Performance Evaluation on Otto Engine Generator Using Gasoline and Biogas from Palm Oil Mill Effluent

Irvan\(^1\)*, B Trisakti\(^1,3\), T Husaini\(^1,3\), A Sitio\(^2,3\) and TB Sitorus\(^2,3\)

\(^1\)Chemical Engineering Department, University of Sumatera Utara, Medan, 20155, Indonesia
\(^2\)Mechanical Engineering Department, University of Sumatera Utara, Medan, 20155, Indonesia
\(^3\)Sustainable Energy and Biomaterial Center of Excellence, University of Sumatera Utara, Medan, 20155, Indonesia

E-mail: *i_v_a_n_mz@yahoo.com

Abstract. Biogas is a flammable gas produced from the fermentation of organic materials by anaerobic bacteria originating from household waste manure and organic waste including palm oil mill effluent (POME). POME is mainly discharged from the sterilization unit of palm oil processing into crude palm oil. This study utilized biogas produced from liquid waste palm oil for use as fuel in the Otto engine generator 4 – stroke, type STARKE GFH1900LX with a peak power of 1.3 kW, 1.0 kW average power, bore 55 mm, stroke 40 mm, \(V_d\) \(95 \times 10^{-6}\) m\(^3\), \(V_c\) \(10 \times 10^{-6}\) m\(^3\), compression ratio of 10.5 : 1 , and the number of cylinders = 1. The objective of this study is to evaluate the performance of Otto engine generator fueled with biogas that generated from POME, then comparing its performance fueled by gasoline. The performance included power, torque, specific fuel consumption, thermal efficiency, and the air-fuel ratio. Experiment was conducted by using a variation of the lamp load of 100, 200, 300, 400, and 500 W. The results revealed that the use of biogas as fuel decreased in power, torque, brake thermal efficiency, and air fuel ratio (AFR), while there is an increasing of value specific fuel consumption (SFC).

1. Introduction

Fossil fuels mentioned as the most important energy sources in the world are depleting day by day. In addition, environmental issues have become dilemma due to more fossil fuel are used. Many researchers especially in Indonesia have developed alternative fuel in order to overcome the above problems such as biogas, bioethanol, biodiesel etc. Biogas is a clean and renewable resource that can be used as fuel or other purposes. It discharges less harmfully pollutant to the atmosphere than the burning of fossil fuel. The main constituents in biogas are methane (CH\(_4\)), carbon dioxide (CO\(_2\)), and hydrogen sulfide (H\(_2\)S) [1].

Biogas can be produced using a wide range of feedstock include municipal wastewater, diary manure, food processing wastewater and agricultural waste [2]. Indonesia as tropical country has numerous biogas resources generated from agricultral production especially in palm oil industries such empty fruit bunches, fibre, shell and palm oil mill effluent (POME).

POME, which is brownish, viscous and acidic liquid waste (pH ranges between 4 and 5), cannot be discharged directly to the environment without prior treatment. POME has high chemical oxygen demand (COD), biological oxygen demand (BOD) and suspended solid by approximately 90,000,
30,000 and 25,000 mg/l, respectively and generally was discharged at high temperature (80-90°C) [3, 4, 5]. Table 1 summarizes the properties of palm oil mill effluent [6].

| Parameters        | Values          |
|-------------------|-----------------|
| pH                | 4 – 5           |
| Total Solid (TS)  | 40,500 – 72,000 |
| Volatile Solid (VS)| 34,000 – 49,300 |
| COD               | 44,300 – 102,000 |
| BOD               | 25,000 – 65,714 |
| Kj-N              | 560 – 1,200     |
| Fat               | 1,700 – 9,200   |

* Unit for all parameter is mg/L except pH

Typically, 1 ton of fresh palm oil fruit bunch (FFB) generates approximately 0.1 ton or 0.65 m³ of POME [7]. Thus, there is a great potential for POME to be utilized as the fuel to produce renewable energy. Moreover, besides reducing pollutant, a by-product from the production of biogas, can be used as liquid fertilizer and pesticide.

Some researchers have performed various tests in order to study the performance of engine fueled by biogas [8, 9, 10, 11]. They focused mainly on some parameters such as: compression ratio, the torque and power. The results of their study lead to the conclusion that biogas fueled engines have a good prospect in future.

Irvan et al in 2016 conducted POME conversion into biogas at laboratory scale and pilot scale using anaerobic microbes at temperature 55°C (thermophilic) [12]. This research aimed to utilize biogas produced from pilot scale as fuel for Otto engine generator. Then the performance included power, torque, specific fuel consumption, thermal efficiency, the air-fuel ratio, exhaust emissions and combustion in spark plugs were evaluated and then comparing it using gasoline.

2. Materials and Methods

2.1. Production of Biogas

Biogas was obtained by anaerobic fermentation of POME in the digester at working volume of 3.7 m³. Schematic drawing of pilot plant is shown in figure 1.

Fresh POME was filled into the continuous stirred feed tank, here POME was heated up to 70°C. Hot POME was then fed to the mixing tank by a centrifugal pump every two hours. The amount of daily feeding POME became 616 liters per day. Hydraulic retention time (HRT) of digester was maintained at 6 days. Hot POME and return sludge were mixed in the mixing tank for approximately five hours and still maintained at 70°C. Then this mixed waste was pumped by screw pump into an anaerobic digester every two hours. The digested slurry was overflowed from the digester to the gravity thickener where the digested slurry was concentrated and returned to the mixing tank. The effluent was discharged to the outside from the top surface of the gravity thickener. Production of biogas was measured by using a wet gas meter (SHINAGAWA, Model W-NK-0.5B). Concentrations
of H₂S and CO₂ in the biogas were measured by using a suction gas injector (GASTEC, type GV-100S) and inspection tube (GASTEC, 25 – 1600 ppm). Characteristics of biogas produced from the pilot plant are presented in Table 2.

![Schematic drawing of pilot plant](image)

**Figure 1.** Schematic drawing of pilot plant

| Parameter        | Unit     | Values |
|------------------|----------|--------|
| Gas generation   | NL/gr VS* | 0.68   |
| Methane          | %        | 60     |
| CO₂              | %        | 30     |
| H₂S              | ppm      | 40     |

### 2.2. Otto Engine Generator Fed with Biogas

The engine used in this study was 4 – stroke, type STARKE GFH1900LX with a peak power of 1.3 kW, 1.0 kW average power, bore 55 mm, stroke 40 mm, $V_d 95 \times 10^{-6}$ m³, $V_c 10 \times 10^{-6}$ m³, compression ratio of 10.5 : 1, and the number of cylinders = 1. Although, the objective of this work is to determine the performance of the Otto engine fed with biogas, it also used gasoline as a reference parameter.

Engine performance tests were conducted by varying the electrical power above 100 kW. When the electrical power was given then the electrical voltage and current were measured by using a multimeter. Meanwhile, a tachometer was used to determine the rotation number of the engine. By using gasoline, performance test was carried out for 5 minutes each load variation, then amount of fuel mass reduced in the tank were measured. Using biogas, performance test was performed by flowing it from the 100 L storage tank at 6 bar to the modified carburetor. The engine was turned on until the content of storage tank became empty and the time was measured by using stopwatch.
3. Results And Discussions

3.1. Engine power

Experiments in order to know performance test of the engine by using gasoline and biogas were conducted by varying the number of lamps used. Figure 2 shows the engine power curves by using gasoline and biogas.

![Figure 2. The engine power curves by using gasoline and biogas](image)

By using gasoline, if number of lamps were added then rotation and power increased. A load of 1 lamp, the engine generated rotation by 4049.5 rpm with output power of 114.1 Watt, and the load of 5 lamps, rotation and power were 4458.5 rpm and 517.6 Watt respectively. Biogas used as fuel with one lamp, the engine generated a power of 107.25 Watt at 4188.5 rpm engine speed, and the load of 5 lamps were 424.7 Watt at 4398.0 rpm.

The decreasing of rotation number and output power were caused by the CO$_2$ content in the biogas which reaches 30%. It affected to the combustion of biogas inside the engine which became slower and the heat value of biogas became lower. At last, biogas were accumulated inside the heat chamber, caused combustion process became inefficiency. This was indicated by the decreasing of rotation, followed with a drop in generated power generator engine.

3.2. Torque

Similar to engine power, using gasoline, if number of lamps were added then the greater the torque produced. A load of 1 lamp, the engine produced 0.269 Nm torque at 4049.5 rpm, and the load of 5 lamps, 1.019 Nm torque was obtained at 4458.5 rpm. Figure 3 shows the torque curves by using gasoline and biogas.

![Figure 3. The torque curves by using gasoline and biogas](image)
From Figure 3 we can see that the torque generated by engine using biogas, load of 1 lamp up to 4 lamps are not so much different, but when the generators were loaded with 5 lamps, the torque was lower than the gasoline engine. The decreasing of torques was caused by engine rotation which also decreased.

3.3. Specific Fuel Consumption

Engine performance may be described in several ways, one of the useful parameters is specific fuel consumption (SFC). It is defined as the weight of the fuel burned per unit time, per unit thrust. Generally, if the electrical load is increased then SFC value becomes smaller. Figure 4 shows the SFC curves by using gasoline and biogas. As shown on figure 4, engine with biogas has SFC value greater than the engine with gasoline. This is because the rate of fuel of biogas is greater than the gasoline.

The greatest value of SFC, indicated by engine with biogas at the load of 1 lamp generating power about 107.25 Watt at 4188.5 rpm, was around 16037.30 g/kWh. While, the lowest value of SFC was 1437.31 g/kWh, at the load of 5 lamp generating power about 517.66 Watt at 4458.5 rpm.

![Figure 4. The SFC curves by using gasoline and biogas](image)

3.4. Brake Thermal Efficiency

Brake thermal efficiency (BTE) can be defined as the ratio of the heat equivalent of the brake output to the heat supplied to the engine. For engine by using gasoline or biogas, if the number of lamp is increased, then the BTE value also increased. Figure 5 shows the BTE curves by using gasoline and biogas. As shown on figure 5 that gasoline engine has BTE value higher than biogas engine. This is because the fuel rate of biogas is greater than gasoline.
Figure 5. The BTE curves by using gasoline and biogas

Figure 5 shows the highest thermal efficiency is 5.87% by using gasoline at a load of 5 lamps with output power 517.64 at 4458.5 rpm. While, the lowest thermal efficiency was 1.31%, at a load of 1 lamp generating power about 107.25 Watt at 4188.5 rpm.

3.5. Air Fuel Ratio

Air fuel ratio (AFR) is the mass ratio of air to fuel present in a combustion process such as in an internal combustion engine. The AFR is an important measure for anti-pollution and performance-tuning reasons. In general, if the electrical load is increased then AFR value becomes smaller. Figure 6 shows the AFR curves by using gasoline and biogas. As shown on figure 6, engine with gasoline has AFR value greater than the engine with biogas.

Figure 6. The AFR curves by using gasoline and biogas

Figure 6 shows the highest air fuel ratio is 18.68 by using gasoline at a load of 1 lamp with output power 114.1 at 4049.5 rpm. While, the lowest thermal efficiency was 4.5, at a load of 5 lamps generating power about 424.74 Watt at 3898.5 rpm.
4. Conclusion

Otto engine generator by using biogas as fuel could generate maximum power and torque of 424.74 Watt and 1.04 Nm, respectively. These power and torque are approximately 42% and 49% of the power and torque that can be generated from the same engine by using gasoline. Because of biogas fuel rate is greater than the gasoline, then specific fuel consumption of biogas become larger and brake thermal efficiency of biogas is smaller than gasoline. In the combustion process, biogas engine required less air than gasoline engine.

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