Investigation on Emission Characteristics of a Biogas Fuelled Electric Generator

by Ig Artha Negara

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I Gede Artha Negara[1], I Gede Santosa[2] I Made Anom Adiaksa[3] I Wayan Suma Wibawa[4] Made Ardikosa Satrya Wibawa[5]

[1]Department Mechanical Engineering, Bali State Polytechnic, Bali, Indonesia
artha_negara@pnb.ac.id

[2]Department Mechanical Engineering, Bali State Polytechnic, Bali, Indonesia
gedesantosa@pnb.ac.id

[3]Department Mechanical Engineering, Bali State Polytechnic, Bali, Indonesia
madeanomadiaksa@pnb.ac.id

[4]Department Mechanical Engineering, Bali State Polytechnic, Bali, Indonesia
sumawibawa@pnb.ac.id

[5]Department Mechanical Engineering, Bali State Polytechnic, Bali, Indonesia
ardikosa_satrya@pnb.ac.id

***Abstract*— Utilization of renewable energy plays a pivotal role in dealing with the problem of clean and sustainable energy supply. One of them is the use of biomethane. Biomethane also known as an advanced biogas. This is considered due to the availability of feedstock and ease to obtain. This paper aims to investigate the emission characteristics of biogas fuel in electric generator engine. A 420 CC spark ignition four stroke engine with a maximum output power of 6000 W is applied in this paper. The investigation was carried out under various electric load conditions. Compared to gasoline, biogas emits relatively lower CO emissions than gasoline under variations in electric load. Results show that CO emissions of both fuels are relatively decreasing as the electric load increases. HC concentration decreased with increasing electric load while operating engine using gasoline. The maximum CO_2 emission achieved using gasoline is 8.5% around a 300 W electric load. NO emissions from both biogas and gasoline fuels increase as the electric load increases. The maximum NO observed at electric load of 500 W is 72 ppm and 25 ppm using gasoline and biogas respectively. Biogas fuelled electric generator system can achieve clean and sustainable energy supply.**

Keywords—biogas, electric generator, emission analysis, sustainable, green energy

I. Introduction

In recent years, the Indonesian government has seriously executed a bioenergy development program to achieve a renewable energy mix of 23% by 2025 [1]. This is due to the country is currently facing a crisis of fossil energy such as oil, coal and natural gas. Fossil energy reserves are running low, this condition is inversely proportional to the increasing human population [2][3]. Indonesia has a commitment to achieve net zero emissions by 2060 or sooner [4]. Indonesia is a country with large, widespread and diverse renewable energy potential. Based on data from the Ministry of Energy and Mineral Resources, Indonesia has potential bioenergy resources of 57 GW and only 3.073 MW has been utilized [5]. The development of bioenergy can replace fossil energy in almost all sectors, such as electricity, transportation, industry and households [6]. One form of utilization of bioenergy is biomethane. Indonesia as one of the largest palm oil producing countries in the world indicates the high potential of biomethane to be developed. Biomethane is well known as advanced biogas [7]. Biomethane is a byproduct produced through advanced processing of biogas. Biogas is formed through the fermentation process of organic bacteria such as animal manure and organic waste in a reactor called an anaerobic digester. Biogas is dominated by methane (CH_4) 45−75%, carbon dioxide (CO_2) 25−45%, and other gases in lower concentrations depending on the feedstock [8], [9].

Biogas reactors provide positive impacts such as sustainability and affordable fuel sources for lighting, cooling, cooking and electrical energy [10], [11]. The application of biogas reactors in rural areas provides benefits to the community in providing a source of clean energy. Methane is the most important component in biogas as a fuel source with an energy level of 6−6.5 kWh/m3 [7], [12], [13]. Every 1 m^3 of biogas has a calorific value of 22 megajoules, while 1 m^3 of methane contains 36 megajoules of calorific value. However, methane is also a gas that is 20 times more dangerous than carbon dioxide gas. Biogas also contains impurity gases which cause it to be corrosive [14]. Purification is highly recommended to separate the hydrogen sulfide (H_2S) component and unwanted gases to produce high-purity biogas [15], [16]. Biogas is highly recommended as a fuel [17]. Various studies have tried to use biogas as a fuel such as engine fuel. Minor modifications are required on the intake manifold to make it easier to operate using biogas. A research describes the design of the intake manifold system to improvise the volumetric efficiency of the engine. The low throat diameter intake manifold system design causes the fuel inlet pressure to increase. The study was carried out by Lim et al. [18] in investigating biogas as a fuel for vehicles. Research shows that at varying levels of CO_2 simulated biogas, NO emissions have increased and also produce high HC concentrations due to poor combustion quality. An experimental analysis by Jatana et al. [19] showed that engine combustion was reduced using biogas compared to diesel fuel. This is due to the presence of CO_2 concentration in the biogas and engine performance does not decrease until the CO_2 concentration increases to 40%.

This paper focuses on investigating the exhaust emission characteristics of biogas fuel from cowdung on electric generator engines. Biogas fuel exhaust emissions are compared to 90% RON gasoline which is the original engine fuel under various electric loading conditions. The generator electric engine is equipped with a power of 6000 W and a cylinder volume of 420 CC. This paper also explains how engine speed (rpm) of the electric generator engine affects the use of biogas and gasoline fuels.

II. METHOD

A. Material

Material tested in this study is biogas from Bali cowdung. This material is considered due to the availability of abundant and affordable feedstock. Cowdung experiences an anaerobic fermentation process. Fixed dome digester is applied in this research. This digester consists of two parts, one is the digester as a place for digesting biogas feedstock and the other is a fixed dome which is a place for gas collection. The advantages of this reactor are simple construction and easy maintenance. Biogas concentrations such as anaerobic digestion and landfill are reported in [20] which can be seen in Table 1. Table 1 describes biogas dominated by methane (53−70 vol%) and carbon dioxide (30−50 vol%) in an anaerobic digester. This is different from biogas landfills, where methane (30−65 vol%) and (25−47 vol%) carbon dioxide is observed. Gasoline fuel with 90% RON is applied in this paper for comparison of fuel exhaust emission characteristics. Table 2 shows the specifications of the electric generator engines used in this study. From this table, the engine type is 420 CC 4 stroke single cylinder with a maximum output power of 6000 Watt. The engine has been redesigned on the intake venturi system.

TABLE 1. ANAEROBIC DIGESTION AND LANDFILL BIOGAS COMPOSITION

Component	AD biogas	Landfill biogas	Units
CH_4	53−70	30−65	vol%
CO_2	30−50	25−47	vol%
N_2	2−6	<1−17	vol%
O_2	0−5	<1−3	vol%
H_2	NA	0−3	vol%
C_xH_y	NA	NA	vol%
H_2S	0−2000	30−500	ppm
NH_3	<100	0−5	ppm
Chlorines	<0.25	0.3−225	mg Nm^3

TABLE 2. ELECTRIC GENERATOR SPECIFICATION

Parameter	Specification
Model	General ET800LE Generator
Engine type	4 stroke, single cylinder spark ignition, 16 HP
Cooling system	Air cooling
Frequency	50 Hz
Output power	5500 watt
Maximum power	6000 watt
Cylinder volume	420 CC
Voltage setting	AVR
Starter type	Electric and manual

B. Experimental Setup of Bogas Fuelled Electric Generator

Experimental setup in working conditions using biogas is shown in Fig. 1. The main experimental components of this research are: Spark ignition electric generator, biogas mixer chamber, biogas bag, multi gas tester, electric load and gas emission analyzer. The selected fuels for investigation of exhaust emissions are biogas and gasoline. Biogas from cowdung produced is stored in bag. Biogas purification is carried out to reduce the hydrogen sulfide concentration level. The average concentration of methane was investigated with a multi-gas tester, where the amount of methane was about 40 vol%. The biogas air mixture component has been added to the system. The amount of air and biogas levels can be controlled manually through valves. Biogas mixer schematic is shown in Fig. 2. Engine has been minor modified to allow it to operate on biogas fuel. Generator is equipped with an electric starter motor to operate. Variations of light bulb loading were added from 0 W, 100 W, 200 W, 300 W, 400 W and 500 W for investigations. Concentrations of exhaust emissions such as carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NO) are measured using a gas analyzer where the specifications of the device are shown in Table 3.

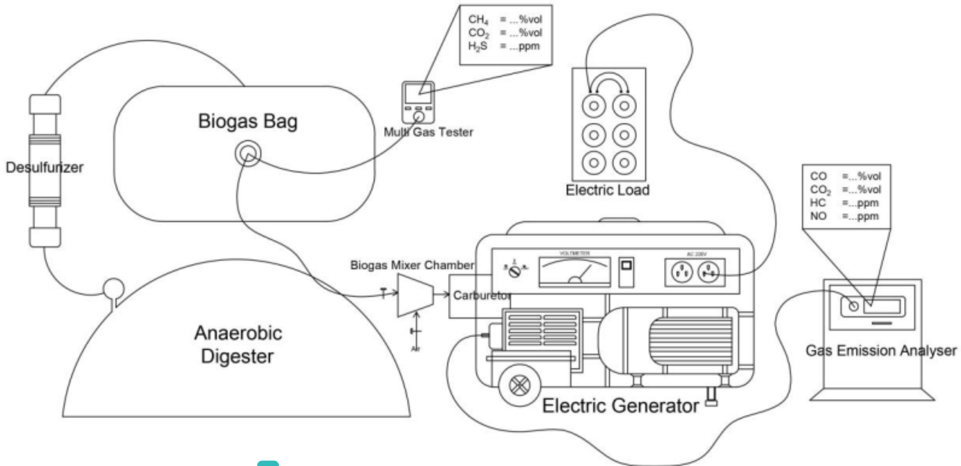

Fig. 1. Schematic representation of the experimental setup

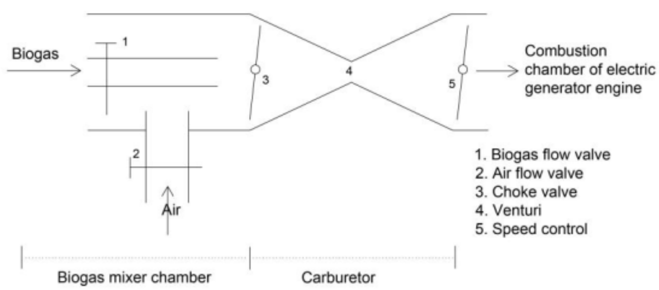

Fig. 2. Biogas mixer chamber schematic

The overall engine combustion reaction using biogas and gasoline fuels is described in equations (1) and (2) respectively. The combustion reaction of methane with oxygen produces carbon dioxide and water vapor. The mixer is equipped with various valves to control amount of air and fuel.

$$CH_4 + O_2 \rightarrow CO_2 + H_2O \qquad (1)$$

$$C_8H_{18} + O_2 \rightarrow CO_2 + H_2O \qquad (2)$$

TABLE 3. SPECIFICATION OF EXHAUST GAS ANALYSER[21]

Parameters	Measured range	Resolution
CO	0–10% vol.	0.01% vol.
CO_2	0–20% vol	0.1% vol.
HC	0–20.000 ppm	10 ppm (>2000 ppm)
NO	0–5.000 ppm	1 ppm

III. Result and Discussion

A. *Pollutant Emission Characteristics of Engine*

Fig. 3 shows CO exhaust emissions for biogas and gasoline with variations in electric loading. Carbon monoxide is determined from the mixed gas fuel temperature [22]. From the figure, it can be seen that CO emissions of both fuels are relatively decreasing as the electric load increases. Under 100 W load conditions, CO emissions were observed to be 2.2% using biogas and 4.6% for gasoline. CO decreased at 200 W load, which was 1.6% using biogas and 4% on gasoline. At a load of 500 W, 0.16% CO biogas was observed and 1.1% for gasoline. Biogas CO emissions are lower overall than gasoline. This results due to biogas derived from organic materials through an anaerobic fermentation process [3]. Fig. 4 shows the effect of loading on hydrocarbon gas emissions. From this figure, it can be seen that the HC concentration of gasoline is relatively higher than biogas fuel. This is due to the quality of combustion in the engine. HC concentration decreased with increasing electric load while operating the engine using gasoline. However, HC concentration tends to be the same as the electric load increases under biogas operation. Through observations, HC biogas emissions were 16 ppm at 100 W load conditions and 52 ppm gasoline with the same load. At an electric load of 500 W, the observed biogas HC concentration was 11 ppm while it was 30 ppm for gasoline. Fig. 4 also shows that gasoline containing high hydrocarbons such as octane is observed to emit higher levels of HC than biogas which contains only methane [23].

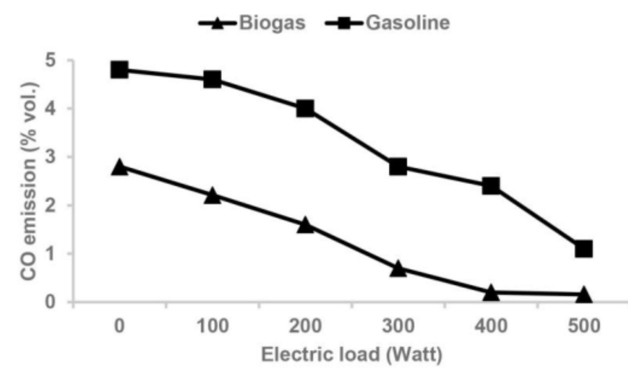

Fig. 3. Carbon monoxide (CO) emission

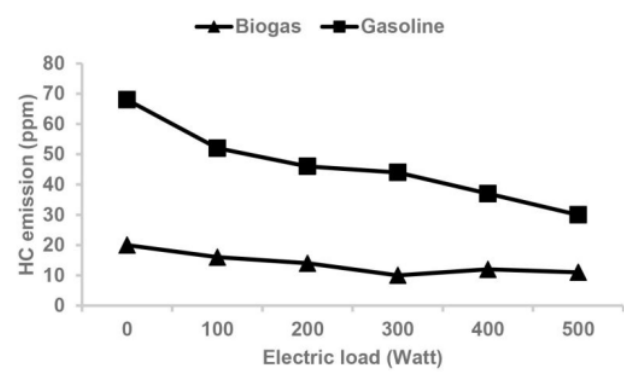

Fig. 4. Hydrocarbon (HC) emission

Variations of CO_2 concentration in engine exhaust emissions with an electric load are shown in Fig. 5. From the figure, it can be seen that biogas and gasoline emit significantly increased CO_2 concentrations at an electrical load of 100−300 W. It is evident from Table 1 [20] that 25−40% of biogas is composed of CO_2. At an electric load of 100 W, it was observed that biogas produced 4.3% CO_2 emissions while 7.9% for gasoline. Biogas CO_2 was observed to be 4.5% under a 200 W electric load and 8.2% for gasoline at the same electric load. The maximum CO_2 emission achieved using gasoline is 8.5% around a 300 W electric load. The concentration of NO engine exhaust emissions with variations in electric load is shown in Fig. 6. The presence of NO emissions is affected by the concentration of oxygen as well as the temperature of the fuel gas. Based on observations, gasoline produces relatively higher NO emissions than biogas. NO emissions from both biogas and gasoline fuels increase as the electric load increases. The maximum NO observed at electric load of 500 W is 72 ppm and 25 ppm using gasoline and biogas respectively. Both types of fuel show the same trend of increasing NO emissions. Fuel composition and impurities affect the concentration of NO exhaust emissions [18]. Overall, the highest NO emissions were emitted using gasoline due to the high presence of octane in gasoline when compared to biogas.

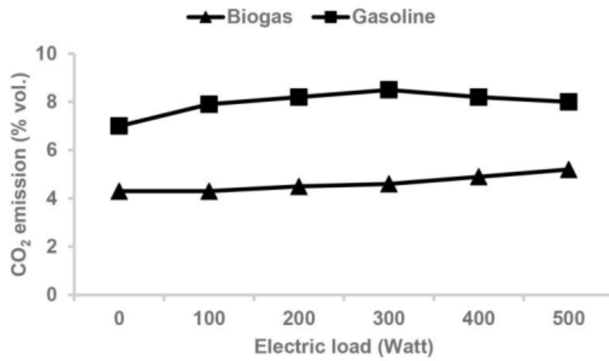

Fig. 5. Carbon dioxide (CO_2) emission

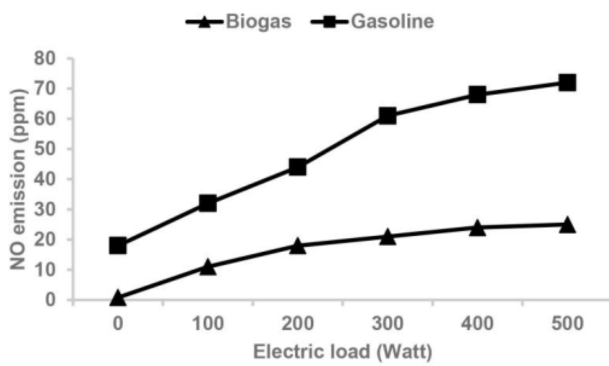

Fig. 6. Nitrogen oxide (NO) emission

B. Comparison of Engine Speed

Comparative of engine speed to the electric load is presented in Fig. 7. There was no significant difference found in gasoline as a fuel for electric generator engine. However, there are small variations in engine speed which are influenced by quality of fuel combustion, temperature and pressure during combustion process. From the figure, biogas produces a relatively lower engine speed than gasoline. This is due to calorific value of biogas is lower than gasoline and causes variations in engine speed [23]. The maximum engine speed observed while operating with gasoline is 3000 rpm and 2604 rpm for biogas with a similar electric load. There is a 13.2% reduction in engine speed when operating on biogas fuel.

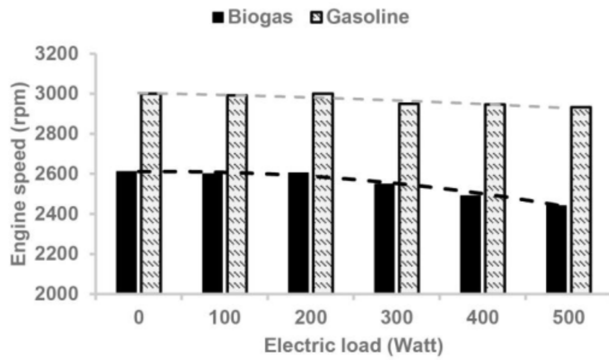

Fig. 7. Variation of engine speed (rpm)

IV. CONCLUSIONS

This paper deals with investigation of exhaust emission characteristics of single cylinder spark ignition biogas fuelled electric generator engines with variations in electric load. Results based on experimental analysis show that biogas produces relatively lower concentrations of exhaust emissions than gasoline under variations in electric loads. Biogas emits the lowest concentration of CO emissions under a 500 W electric load. The lowest concentrations of hydrocarbons are found under a 300 W electric load conditions using biogas. There is a decrease in engine speed of 13.2% while operating using biogas under a 200 W electric load. Overall the gasoline generator engine can be converted to be able to operate using biogas fuel by adding minor modifications to the engine intake manifold system. Biogas electric generators can be a capable option as an alternative fuel and for IC engines as the emission of the engine generates lower emission concentration levels than gasoline.

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