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Performance and emissions of an engine fuelled by biogas of palm oil mill effluent

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Abstract. This research investigates the performance and emissions of an engine by biogas and gasoline. The experiments use biogas of palm oil mill effluent (POME) with turbocharger at engine loading conditions (100, 200, 300, 400, and 500 Watt). Specific fuel consumption and thermal efficiency are used to compare engine performance, and emission analysis is based on parameters such as carbon monoxide (CO), hydrocarbon (HC), carbon dioxide (CO_2) and oxide (O_2). The experimental data show that the maximum thermal efficiency when engine use biogas and gasoline is 20.44% and 22.22% respectively. However, there was CO emission reduction significantly when the engine using POME biogas.

1. Introduction

One of the innovative solutions in the utilization of renewable energy is the use of alternative fuels such as biogas from palm oil mill effluent (POME) [1,2]. As noted, Indonesia has a lot of raw materials to produce biogas in large quantities. The data of ESDM ministry said that the area of Indonesian palm oil plantation about 13.5 million hectares and for every process of palm fruit production, producing one ton of CPO, it will produce about five tons of POME which still contain many organic substances [3]. The equipment that use a lot of hydrocarbon fuel are internal combustion engines. Internal combustion engines applied in many sectors such as transportation, agriculture and power generation. The fossil fuels such as gasoline and diesel oil use in internal combustion engines produce carbon dioxide (CO), carbon dioxide (CO_2), nitrogen oxide (NOx), sulphur oxide (SOx) and particulates that are polluting the environment. But gas produce an exhaust gas that is environment friendly when used by Otto or Diesel engines [4]. A note that the main components of the biogas constituent are methane (CH_4), carbon dioxide (CO_2) and some other elements such as hydrogen (H_2), nitrogen (N_2) and water vapor (H_2O) [5,6]. This study aims to determine the performance of the engine equipped with a turbocharger when using biogas of POME.

2. Literature Study

2.1. Palm Oil Mill Effluent (POME)

Palm oil mill effluent (POME) is a liquid condensate of sterilization processing which derived from

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palm oil processing to crude palm oil. The properties of POME contain organic compounds and nontoxic. [7]. In general, the main characteristic of POME can be shown in table 1. To be used as gas fuel, POME must be treated specifically by applying technologies such as anaerobic digestion, gasification processes, pyrolysis and carbonization [8,9,10,11].

Table 1. The main characteristic of POME [12]

No.	Parameter	Unit	Range
1	Biological oxygen demand	mg/l	20,000-30,000
2	Chemical oxygen demand	mg/l	41,000-99,000
3	Volatile solid	mg/l	23,200-53,900
4	Total solid	mg/l	28,000-64,700
5	Fat	mg/l	1,700-9,200
6	Kj-N	mg/l	560-1,200
7	pH		3.9 – 4.6

2.2. Parameters of Internal Combustion Engine

The performance of the internal combustion engine is specifically indicated by the value of the parameters of the engine. Some of these parameters can be described as follows [13]. The power is influenced by engine speed and torque that produced by the engine. In most cases, in the internal combustion engine, it is known two type of power that consists of shaft power and power indicator. As a practice, it uses only the shaft power. The shaft power, or effective power is the power that produced by an engine on the output shaft or it is commonly known as brake horse power which is calculated by the equation:

$$\dot{W} = \frac{2\pi \cdot N \cdot \tau}{60000} \qquad \text{kW} \qquad (1)$$

Where N is engine speed (rpm), and τ is engine torque (Nm).

The specific fuel consumption is the amount of fuel that should consume per unit of power which produced per hour of operation. Indirectly, the specific fuel consumption is an indication of the engine efficiency for generating power from fuel combustion. The value of specific fuel consumption can be defined as follows:

$$Sfc = \frac{\dot{m}_f}{\dot{W}} \cdot 3600000 \qquad \text{g/kWh} \qquad (2)$$

Where $\dot{m}_f$ is the mass flow rate of the fuel (kg/s).

The thermal efficiency of an internal combustion engine constituted the ratio between the output energy and the chemical energy of fuel, that can be stated as:

$$\eta_t = \frac{\dot{W}}{\dot{m}_f \cdot Q_{HV} \cdot \eta_c} \qquad (3)$$

Where Q_{HV} is the calorific value (kJ/kg), and η_c is combustion efficiency 0,97.

Mean effective pressure is a good parameter to compare engines for design or output because it is independent of engine size and speed. The value of mean effective pressure can be defined by using an equation:

$$mep = \left(\frac{4\ \pi\ \tau}{V_d}\right).1000 \qquad kPa \tag{4}$$

Where V_d is displacement volume (cm^3).

3. Method

3.1. Material

The experiments were using biogas of POME and gasoline. Loads of the engine are five lamps with 100 watts respectively.

(a) (b)

Figure 1. a) calorimeter bomb b) emission analyzer Sukyong SY-GA 401

The main equipment used in this study consisted of:

a. Single cylinder stationary Otto engine
b. Calorimeter bomb to determine the calorific value of the fuel
c. Emission analyzer Sukyong SY-GA 401 to determine the composition of exhaust emissions CO, CO_2, HC, and O_2.

3.2. Experimental Scheme

The GFH1900LX engine that used in this research is the type of a four stroke one cylinder stationary engine which specifications are summarized in table 2. The scheme of experimental is shown Figure 3. All experimental data were taken after the engine was properly warmed up 15 minutes after starting. An emission analyzer Sukyong SY-GA 401 with an accuracy of ±5% were used to measure the exhaust gases which placed on the exhaust gas manifold. For each fuel, different emission data were taken over three repetitions. The testing was under the variety engine loads of 100W, 200W, 300W, 400W and 500W. The accuracy of torque measurement is about ±0.2 Nm, and the accuracy of rotation controlling ±10 rpm. The engine was started by using gasoline fuel, whereas it was warmed up, should switch to the biogas. After switching fuels from one type to another, the engine was running about 10 minutes to get stable condition with the new fuel before the measurements were taken. Engine torque and fuel consumption were measured to calculate the power, specific fuel consumption and thermal efficiency of the engine. An 8 ml burette and a timer are used to measure the fuel consumption. The accuracy of the burette about ±0.1 ml and the timer about ±0.01 s.

Table 2. Engine specifications [14]

Type	GFH1900LX / Otto engine
Capacity	900 watts / 220V / 50Hz
Peak power	1,3 kW
Power factor	1
Cooling system	3.0 Hp *air cooled* OHV/ 3600 rpm
Bore	55 mm
Stroke	40 mm
Compression ratio	10,5 : 1
Number of cylinders	1

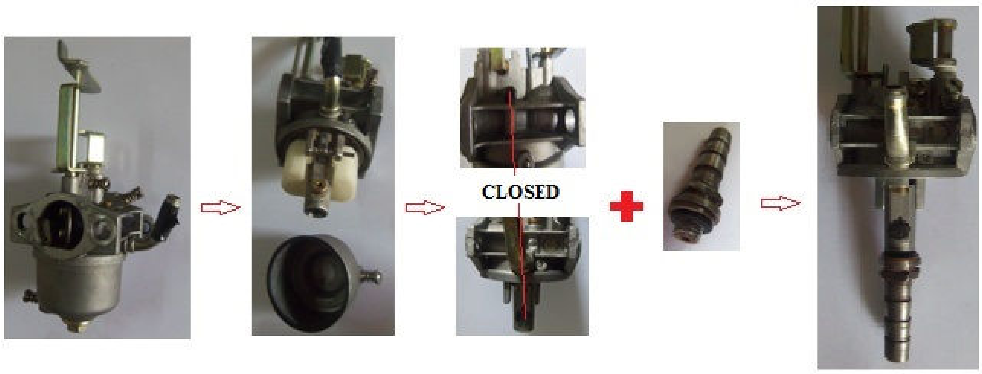

Figure 2. Modification on carburettor components

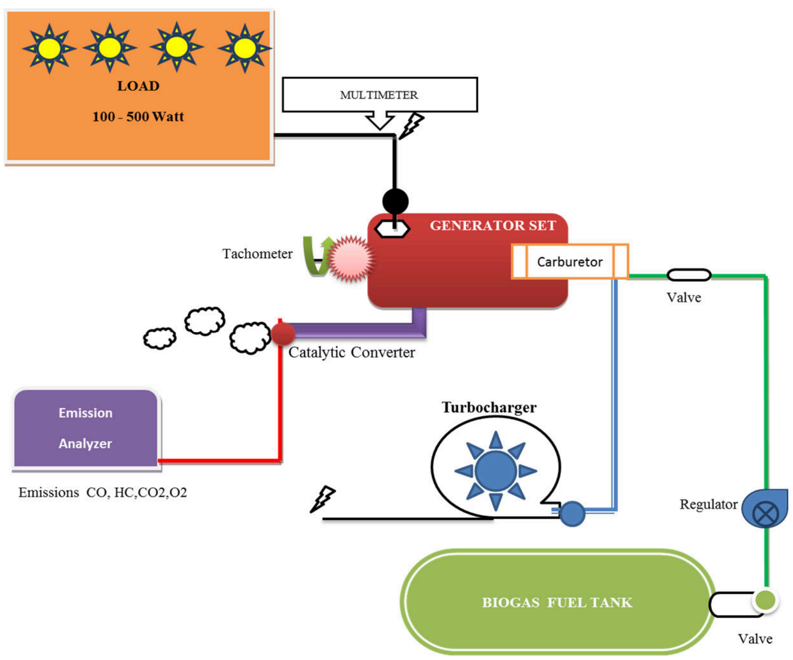

Figure 3. Experimental scheme

4. Results and Discussions

4.1. Calorific Value of Fuels

The calorific value of fuel was examined by using a bomb calorimeter apparatus with the accuracy of ±5%. To get the calorific value of gasoline were the experiments carried out which each fuel as many as five samples. Then the average results of the five samples were to obtain the calorific value of the fuel. The observation results obtained that the calorific value of gasoline is 43964 kJ/kg. The calorific value of biogas of POME is obtained 35900 kJ/kg [3]. The calorific value of fuel shows the energy that generated during the combustion process of fuel per unit mass which is influenced by the composition of the fuel constituent.

4.2. Torque

Figure 4 shows the experimental data that the maximum torque is obtained 2.75 Nm when the engine uses gasoline with a turbocharger for a load of 500 watts. The minimum torque is obtained at 1.04 Nm when engine using biogas of POME with a turbocharger for a load of 100 watts. The torque generated when engine using biogas of POME is lower because the torque is influenced by the energy of fuel combustion. The energy of fuel combustion is influenced by the calorific value of the fuel used.

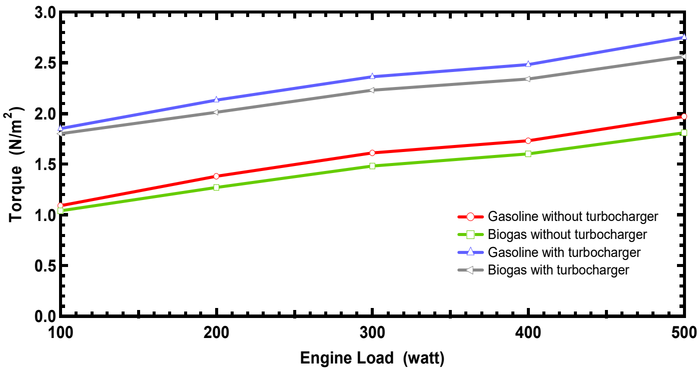

Figure 4. Engine torque versus engine load.

4.3. Power

Figure 5 shows the test results for shaft power when the engine using gasoline and biogas of POME. Based on the test data and calculations has obtained the maximum power of 1.62 kW when engine using gasoline with a turbocharger for a load of 500 watts.

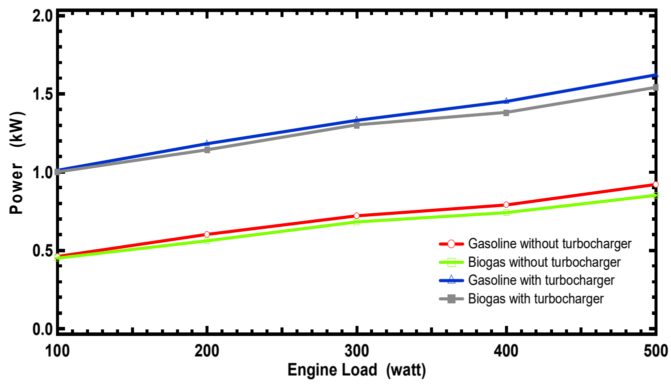

Figure 5. Engine power versus engine load

The minimum power is obtained 0.45 kW when engine using biogas of POME without a turbocharger for a load of 100 watts. The average increase of engine power is about 67.43% after using a turbocharger both when using gasoline or biogas. The addition of a turbocharger increases the amount of air entering the combustion chamber, so this makes the air-fuel ratio (AFR) increased. As noted, AFR parameter also affects the shaft power generated by the engine.

4.4. Specific Fuel Consumption (Sfc)

Based on the test results shown in figure 6, the maximum sfc is obtained 2336.70 g/kWh when engine using biogas of POME without turbocharger for a load of 100 watts. The minimum sfc is obtained 386.85 g/kWh when engine using gasoline with turbocharger for a load of 500 watts. The average decrease of specific fuel consumption generated when using turbocharger is about 55%. As noted, when using a turbocharger that the rate of air entering into the combustion chamber increases while the amount of fuel used is reduced. It can be said that the specific fuel consumption when the engine using biogas of POME has increased. One of them is caused by calorific value of biogas is lower than gasoline. This makes the fuel needed more than when engine using gasoline for all conditions of testing.

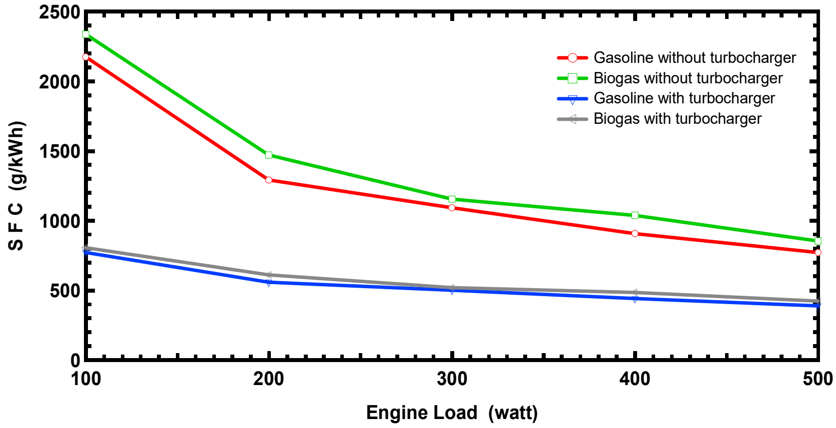

Figure 6. Specific fuel consumption versus engine load

4.5. Thermal Efficiency

Figure 7 shows the thermal efficiency obtained during experiments. The experiment's data show that the maximum thermal efficiency 22.22% when the engine using gasoline with a turbocharger for a load of 500 watts.

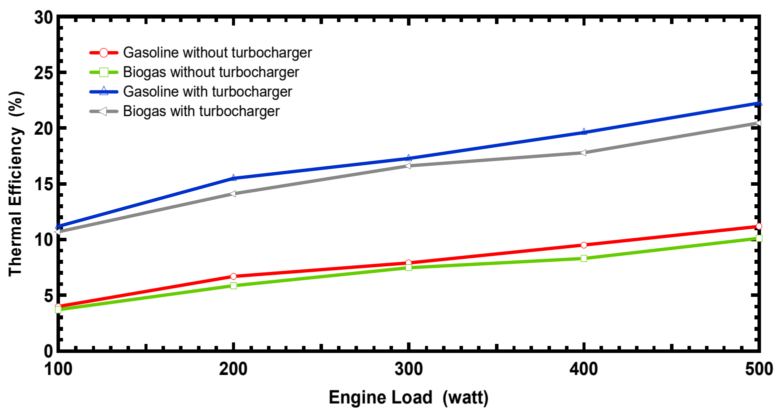

Figure 7. Thermal efficiency versus engine load

The minimum thermal efficiency obtains 3.68% when the engine using biogas of POME without a turbocharger for a load of 100 watts. The increasing of thermal efficiency produced by using a turbocharger both when using gasoline and biogas is about 68.73%. It should be noted that the thermal efficiency of the internal combustion engine is influenced by several parameters such as engine shaft power, the fuel flow rate to the combustion chamber and the calorific value of the fuel used. All three parameters simultaneously affect the achievement of thermal efficiency of an internal combustion engine.

4.6. Mean Effective Pressure

The experimental data shown the maximum mean effective pressure (mep) is 363.64 kPa which occur when the load 500 watt using gasoline with a turbocharger in figure 8. The minimum mean effective pressure is obtained 138.13 kPa by using biogas without a turbocharger on the load of 100 watts. As noted, that the maximum mean effective pressure of good engine designs is well established, and is essentially constant over a wide range of engine sizes. The actual mean effective pressure is a particular engine develops that can be compared with this norm and the effectiveness with which the engine's displaced volume can be assessed. For design calculations, the engine displacement required to provide a given torque or power at a specified speed that can be estimated by assuming the appropriate values for mean effective pressure for that particular application [15].

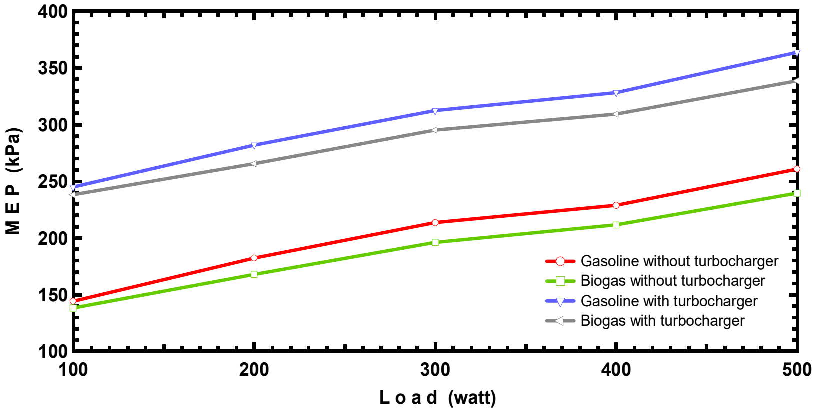

Figure 8. Mean effective pressure versus engine load

4.7. Combustion and Gas Exhaust

In this testing, also examined the effect of combustion conditions on the spark plug and exhaust gas emission composition produced by the engine. To know the combustion process in the combustion chamber, one of them can be reviewed of the spark plug conditions after use. The color of the electrode of the spark plug can indicate the combustion process takes place inside the combustion chamber. It appears in figure 8 that the spark plug electrodes during testing when engine using gasoline tend to be darker than when using biogas of POME.

Figure 9. Conditions of spark plug when using (a) gasoline (b) biogas POME

Table 3. Measurement data of exhaust gas with gasoline

Load	Without turbocharger				With turbocharger			
(watt)	CO (%)	HC (ppm)	CO_2 (%)	O_2 (%)	CO (%)	HC (ppm)	CO_2 (%)	O_2 (%)
100	3.67	839	1.48	14.62	2.65	726	1.69	14.93
200	4.20	441	1.60	13.35	3.15	322	1.83	13.77
300	4.42	324	1.68	13.48	3.27	218	1.90	13.79
400	4.45	281	1.76	12.91	3.47	164	1.89	13.27
500	4.82	206	1.83	12.73	3.68	121	1.97	13.21

Table 4. Measurement data of exhaust gas with biogas POME

Load	Without turbocharger				With turbocharger			
(watt)	CO (%)	HC (ppm)	CO_2 (%)	O_2 (%)	CO (%)	HC (ppm)	CO_2 (%)	O_2 (%)
100	2.98	778	5.68	12.63	1.92	703.00	6.75	13.75
200	3.22	644	5.68	11.87	2.34	369.00	6.73	12.99
300	2.78	598	7.38	9.43	1.56	323.00	8.45	10.55
400	2.88	353	8.18	8.92	1.45	235.00	9.22	10.12
500	2.15	322	7.78	7.88	1.21	211.00	9.87	9.33

Exhaust emissions, which investigated include carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbon (HC) and oxygen (O_2) levels. Tables 3 and 4 show the measurement data of exhaust gas composition when using gasoline and biogas of POME. A note that CO emissions arise because at the time of burning process occurs lack of oxygen. The lack of oxygen supply causes incomplete combustion where the C atom lacks O_2 to form CO_2. Table 4 shows that the use of gasoline fuel produces the most CO for engine load. This is due to the gasoline consisting of C_7 (heptane) to C_{11} hydrocarbon groups having more C atoms than biogas consisting of methane or C_1 group hydrocarbons. Reduction of CO emission when using biogas of POME is significant thereabouts 55-75% when compared using gasoline. The emissions of HC also occur due to lack of oxygen, so that the combustion process takes place imperfectly because many carbon atoms that do not get enough oxygen to form HC gas. The result of the measurement emission with engine load variations is obtained minimum HC level of 121 ppm occurs when engine using gasoline with a turbocharger for a load of 500 watts. The maximum HC has obtained 839 ppm when the engine using gasoline without a turbocharger for a load of 100 watts.

5. Conclusions

The performance and emission of a single cylinder engine fuelled with biogas of POME have been observed and analyzed compared to the base line of gasoline. The results showed an increase in engine power and thermal efficiency with decreased in specific fuel consumption ranged from 45% - 68% when the engine using a turbocharger. Measurement data on exhaust emissions indicate that there are reduced of CO and HC emissions, as well as increases in CO_2 and O_2 when engine using biogas of POME with turbocharger ranges of 40% -75% when compared with using gasoline.

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