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Effects of CPO Biodiesel Blend Ratio on the Performance and Emission of Compression Ignition Engine

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Abstract: This study investigates the effect on performance and emission of various biodiesel blend which is 7.0 % (B7), 15.0 % (B15), and 30.0 % (B30) by using crude palm oil as the feedstock and blending with diesel fuel. Parameters involved in this test are brake power, torque, and fuel consumption that is carried out by running 4-cylinder common rail CI engine of Toyota Hilux on a chassis dynamometer with different road speed which is 60, 90 and 110 km/h. The SPTC-any car autocheck gas and smoke analyzer were used to determine gas emission such as HC, CO, CO_2, O_2, NO_x, Lambda, and smoke opacity while ONOSOKKI were used to measure fuel flow rate. The increase in the blending ratio has resulted in low emission for CO and NOx. Brake power increase but decreasing torque occurs at high road speed due to mechanical friction. The high viscosity of fuel increases fuel consumption and decrease engine performance.

Keywords: Biodiesel, crude palm oil, emission, performance

1. Introduction

Diesel fuel had been used worldwide many years back and this fuel is produced from fossil. Nowadays, the lack of fossil fuels has made some innovations towards diesel fuel not to depend much on fossil fuels. Biodiesel is the main alternative where biodiesel is easy to reach from vegetable oil or fish oil plus biodiesel is renewable, biodegradable and environmentally friendly compared to diesel fuel. The production of biodiesel based on transesterification converts triglycerides with alcohols enhanced by the presence of a base catalyst or acid catalyst decided by the content of free fatty acid present in the oil [1-2]. However, there are many problems faced by most biodiesel fuel that are not suitable with a diesel engine due to their variant fuel properties that make the diesel engine does not operate efficiently. The key point in producing biodiesel is oxidation stability, bio-fuel composition, stoichiometric point and oxygen content on the fuel compared to diesel fuel.

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Different feedstock has their biodiesel properties and crude palm oil (CPO) have properties that are nearly the same as diesel fuel in terms of cetane number, the heat of vaporization and stoichiometric air/fuel ratio. CPO fuel properties can reduce greenhouse gas effects such as HC, PM and CO as the fuel is non-toxic and less sulphur [3]. Fuel viscosity will affect combustion process that can influence emission and performance as high viscosity will increase fuel quantity, spray pattern, and ignition timing. CPO had lower viscosity fuel and did not affect the injection system and provide smooth fuel even with 100 °C heating. Research has been done and the result shows that CPO has high peak pressure of approximately 6.0 % and low period ignition delay of about 2.6 °C. A lower amount of heat was released compared with diesel fuel [4]. CPO is said to be low CO and CO_2 release compared with diesel fuel as CPO biodiesel consists of high oxygen content but increases in NO_x gas as NO_x emission is mainly caused by high combustion temperature [5]. Engine combustion systems and biodiesel sources are the main reason for engine performance and emission. Rahman [6] used CPO at a four-cylinder CI engine coupled with eddy current dynamometer said that NOx and particulate emission increase at high load and high-pressure injection produce high NO_x less particulate emission. It is why NO_x concentration is not the same for every research, even with the same biodiesel fuel used. In this research, performance and emission of CI engine are determined by using a 4x4 Toyota Hilux common rail diesel engine that runs on a chassis dynamometer using three different blends of CPO which is B7, B15 and B30 at the variable road and engine speed.

2. Materials and Methods

2.1 Experimental setup

The fuel tested on the 4-cylinder common rail diesel engine of Toyota Hilux is crude palm oil (CPO) based biodiesel blends with diesel fuel. The crude palm oil is blended with diesel fuel at numerous blending proportions at 7.0, 15.0 and 30.0 % by fuel. These blended fuels are denoted as B7, B15 and B30 and the fuel properties are shown in Table 1. Engine fuel consumption was measured using the precision ONOSOKKI volumetric fuel flow meter attached between fuel tank and fuel pump. Gas emission was analyzed by using SPTC-anycar autocheck gas and smoke analyzer that are measuring gas such as carbon dioxide (CO_2), oxygen (O_2), hydrocarbon (HC), nitrogen oxide (NO_x), carbon monoxide (CO), Lambda, Air/Fuel ratio and smoke opacity. Experimental setup diagram of the performance and emission test also engine specification include operating parameters shown in Figure 1 and Table 2 respectively. The tested vehicle that used is Toyota Hilux with common rail direct injection 2494 cc 4-cylinder engine. This engine was designed to create 80 kW maximum power at 3600 rpm and a maximum torque of 325 Nm at 2000 rpm with a compression ratio of 17.4:1. The dynapack chassis dynamometer was used to simulate the engine performance similar to the vehicle's actual behavior on the road. The chassis dynamometer can work on both 2WD and 4WD with maximum power 600 kW and 800 hp. For this experiment, the running speeds were simulated at 1680, 2520 and 3080 rpm that equivalence to 60, 90 and 110 km/h road speed, respectively.

Table 1: Properties of test fuels [7-8]

Fuel type	Density (g/cm^3)	Kinematic viscosity (Cp)	Flash point (°C)	Water content (ppm)
B7	0.829	3.0	71.5	57.0
B15	0.840428	3.0	93.5	219.0
B30	0.845852	3.1	97.0	397.1

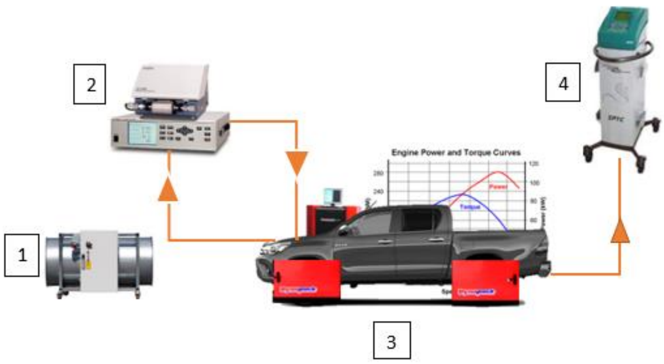

Figure 1: Dynapack chassis experimental setup

1. Air blower.
2. Ono Sokki fuel flow meter.
3. Dynapack 4WD chassis dynamometer.
4. Exhaust gas and smoke analyser.

Table 2: Engine specification

Engine specification	Descriptions
Bore x stroke	92.0 x 93.8 mm
Displacement	2494 cc
Compression ratio	17.4:1
Fuel system	Common rail direct injection
Maximum power	80 kW @ 3600 rpm
Maximum torque	325 Nm @ 2000 rpm

3. Results and Discussion

The impact of crude palm oil on a diesel engine in terms of performance and emission for B7, B15 and B30 is discussed here.

3.1 Brake Power

Brake power comes from an engine transmitted from heat energy into mechanical energy that can be traced from the output shaft. Brake power can be tested using a dynamometer where the output torque and rotational speed as the medium to measure the brake power achieve from shaft horsepower. Figure 2 illustrates the brake power achieve from running on a dynamometer where the speed is set at 60, 90 and 110 km/h while the accelerator pedal position is fixed at 90.0 %. Brake power decreases as road speed increase for all fuel blends. Brake power at 60 km/h for B7, B15 and B30 were 37.97 kW, 36.63 kW and 36.05 kW, respectively. The power then increases when the road speed reaches 110 km/h for B7, B15 and B30 where the power is 54.29 kW, 52.90 kW, and 52.66 kW, respectively. Brake power increase when road speed increase but decreasing among biodiesel blend. It is due to fuel viscosity of B30 as increasing of blending ratio will increase fuel viscosity that results to injection pump unable to supply sufficient fuel to fill the pumping chamber then effect to power loss [9].

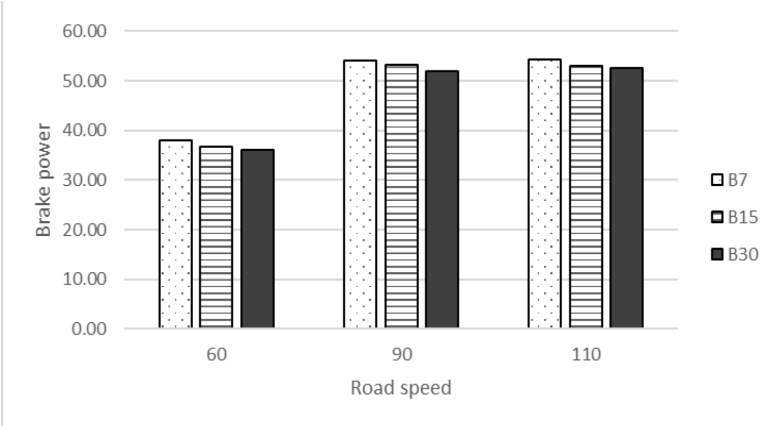

Figure 2: The relationship between brake power (kW) and road speed (km/h) for B7, B15 and B30

3.2 Brake specific fuel consumption

Brake specific fuel consumption is fuel consumption rate used by a vehicle. A lower value of brake specific fuel consumption means that less fuel usage produces the same amount of work. The variations of fuel consumption for B7, B15 and B30 are shown in Figure 3. Fuel consumption is increase when road speed increase with 90.0 % accelerator pedal position. B7 has recorded high fuel consumption compared with another blending because it has a low calorific value on the fuel. Calorific value is the main reason for the increase and decrease in fuel consumption. The high calorific value will offer low fuel consumption while low calorific value results to high fuel consumption due to high oxygen content on the fuel[10-11]. More biodiesel fuel is needed on the engine to compensate for the loss of heating value in biodiesel [12]. Among all biodiesel-diesel blend, B30 have better brake specific fuel consumption.

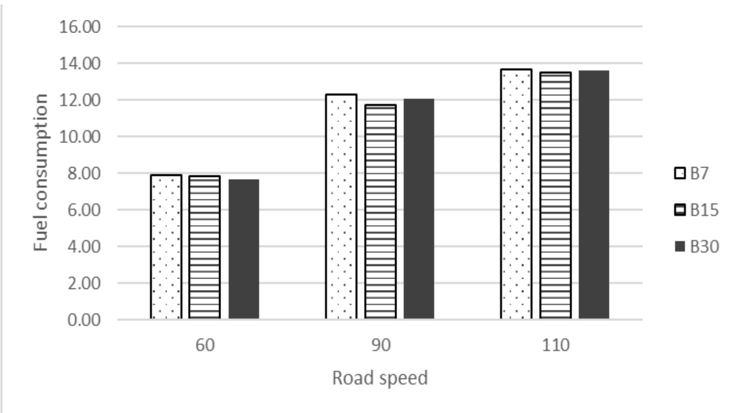

Figure 3: The relationship between fuel consumption (kg/h) and road speed (km/h) for B7, B15 and B30

3.3 Torque

Torque decrease with the increase of all blends and at high road speed. A comparison between all blending ratios shows that B30 recorded the lowest torque than other blends at high speed. Due to the high viscosity of fuel blends that can increase mixture momentum and penetration on the cylinder, increasing fuel blending will increase fuel viscosity [3]. More work is needed to burn the high viscosity fuel, thus decrease the torque. Decreasing torque when at high engine speed is also due to mechanical friction [9]. B7 reaches high engine torque among other blends for all road speed.

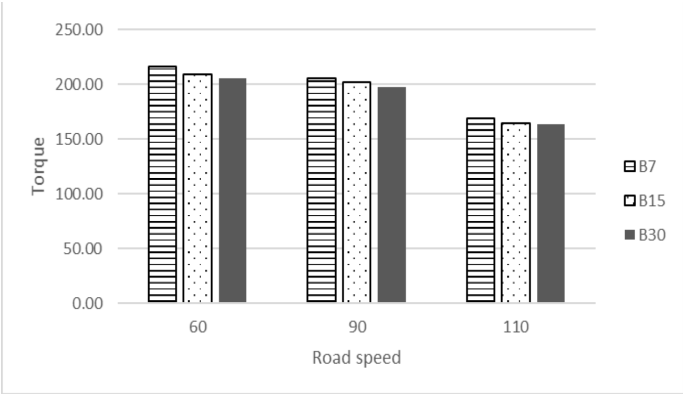

Figure 4: The relationship between torque (Nm) and road speed (km/h) for B7, B15 and B30

3.4 Carbon Dioxide Gas Emission

The result from Figure 5 illustrates that carbon dioxide content is decreasing for all kind of blend mixture. Decreasing of carbon dioxide due to high oxygen content on biodiesel. Oxygen content on fuel will increase when more biodiesel is blended with actual diesel fuel. B30 have lower carbon dioxide content compared to B7 and B15 at all road speed. The other factor of decreasing carbon dioxide content is low carbon content, less energy consumption, and biodiesel combustion [11].

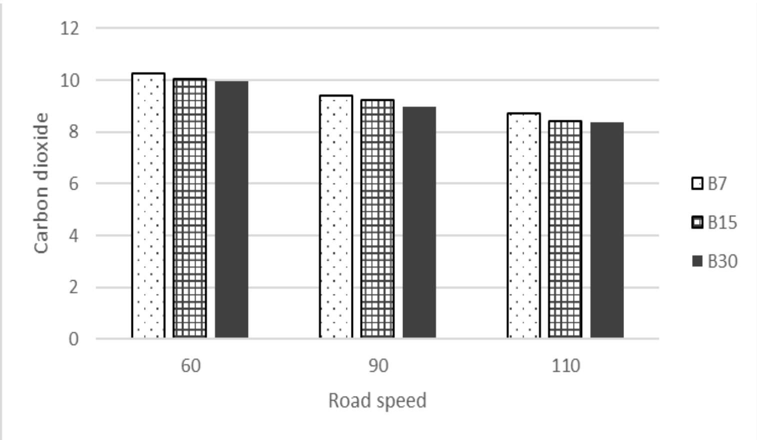

Figure 5: Effect of CPO blending on carbon dioxide gas emission

3.5 Carbon Monoxide Gas Emission

Carbon monoxide content higher for all blends at the 60 km/h speed. The increase of blend will add more oxygen content and result in a more efficient burning process, thus lowering CO gas emissions. B7 and B30 contain more CO gas content than other blends at high speed which is 110 km/h at 3000 rpm. A low concentration of oxygen was the main reason formation of a high volume of CO emission [12]. The other reason is the decrease in temperature that results to the formation of CO emission. The low temperature inside the combustion chamber results in high CO formation as the combustion process does not operate in full efficiency.

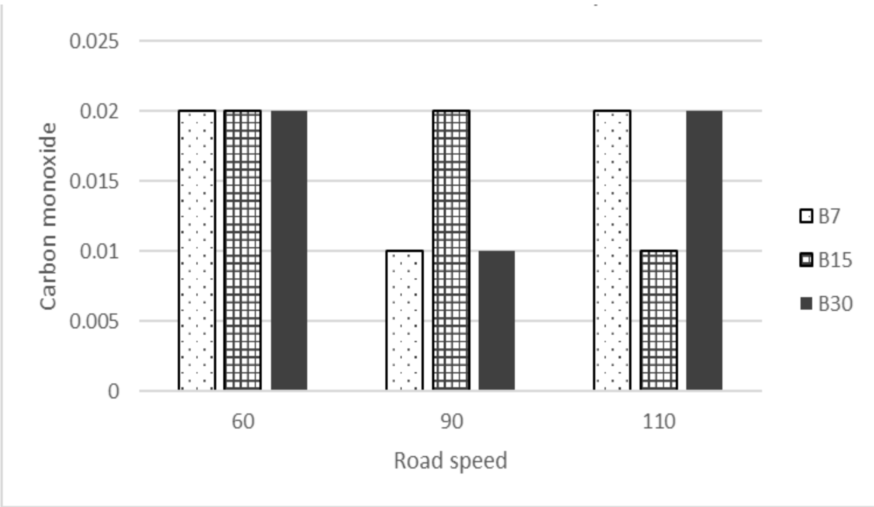

Figure 6: Effect of CPO blending on carbon monoxide gas emission

3.6 Hydrocarbon Emission

Hydrocarbon content gradually increases when road speed increase for all kind of blends. B15 and B30 have high HC content compared to other blends at high road speed. B7 is the lowest hydrocarbon content release among other blends at high road speed. Increasing of HC emission for B15 and B30 is due to high viscosity of fuel as the blending ratio increases. Increasing of HC also effect cylinder temperature that is generally high [11]. The formation of HC is nearly the same as CO but the temperature of near-complete combustion for HC is lower than CO.

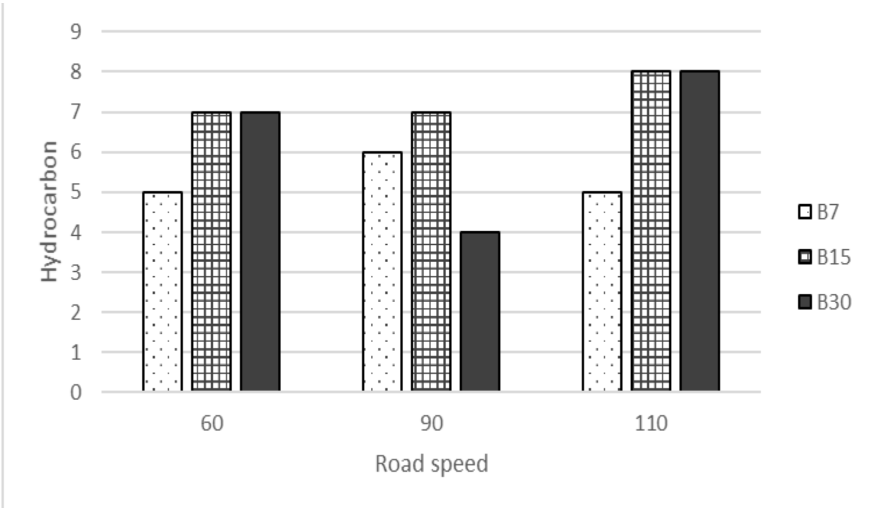

Figure 7: Effect of B7, B15 and B30 and road speed (km/h) on hydrocarbon gas emission

3.7 Oxygen Gas Emission

Oxygen content is related to CO content. High oxygen will result to low CO and vice versa. Figure 8 shows that oxygen content low at low speed and increase when road speed is increase. The increasing of oxygen content also recorded for all blending ratio which is B30 has the highest oxygen content compared with other blends. Biodiesel has high oxygen content, and increasing blending will result in increased oxygen content on fuel [12]. A high biodiesel blending ratio will increase the presence of oxygen content on fuel.

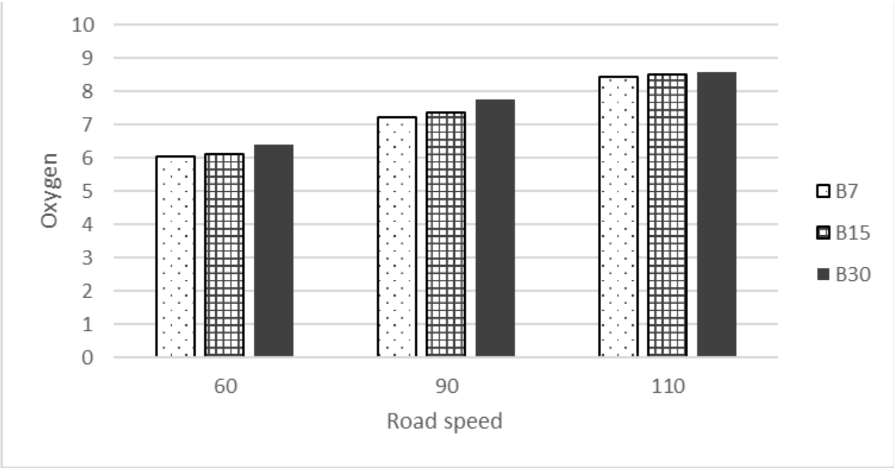

Figure 8: Effect of CPO blending on oxygen gas

3.8 Nitrogen Oxide Emission

B15 and B30 biodiesel blend have shown decreased NO_x emission gas release when road speed is increased. B7 shows the opposite result which is NO_x gas is high compared to others at high road speed. Type of feedstock use is the main factor in the increase and decrease of NOx gas. Crude palm oil show decreasing in NO_x gas compare with another feedstock. Nearly all cited studies report that the biodiesel-fuelled engine has a slight increase of NOx emission [14]. The formation of NOx depends on the combustion temperature and oxygen content in the mixing combustion product [9]. High oxygen content on fuel will result in increased NO_x gas release as Oxygen reacts with Nitrogen. The reduction of NOx gas can be caused by temperature on the combustion chamber that not triggered Nitrogen molecule thus produce low NOx gas. Exhaust Gas Recirculation (EGR) rate plays a role in diluting oxygen concetration in the combustion chamber [13].

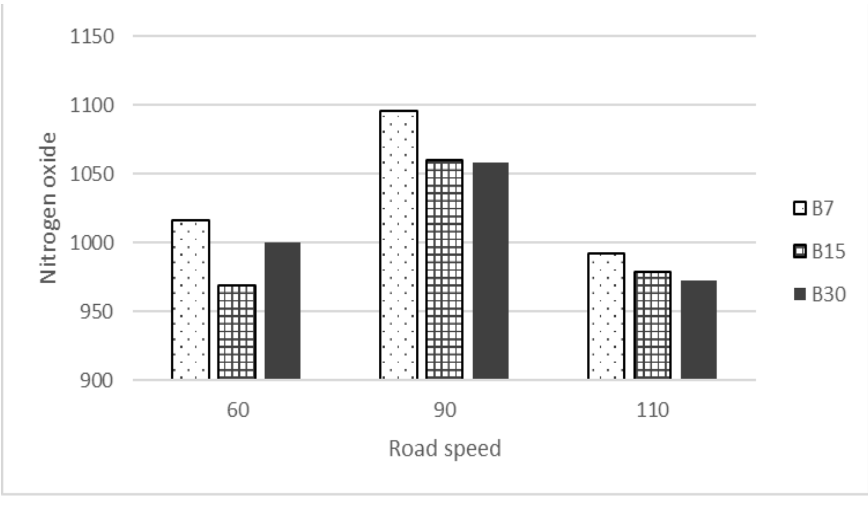

Figure 9: Effect of CPO blending on nitrogen oxide emission

3.9 Lambda

Lambda is the actual air-fuel ratio divided by the stoichiometric air-fuel ratio needed to do a complete combustion of fuel delivered. The burning of the air-fuel mixture influences a different reading of lambda. In general, diesel engines lean at ideal and low load because airflow is constant and fuel can be controlled through acceleration [15]. Most of the modern diesel engines run lean air-fuel mixture between 1.65 and 1.10. That means diesel engines run at high efficiency at lambda = 1.65 or above where the fuel consumption is also low at this lambda reading. According to Figure 10, all blend show lambda reading that is called lean. At 60 km/h road speed around 1500 rpm, all biodiesel blends show the reading between a lean air-fuel mixture. The value of lambda keeps increasing when road speed increase shows that the engine gains more efficiency and low fuel consumption. R. Douglas [16] has come out with a mathematical expression of combustion efficiency and equivalence factor. A calculation has been made using the equation and the result shows that the diesel engine's best combustion efficiency is at lambda = 2.00.

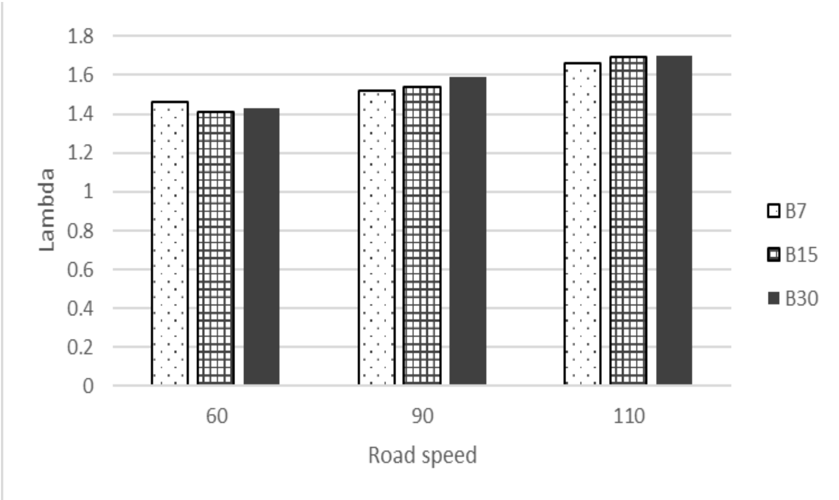

Figure 10: The relationship between lambda and road speed on B7, B15 and B30

3.10Smoke opacity

Smoke opacity is the main problem for CI engines. High smoke opacity shows that the engine has incomplete combustion of the air-fuel mixture. High smoke opacity might be from high combustion temperature. A high amount of oxygen on fuel can lead to complete combustion and decrease smoke opacity. Smoke opacity increase for B15 and B30 while B7 slightly decreases but B30 still the blends that release low smoke opacity. The increase of smoke opacity depends on the forming of hydrocarbon and sulphur formation. Poor atomization may increase smoke opacity that relates to heavy fuel molecules, high viscosity and low volatility of fuel used [17].

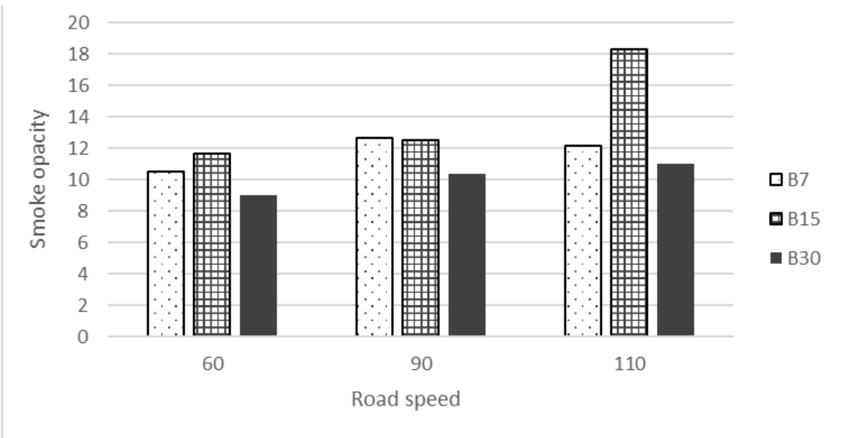

Figure 11: The relationship between smoke opacity and road speed on B7, B15 and B30

4. Conclusion

In this research, the CPO biodiesel fuel is successfully tested with three different blends of biodiesel which are B7, B15 and B30. The fuel tests with Toyota Hilux run on a chassis dynamometer at 60, 90 and 110 km/h road speed. The conclusion has been made that all diesel blend has low engine performance in brake power and torque, but fuel consumption is low at high speed for all blends. It is proved when lambda reading show that fuel combustion is lean at high road speed. For emission, CPO releases high oxygen on exhaust gas, thus decreasing the CO gas and CO2 gas for B7 and B30. Nitrogen oxide decrease for B15 and B30 but B7 maintains high NO_x gas when at high speed. Overall, the usage of CPO biodiesel blend has low emission gas release. Improvement can be made on fuel blendings such as adding some chemical additive to get high kinematic value and improvement in viscosity that is useful for increasing torque and brake power.

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