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PERFORMANCE AND EMISSIONS OF A DIESEL POWER GENERATOR FUELLED BY BIODIESEL CALOPHYLLUM INOPHYLLUM – ETHANOL BLENDS

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ABSTRACT

The effect of ethanol on diesel engine performance using B30 fuel has been investigated, namely a mixture of 30% calophyllum inophyllum biodiesel and 70% petrodiesel. The ethanol concentration mixed to B30 was 10% and 20% vol/vol. The experiment was conducted on a single-cylinder four-stroke diesel engine with a natural air system and joined with a generator that functioned as a dynamometer. The test was applied three times to the machine for each load, involving 0, 200, 400, 600, and 800W at a constant rotation speed of 2000 rpm. The experiment reveals that the consistent engine speed method and lamp load produce the same torque (Nm) and effectiveness power (kW) between fuels, impacted by the governor's mechanism. The 20% ethanol (B30E20) has the highest effective thermal efficiency of 28.41% and effectiveness fuel consumption of 0.46 kg/kWh. The addition of 20% ethanol reduced exhaust emissions of carbon monoxide and hydrocarbons up to 0.09% and 27.33 ppm. However, there was an exhaust emissions increase of carbon dioxide up to 8.0%. The exhaust emissions increase of carbon dioxide cannot be considered as a negative consequence because it can be reused (consumption) in the photosynthesis process raw material biofuels.

1. INTRODUCTION

Issues of global environmental and climate change due to the development and use of fossil-based energy consider in the choice of the alternative fuel for diesel engines (compression ignition engines) [1]. Biodiesel is an alternative fuel to petrodiesel (petroleum diesel). The biodiesel characteristics are good lubricity, non-toxicity, aromatic-free, eco-friendly, and renewable [2]. Nonetheless, its use causes problems in diesel engines, such as filter blockage, nozzle blocking, injector coke (sediment), fuel storage, and poor nozzle spray atomization [3].

[4] found that the addition of 30% CIB-Calophyllum Inophullum Biodiesel (B30) increased kinematic viscosity by 24.48%, density as 1.54%, and cetane number as 1.91% higher than petrodiesel. However, another characteristic the calorific value is 0.90%, and the flashpoint is 11.18% lower than petrodiesel. Alcohol can improve biodiesel characteristics. Ethanol (C2H5OH) is a type of alcohol from the fermentation process of biomass raw materials and can use in diesel engines without modification [5]. [6] proved that the addition of 5% ethanol to 20% palm biodiesel (B20E5) reduces kinematic viscosity to 3.57%, density to 1.05%, flashpoint to 35.71%, and heating value to 6.31% lower than 20% palm biodiesel.

The diesel engine performance depends on the characteristics of the fuel used. Based on the explanations above, this study aimed to examine the effect of adding 10% and 20% ethanol to 30% biodiesel and 70% petrodiesel (B30). Biodiesel produces from Calophyllum Inophyllum seed oil. The development and use of CI as a non-food biodiesel raw material can expect to have a favorable influence on the economy and the environment. It can realize an energy balance approach by reducing fossil fuels, greenhouse gas emissions, adverse effects healthy and environmental damage [7].

2. METHODE

2.1 Fuel Preparation

Biodiesel produce from CI seed oil from Bondowoso, East Java, Indonesia. The CI seeds are extracted mechanically and followed by the esterification and transesterification process of triglycerides. Petrodiesel is obtained from BBM terminal of PT Pertamina Tanjung Wangi, Suplai and distribution area V, Ketapang Banyuwangi, East Java, Indonesia. Ethanol with purity of 99.5% was obtained from PT Energi Agro Nusantara, a subsidiary of PT Perkebunan Nusantara X, Mojokerto, East Java, Indonesia.

2.2 Fuel blends

The Calophyullum Inophullum Biodiesel (CIB) and petrodiesel blends at a ratio of 30: 70 % (vol/vol) (B30). Ethanol and B30 blends using a magnetic stirrer in 7.5 minutes with a rotation speed of 1500 rpm [6]. Ethanol concentrations were 10% (B30E10) and 20% (B30E20). The biodiesel-petrodiesel and ethanol mixed were observed for 24 hours to ensure stability. After stabilization, the next step is to test the characterization and performance test of the diesel engine.

2.3 Experimental Settings and Procedures

Experiment conducts on the MDX-170 Matsumoto four-stroke single-cylinder diesel engine with a natural air system. The diesel engine joined with a Daiho SD-3 single phase generator which functioned as a dynamometer. The engine geometry and fuel injection characteristics are not changed. The fuel is injected mechanically by the system. Figure 1 represents the schematic diagram of the experimental setup. Table 1 presents the main properties of diesel engines.

Table 1. Spesification of diesel engine

Variables	Temperature (°C)
Merk	MDX-170 Matsumoto
Engine modle	OHV, 4 strokes
Number of cylinders	1
Cylinders volumen (cc)	211
Output max (kW)	3.1
Output max (rpm)	3600

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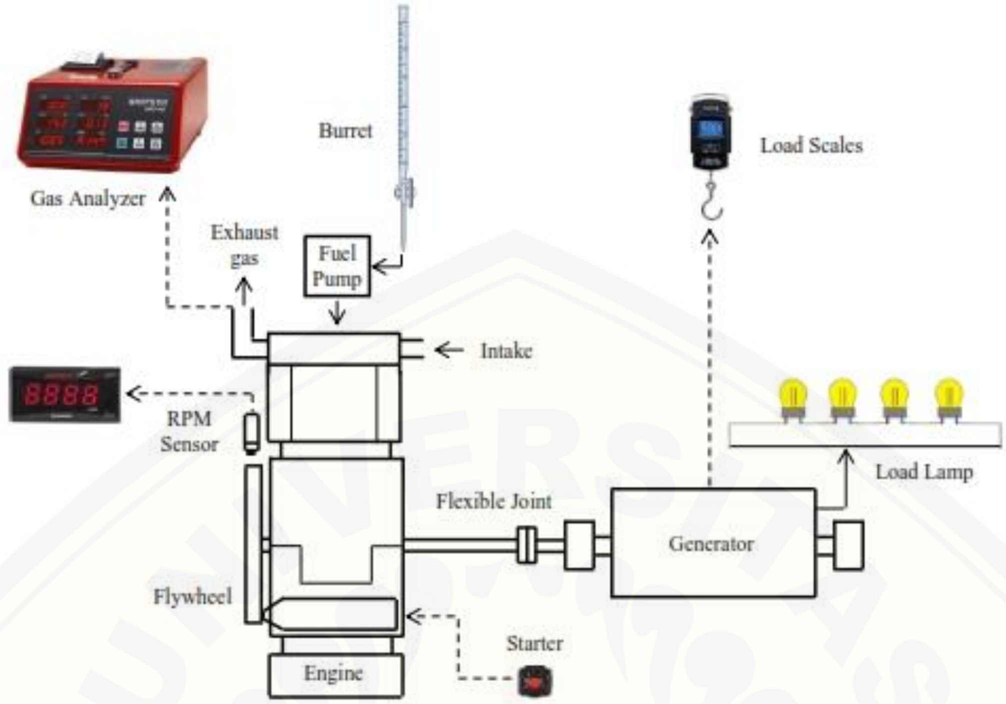

Figure 1. Experimental setup

Speed of fuel consumption is measured using a stopwatch with an accuracy of ± 0.001 s. The braking force is determined using a load cell placed in the generator arm with an accuracy of ± 0.001 kg. The HG-520 Hashbon, a gas analyzer model, is used to measure exhaust emissions. The measuring instrument accuracy of carbon monoxide (CO) emissions is ± 0.01%, carbon dioxide (CO2) emissions are ± 0.1%, and hydrocarbon (HC) emissions are ± 0.01 ppm. The three tests were conducted for each load, involving 0 W to 800 W (0% to 100%) with 200 W raised at intervals at a consistent speed of 2000 rpm. The fuel filter is replaced with every different fuel variation to prevent previous fuel contamination. The data collection is collected when the engine has been turned on for 10 minutes to reach steady-state conditions.

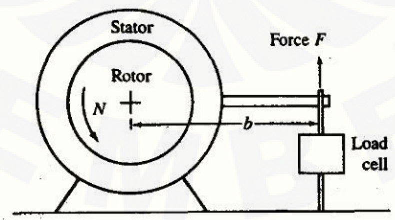

Figure 2. Illustration of torque measurement

The primary data of the results are converted into engine performance data using calculation. Figure 2 illustrated the torque measurement on the shaft (rotor) using the braking principle with the stator is given a lamp load W. The maximum load read by the load cell (load measuring instrument) is the braking force equal to the rotating force of the engine shaft (F).

3. RESULT AND DISCUSSION

3.1 Fuel Characteristic

The chromatographic tests are used to estimate the fuel-air ratio. The CIB chromatography test was conducted at the Laboratory for Bioscience, State Polytechnic of Jember. Figure 3 showed the results of the CIB chromatography test.

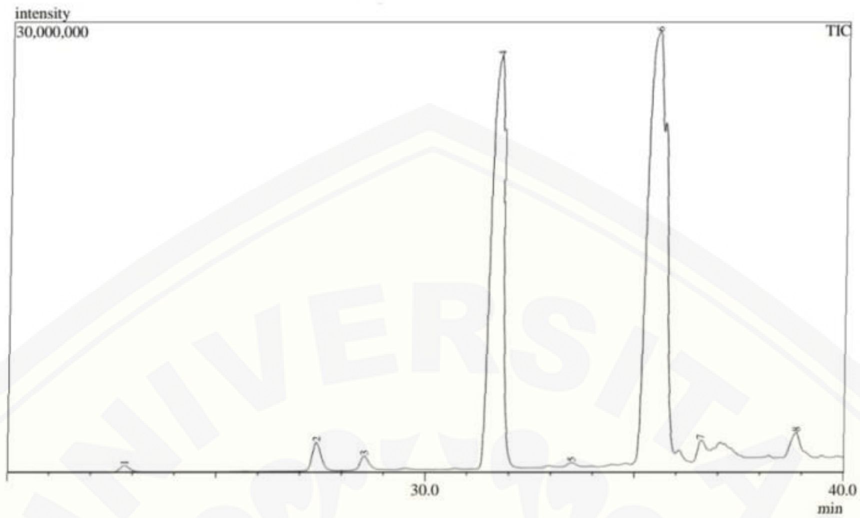

Figure 3. biodiesel chromatograpy test

Table 2 presented the percentage CIB molecular composition from the chromatographic test. The peak and area of 1-8 positions indicated the percentage of each molecule of CIB composer.

Table 2. Chromatography test of biodiesel

Peak No.	R.Time	Area	Area %	Height	Height %	Height	Structure
1.	22.804	5533299	0.41	391803	0.62	Methyl Laurate	$C_{13}H_{26}O_2$
2.	27.390	26408580	1.95	1864416	2.97	Methyl Myristate	$C_{15}H_{30}O_2$
3.	28.584	12067705	0.89	906348	1.44	Methyl Archidonate	$C_{21}H_{34}O_2$
4.	31.699	573831590	42.38	27508538	43.77	Methyl Palmitate	$C_{17}H_{34}O_2$
5.	33.489	3252976	0.24	258790	0.41	Methyl Margarate	$C_{18}H_{36}O_2$
6.	35.462	682409212	50.40	28795030	45.82	Methyl Oleate	$C_{19}H_{36}O_2$
7.	36.594	21541304	1.59	1416726	2.25	Methyl Linoleate	$C_{19}H_{34}O_2$
8.	38.852	28877745	2.13	1704866	2.71	Methyl Archistate	$C_{21}H_{42}O_2$
		1353922411	100	62846517	100.00		

The physical chemistry test was conducted to determine the effect of ethanol and biodiesel on density, viscosity, flash point, calorific value, and cetane number. The fuel characteristics were tested at the Motor Fuel Laboratory of Brawijaya University and PPSDM Migas Cepu, Blora, Central Java, Indonesia.

Table 3 presented the physicochemical test results of the fuel. It can be seen that the density of B30 is 0.86 g/ml, higher than the petrodiesel (0.84 g/ml). The 10% ethanol reduced the density of B30 to 0.85 g/ml, and 20% ethanol reduced the density to 0.84 g/ml. These results were similar to [6]. The low fuel density reduced droplet size and improved air mixed fuel preparation. This result could accelerate the ignition, and the pressure gradient increased, generating a high gas temperature in the cylinder [7].

The B30 had a kinematic viscosity of 3.3 mm^2/s higher than other fuels, such as petrodiesel (3.0 mm^2/s), B30E10 (2.8 mm^2/s), and B30E20 (2.4 mm^2/s). It was similar to [8]. The higher viscosity would generate resistance in the fuel line [9] and caused atomized fuel into larger droplets so the combustion was imperfect and enlarged injector coke (sediment) [10].

Table 3 Fuels characteristics

Bahan Bakar	Density @15° g/ml ASTM-D1298	Viscosity @40° cSt ASTMD-D445	*Flashpoint* °C ASTM-D93	Calor value kJ/kg ASTM-D240	Cetana number ASTM-D613	Ref.
Petrodiesel	0.84	3.0	55.0	46.6	-	Present study
CIME30	0.86	3.3	76.9	44.1	51.5	
CIME30E10	0.85	2.8	30.5	42.5	47.8	
CIME30E20	0.84	2.4	31.5	40.9	49.2	
B7	0.82	3.2	-	44.8	≥ 50	[12]
B3E5	0.82	3.0	-	43.9	56.5	
B7E5	0.83	3.0	-	42.9	56.7	
B10E10	0.82	2.8	-	41.7	53.6	
P20	0.85	2.9	28	43.5	-	[6]
P40	0.85	3.4	30	43.4	-	
P60	0.86	3.9	32	42.5	-	
P20E5	0.84	2.8	18	40.8	-	
P40E5	0.85	3.2	20	40.2	-	
P60E5	0.85	3.6	22	39.2	-	
E5B90D5	0.86	5.1	48	39.9	54	[8]
E10B80D10	0.84	4.3	34	38.3	50.8	
E15B70D15	0.84	3.6	16	36.7	48.5	

The flashpoint decreased significantly related to the augment of ethanol. It was appropriate to [6], [8]. The flashpoints of B30E10, B30E20, petrodiesel, and B30 were 30.5°C, 31.5°C, 55.0°C, and 76.9°C, respectively. The low flashpoint would increase the fuel flammability (combustion power) so it affects the combustion speed, thereby increasing the temperature of the combustion chamber. The low flash point effect was the fuel burns easily at the beginning, occurring detonation and reducing engine performance [11].

As stated by [12], the heating value or energy of biodiesel and ethanol fuel is lower than petrodiesel. The lowest heating values of B30E20, B30E10, B30, and petrodiesel were 40.9 MJ/kg, 42.5 MJ/kg, 44.1 MJ/kg, and 46.6 MJ/kg, respectively. The low fuel energy-reduced pressure and heat release so the fuel consumption increased [11], [13].

The ethanol has a low cetane number, yet it can be improved by adding biodiesel [14]. According to [15], the biodiesel cetane number depends on the distribution of the fatty acids of crude oil. The length of the fatty acid carbon chain and its molecules saturation impact the higher cetane number. The fuels with a lower cetane number lower than the engine's minimum requirements can suspend ignition and reduce cylinder pressure [16]. The lowest cetane numbers of B30E10, B30E20, and B30 were 47.8, 49.2, and 51.5, respectively. The characteristic test results can conform to the standard and quality requirements (specifications) for diesel fuel and a mixture of biodiesel 30% (B-30) when the cetane number (CN) reached 48 based on the Decree of the Directorate General of Oil and Gas of 2019.

3.2 Performance Test Result

The general parameters used to classify engine performance are torque, effective power, fuel consumption, thermal efficiency, and exhaust emissions (carbon monoxide, carbon dioxide, and hydrocarbon).

Figure 4 showed the torque (Nm) towards the lamp load (%). The results showed that the torque graph increased with the increasing load on the engine. The torque value obtained was similar between fuels when it used the constant engine shaft rotation method and lamp load variations. In the maximum load, the torque values obtained from petrodiesel, B30, B30E10, and B30E20 were 7.76, 7.69, 7.78, and 7.75 Nm, respectively. The enhancement of load impacted a larger amount of fuel in the combustion chamber. It is useful for maintaining a constant engine speed. When the lamp load was enhanced, the generator rotation load was heavier. As a result, the engine shaft rotation decreased. The rotation was increased through the governor mechanism (a device to regulate engine rotation stability) [17].

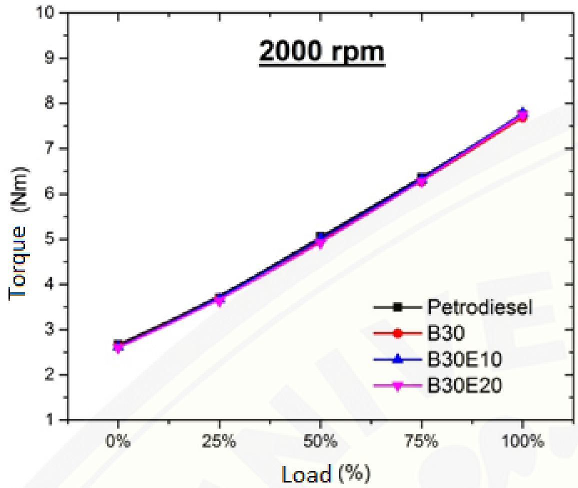

Figure 4 Torsi (Nm)

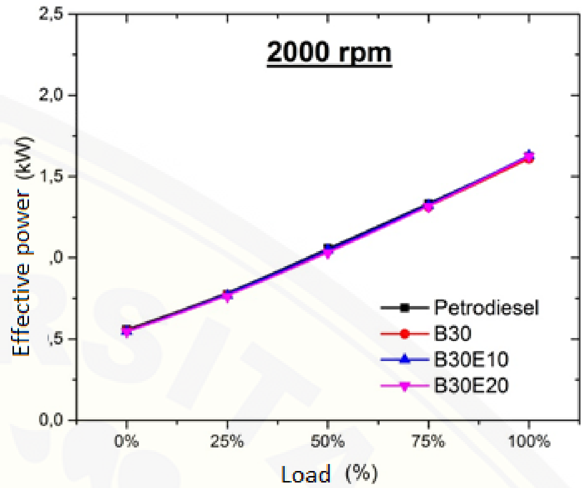

Figure 5. Effective power (kW)

Figure 5 showed the effective power (kW) toward lamp load (%). The results showed an effective power graph similar to a torque graph. It occurred since the effective power of the relationship between torque and load was directly proportional [18]. In the maximum load, the effective power values of petrodiesel, B30, B30E10, and B30E20 fuels were 1.62, 1.61, 1.63, 1.62 kW, respectively.

Figure 6 showed the comparison between the effective power of B30 fuel at the full load with the previous studies on engine shaft rotation. The results showed that the obtained trend was similar to the research performance of 5% sunflower biodiesel mixed fuel [18]. The engine shaft rotation affects the augment of effective power. It was similar to [19]. In the low shaft rotation, the fuel amount in the combustion chamber is low. It affected the reduction of pressure during the combustion process. As a result, the effective power generated was weak. The engine shaft rotation increased along with the enhancement in the throttle (valve), so the fuel in the combustion chamber got larger. Eventually, there was an enhancement of effective power.

The maximum effective power of the B30 at 2000 rpm was 1.61 kW. It was 60.25% lower than the previous study, which is 4.05 kW at the same engine shaft rotation. The low value of effective power at the augment of 30% CI (B30) can be implicated in the enhancement of the fuel kinematic viscosity. The High viscosity caused poor fuel atomization, so it resulting in incomplete combustion. It increased injector coke (sediment) and required a lot of energy to pump fuel [10]. The amount of energy for fuel will reduce the power/torque used to rotate the flywheel, so it can reduce energy efficiency [7].

Figure 7 showed the specific fuel consumption or SFC (kg/kWh) towards lamp load (%). The results showed the SFC graph decreased along with the enhancement of the load in the machine. It was similar to [16]. The large SFC value at the initial load was due to the large of heat lost through the cylinder wall. When the engine load increased, there was a disproportion between the mass flow speed of fuel (kg/h) and the effective power (kW). It impacted the reduction of the SFC value.

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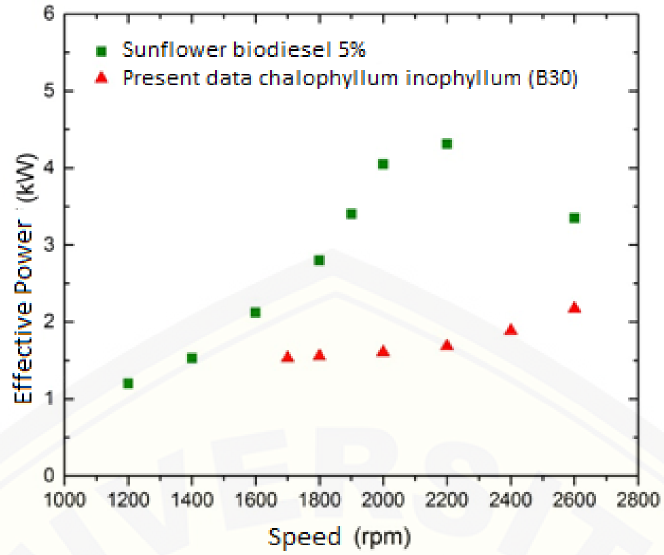

Figure 6. Effective power comparison (kW)

The highest SFC value was B30E20 at 0% lamp load of 0.46 kg/kWh. The B30E10 and B30 also have the highest SFC as 0.45 and 0.43 kg/kWh or an enhancement as 16.56, 13.27, and 8.48 %, respectively, higher than petrodiesel (0.39 kg/kWh). The enhancement of SFC from the lowest calorific value was 40.9 MJ/kg, 42.5 MJ/kg, 44.1 MJ/kg, and 46.6 MJ/kg, respectively. The low calorific value impacted the amount of heat energy smaller, so a larger mass flow speed of fuel was required to get the same work per cycle (effective power) during the combustion process [9], [20]. Figure 8 showed the thermal efficiency or BTE (%) towards the lamp load (%). The test results showed the BTE graph increased along with the load machine. It was similar to [14]. The fuel energy supplied per cycle was not completely released as heat energy in the combustion process. It occurred because the actual combustion process is not complete. The air availability was required to oxidize the fuel in the combustion chamber. The oxygen in ethanol and biodiesel played a role in the combustion phase, thereby increasing thermal efficiency [16].

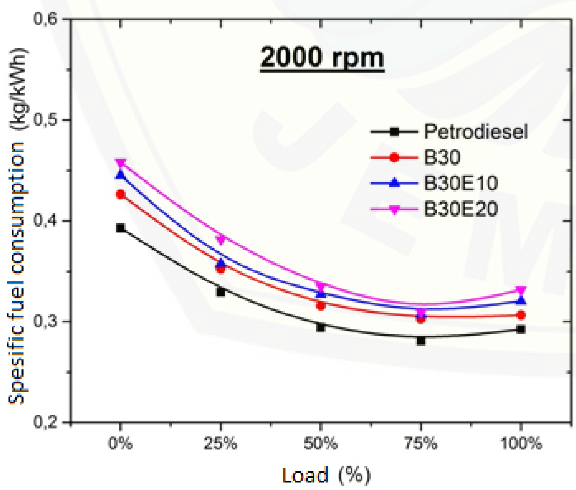

Figure 7. Specific fuel consumption (kg/kWh)

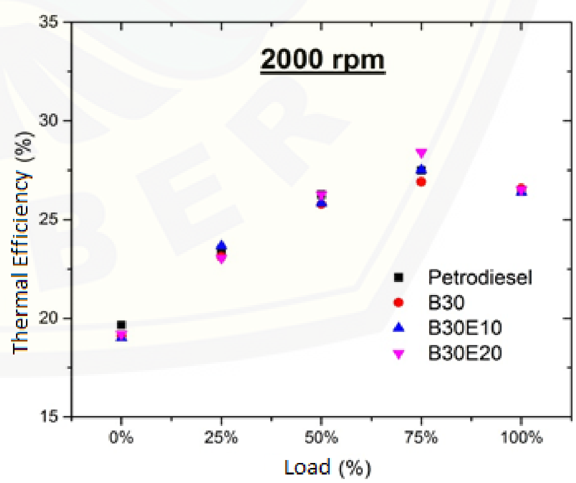

Figure 8. Thermal Efficiency (%)

The highest BTE value was B30E20 with 28.41% at 75% load followed by B30E10 and B30 at 27.52 and 26.9%, respectively. Petrodiesel fuel obtained the highest BTE value at 100% load of 26.41%. Another factor affecting the enhancement of thermal efficiency was fuel density and viscosity. These characteristics contribute to fuel atomization. The fuel in the form of a smooth and flat mist will increase the surface area and spread of the fuel into heat energy, thereby improving ignition and combustion properties [7], [21].

3.3 Emission

Figure 9 showed CO, HC, and CO2 emissions (%) toward lamp load. The CO emissions indicated incomplete combustion, so unburned fuel mold CO emissions [22]. The results showed that the CO emissions graph increased along with the load engine, it was in line with [14]. Ethanol and biodiesel are oxygenated fuel types. This fuel contains oxygen in every chemical bond, so the mixing process between fuel and air tends to be convenient [23]. Stoichiometrically, the lowest air requirement to burn 1 ml fuel was B30E20 at 164.03ml/min, lower than B30E10, B30, and petrodiesel at 168.23, 172.0, and 173.37 ml/min, respectively. The maximum lamp load test result showed that the lowest CO emission was B30E20 at 0.09% followed by B30E10 B30 and petrodiesel, respectively 0.13, 0.15, and 0.16 %.

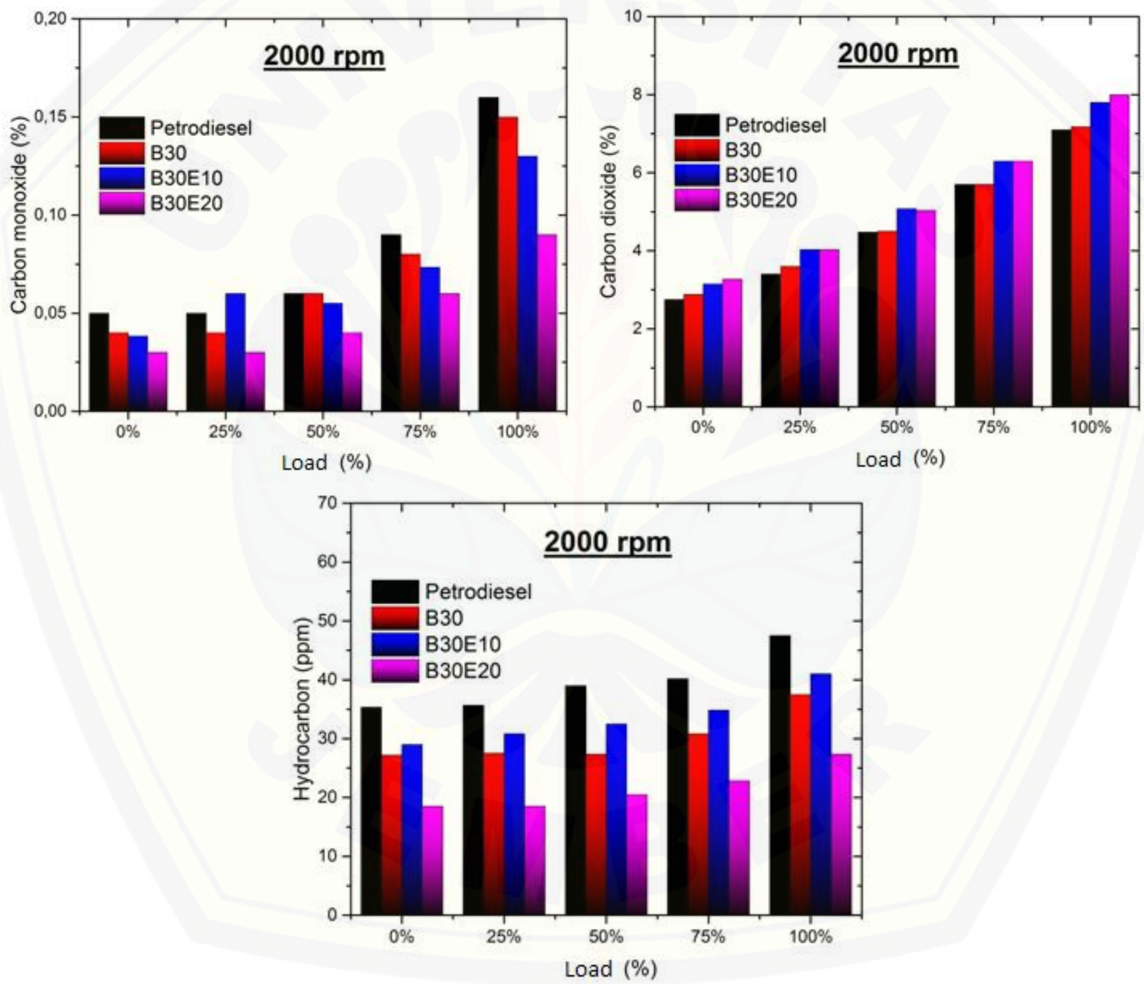

Figure 9. CO, HC, and CO_2 *Emission*

The results showed that the transformation of the CO2 emissions value depended on the load engine, it was in line with [16]. The enhancement of CO2 emissions occurred due to a reduction of CO of the oxidation process. It occurred since the high oxygen levels in ethanol and biodiesel fuels. The high oxygen allowed the CO emissions oxidation, including in the exhaust gas pipelines [14]. The results of 100% lamp load showed that the highest CO2 emissions were B30E20 at 8.0%, followed by B30E10, B30, and petrodiesel fuels, respectively 7.8, 7.18, and 7.1%. The enhancement of CO2 emissions can be reused (consumption) in the photosynthesis process as biofuel raw materials.

The test results showed that the transformation of HC emissions value depended on the load, it was rein line with [16]. The ethanol and biodiesel in the fuel provided advantages, such as post-ignition oxidation and higher flame rates during the fuel-air interaction, especially in the fuel zone. These conditions increased the oxidation of unburned HC, so it will reduce HC emissions [9].

The results of 100% lamp load showed that the lowest HC emission was B30E20 at 27.33 ppm, followed by B30, B30E10, and petrodiesel at 37.50, 41.0, and 47.50 ppm, respectively. The addition of 10% ethanol in the mixed fuel biodiesel-petrodiesel (B30) has a slightly higher HC emission than other oxygenated fuels. A lower cetane number would slow the ignition time, so the fuel air burned after the burning period (the final phase of combustion). In this phase, the piston has conducted the expansion step, so the combustion was incomplete [23]. The low cetane numbers were B30 E10 at 47.8 followed by B30E20, B30 at 49.2 and 51.5, respectively.

The enhancement of engine load at constant shaft rotation affected many fuels being injected into the combustion chamber to produce more power for overcoming the load. The enhancement of fuel was not accompanied by an enhancement of air. The limitation air of the combustion chamber affected incomplete fuel combustion, so in the high load's CO, CO2, and HC emissions were detected larger in the exhaust gas line [22].

4. CONCLUSION REMARKS

The main objective of this study was to determine the effect of adding ethanol to 30% CIB (B30) towards petrodiesel. The results indicated that:

- Ethanol can compensate for the enhancement of density up to 0.84 g/ml and viscosity up to 2.4 mm2/s.
- The torque values (Nm) and effective power (kW) were similar between fuels when these used the constant engine speed method and lamp load variations.
- The ethanol increased SFC higher than B30 and petrodiesel up to 0.46 kg/kWh. Meanwhile, it also increased BTE up to 28.41%.
- In the exhaust emissions, ethanol reduced CO and HC emissions lower than B30 and petrodiesel as 0.09% and 27.33ppm. However, CO2 emissions increased up to 8.0% higher than B30 and petrodiesel. It was because of the reduction of CO emissions that continue the oxidation process of the high oxygen level in ethanol fuel.

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