's ability to optimize fuel usage as the operational load approaches its peak efficiency range, highlighting its potential for efficient energy conversion when utilizing biogas as a renewable energy source [22].

The reduction in biogas consumption at higher loads indicates an increase in fuel efficiency, likely due to an optimized combustion process within the generator with increasing power demand. This is in accordance with previous studies that revealed that at higher loads, the air-fuel ratio tends to be more optimal, which improves the combustion process [27]. However, the relatively stable consumption values at lower loads (150 Watt and 250 Watt) may indicate a minimum baseline fuel requirement to maintain engine stability, regardless of reduced power demand. The adaptability of the generator in managing biogas consumption at various loads underlines its operational reliability and potential to maximize fuel efficiency under various operating conditions [22].

To further substantiate these findings, additional tests at higher loads, closer to the generator's maximum capacity of 2500 Watts, are recommended. This will help evaluate whether biogas consumption continues to decrease with increased loads or whether efficiency plateaus at a certain threshold. Investigating key factors such as air-fuel mixture ratios, combustion efficiency, and system design could also provide insights into optimizing the generator's performance.

More testing under heavier loads - nearing the generator's maximum capacity of 2500 Watts is advised in order to support this research even more. As the load increases, this will assist in determining whether biogas use keeps declining or if efficiency peaks at a particular point. Key elements like system design, combustion efficiency, and air-fuel ratio can all be examined to improve generator performance. Further study is required to optimize the performance of biogas-powered generators. Considering more plentiful biogas sources will help meet peak loads. It is possible to generate energy more efficiently and profitably using this technology, which maximizes the advantages of biogas as a clean and sustainable energy source.

IV. Conclusion

The study concludes that the biogas-fueled generator set showed stable performance in the load range of 150 to 350 Watts. The highest efficiency of 14.51 % was achieved at a load of 350 Watts, indicating optimal combustion under these conditions. Biogas consumption showed good efficiency, with the lowest biogas fuel used at high loads at high loads. Although testing was limited by fuel availability, the results confirms the potential of biogas as a reliable alternative fuel for generator set applications. Further testing with sufficient fuel capacity is needed to evaluate the performance of the generator at maximum capacity, as well as to expand the analysis on exhaust emissions. This is important to support the implementation of biogas as a sustainable energy solution.

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Declarations

Author contribution

All authors contributed equally as the main contributor of this paper. All authors read and approved the final paper.

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Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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