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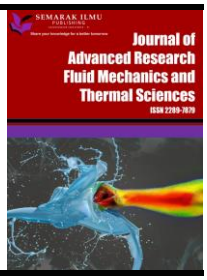

Performance and Emissions Characteristics of Vehicle Fuelled with Blended Palm Biodiesel Before and After Engine Overhaul

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ABSTRACT

Rapid industrialization and growth in population have resulted in a rapid increase in energy demand. Pollutant emissions from diesel engines have caused major impacts in disturbing the ecological system. The Malaysian government implemented the B10 biodiesel program for the transportation sector and B7 for the industrial sector in 2019 to drive the demand for palm oil and increase the sustainability of energy resources. For future implementation, the government is looking toward for higher percentage of blended biodiesel, such as B30 and above. This paper presented the effect of engine overhaul on the performance and emissions of a vehicle fuelled with blended biodiesel (B10, B20 & B30) by comparing before and after the engine overhaul. By using a vehicle Toyota Hilux 2.5L, the vehicle was attached to a chassis dynamometer for determining its performance such as brake power and brake specific fuel consumption (BSFC) at 45% and 90% of Acceleration Pedal Position (APP), respectively. The exhaust gas emissions were measured using a 5-channel analyser for determining the carbon dioxide (CO2), carbon monoxide (CO) and nitrogen oxide (NOx). The experiment was conducted in a steady-state condition with a constant speed of 30, 60, 90, and 110 km/h simulating rural, urban, and motorway speeds. The performance results revealed that blended biodiesel B10, B20 and B30, produced higher brake power, and lower brake-specific fuel consumption after engine overhaul. Emissions results showed that CO was increased at 45% APP but decreased at a higher 90% APP, and in most cases, NOx and CO2 emissions were decreased with an increase in speed for both APP.

1. Introduction

Diesel engines offered more benefits and are required in a wide range of industries compared to other fossil fuels because of their fuel economy, improved efficiency, and long-lasting capacity [1]. Major diesel fuel consumption especially in compression ignition (CI) engines had caused the

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depletion of fossil fuels resources and damaged the environment where the combustion of these fuels deteriorated our air quality. This is due to the emission of air pollutants such as nitrogen oxides (NOx) and particulate matter (PM). In addition, the release of carbon dioxide (CO2) also ignited the climate change issue [2]. To mitigate these issues, Euro emission standards are introduced, and it was started in 2005 with Euro 4 fuel standard sets a maximum of sulphur in automotive fuels is 50 ppm. However, it reduced the lubricity of the fuel [3]. It was reported by [4] that removing sulphur in fuel which called the desulphurization process can be potentially reduced vehicle emissions. Nevertheless, this strict emission standard has forced every country to implement in their country for addressing these environmental challenges. The utilization of non-renewable fuels prompted the researcher to concentrate on alternative renewable fuels and search initiatives for the vehicle's manufacturing consideration [5].

O. Ogunkunle and N. A. Ahmed reported that seed oil biodiesel is a low-cost renewable biofuel with clean-burning properties that have the potential to decrease global dependency on petroleum diesel fuels [6]. Produced biodiesel can be mixed with diesel and used in diesel engines without any modifications. The biodiesel is produced by transesterification or alcoholysis process by reacting oils and alcohol in the presence of acids, bases, enzymes, or other catalysts [7]. However, most diesel engine components, such as fuel injectors and fuel pumps, are self-lubricated, then, the lubricity of biodiesel is significant. The desulphurization process during biodiesel production has caused high-speed diesel to have poor lubricity because of a lack of polar molecules being removed [8].

Most literature found that the best ratio for blended biodiesel is 20:80, which means its mixed fuel is between 20% of biodiesel and 80% of diesel fuel. However, it is found that it lowered PM, THC, and CO emissions while increasing NOx [9,10]. L. G. Schumacher et.al study showed that palm oil blended biodiesel called B20 produced lower thermal efficiency, increased BSFC, reduced emission of CO and HC, and increased NOx emission [11]. Meanwhile, O. M. Ali et.al found that increasing the blended biodiesel ratio to 30% reduced engine brake power by 2.6% and increased BSFC by 3% without a significant difference in thermal efficiency [12]. Another study showed that blended biodiesel in the range of 10% to 40%, produced significant BSFC without sensible change in engine power [13]. The use of 100% palm oil biodiesel (B100) showed a different result between low, mid, and high engine speed where at high engine speed, NOx and CO emission is comparable to diesel fuel, but suffered in CO2 emission compared to diesel fuel [14]. A study using castor biodiesel B20 showed a similar power output as diesel fuel with better combustion and lower PM, CO, and HC emissions compared to diesel fuel [15].

For Malaysia, the National Automotive Policy (NAP) 2020 has been launched projecting the usage of palm oil blended biodiesel (B30) to be implemented by the year 2025 or earlier [16]. However, most car manufacturers approved biodiesel usage of up to 20% blended. Higher blended biodiesel has not been thoroughly evaluated for commercial use in Malaysia. This paper aims to investigate the effect of engine overhaul on engine performance and exhaust emissions for vehicles fuelled with palm oil blended biodiesel. The palm oil blended biodiesel used for this study is B10, B20 and B30 which are provided by Malaysian Palm Oil Board (MPOB).

2. Methodology

A Toyota Hilux 2.5L, the direct injection with common-rail diesel engine was used as a test vehicle. The specifications of the test vehicle are shown in Table 1. The test vehicle is mounted to the chassis dynamometer hub (Dynapack, Model No: 4022) using a coupling mechanism to the tires to measure brake torque and brake power. The Ono-Sokki FZ 2100 was used as fuel consumption measurement, which uses the Coriolis force principle, generated when the movement of mass and rotation coincide.

Exhaust gas emissions such as CO2, CO, and NOx were measured using the Kane AutoPlus emission analyzer. The Innovate Motorsport LM-2 Digital AFR Meter was used to measure the air-fuel ratio. Bosch diagnostic scan tool (Model No: KTS 570 V1.2) was used in the experiment to monitor and record vehicle data such as speed, accelerator pedal position, coolant temperature, intake air temperature, and engine load. The blended biodiesel is palm biodiesel and diesel Euro 5, which are B10, B20 and B30, provided by Malaysian Palm Oil Board (MPOB). The B10 fuel code means the biodiesel blend with 10% of palm biodiesel and 90% of diesel Euro 5 by volume ratio. The fuel properties for blended biodiesel are shown in Table 2. The experiment was conducted in a steady-state condition with a constant speed of 30, 60, 90, and 110 km/h simulating rural, urban, and motorway speeds. Gear is set at position four (gear 4), where the gear ratio is 1:1. The accelerator pedal position represents the load on the engine with a value of 45%, and 90%. The experiment setup is shown in Figure 1. The performances and emissions measurements were conducted at 0 km (before engine overhaul) and 10,000 km (after engine overhaul) mileage. The engine overhaul was performed on the top parts only as shown in Figure 2. The vehicle's mileage was monitored using *Cartrack* services [17].

Table 1
Toyota Hilux 2.5L (Model no: 2KD-FTV) specifications

Engine	4x4, 2.5 litre D-4D Diesel
Engine Code	2KD-FTV
Number of Cylinders	4 *In-line*
Fuel System	Common-rail Direct Injection
Engine Displacement	2494 cc
Bore	92 mm
Stroke	93.8
Compression Ratio	17.4:1
Max Power	120 DIN 80 kW/3600 rpm
Max Torque	325Nm/2000 rpm

Table 2
Fuel properties of blended biodiesel

Properties	B10	B20	B30
Density at 15°C, kg/L	0.8262	0.8315	0.8336
Kinematic Viscosity at 40°C, mm^2/s	3.153	3.224	3.369
Flash Point, °C	72.0	75.0	79.0
Cetane number	57.9	58.0	58.2
Sulfur, mg/kg	2.75	2.51	2.45
Calorific Value, kJ/kg	45634	44964	44409

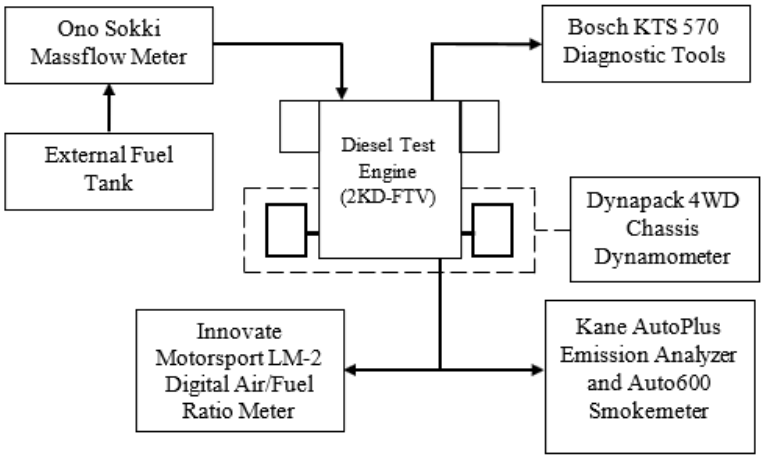

Fig. 1. The experiment setup

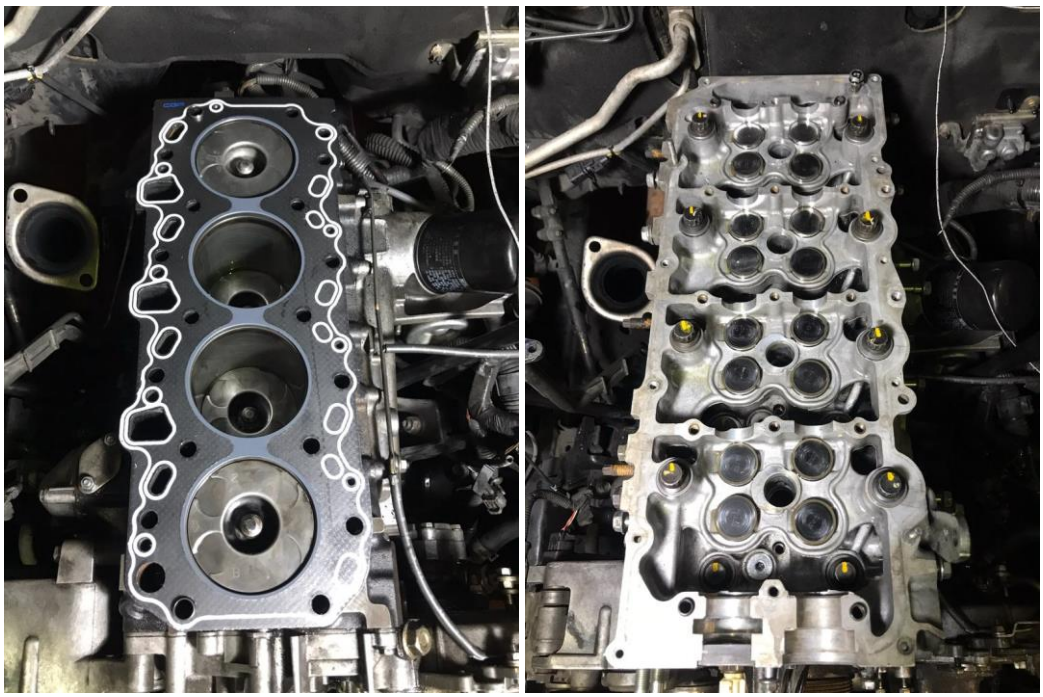

Fig. 2. Engine head with a new gasket and new valve seal after top overhaul

3. Results

3.1 Engine Performance

The engine performance of vehicles fuelled with blended biodiesel for different simulated road speeds before and after engine overhaul are presented in Figures 3 and 4 in terms of brake power and brake-specific fuel consumption (BSFC), respectively. The relationships between different road speeds and different ratios of blended biodiesel at certain accelerator pedal positions (APP) are addressed. Before the engine overhaul, the highest brake power was produced for 45% APP at a road speed of 60 km/h, while for 90% APP was at a road speed of 110 km/h. The brake power decreases with the increase of the blended biodiesel ratio percentage. This might be due to the lower calorific value and higher cetane number of B30 compared to others. In most cases, the brake power slightly increases after the engine overhaul.

The BSFC is highest at 45% APP for a road speed of 110 km/h before and after an engine overhaul. Even though, it was observed the BSFC is slightly better after an engine overhaul. At 90% APP, road

speed does not affect the BSFC. It is also observed that BSFC increased as the percentage of blended biodiesel increased. As the percentage of biodiesel in the blended fuel increases, the calorific value decreases while the specific gravity increases, resulting in higher fuel consumption for the same amount of energy produced.

It is noted that, after the engine overhaul, engine performance is much better compared to before the engine overhaul. It is explained that after long usage of blended biodiesel fuel, the engine performance is slightly lower because the engine started to experience the effect of biodiesel deposits and clogging.

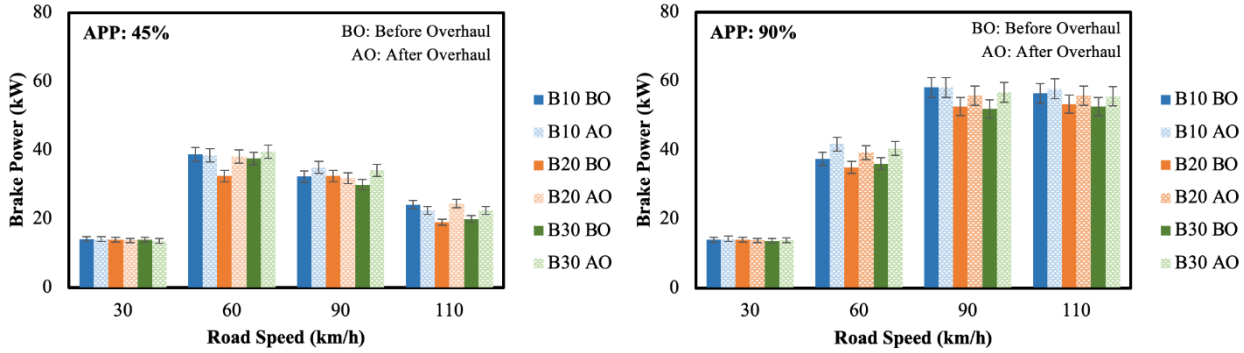

Fig. 3. Brake power comparison between B10, B20 and B30 before and after engine overhaul

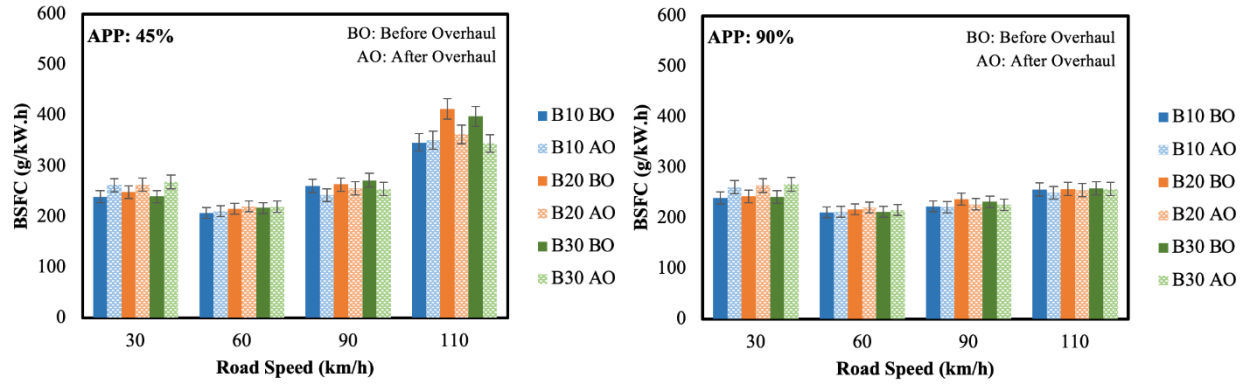

Fig. 4. Brake Specific Fuel Consumption (BSFC) comparison between B10, B20 and B30 before and after engine overhaul

3.2 Exhaust Gas Emissions

The exhaust gas emissions of a vehicle fuelled with blended biodiesel for different simulated road speeds before and after engine overhaul are presented in Figures 5 to 7 in terms of CO_2, CO, and NOx, respectively. The relationships between different road speeds and different ratios of blended biodiesel at certain accelerator pedal positions (APP) are presented. The emissions of carbon dioxide (CO_2) and carbon monoxide (CO) produced by the combustion of B10, B20 and B30 are shown in Figure 5 and Figure 6. It was observed that the emission of CO_2 decreases when road speed increases. When the APP increases from 45 to 90%, an increment of CO_2 emissions was observed for road speeds of 90 and 110 km/h. Increasing percentages of blended biodiesel decrease the CO_2 emission, however, it was not significantly notable, with less than a 1% decrease. It was noted that after the engine overhaul, the CO_2 emissions were much lower compared to before the engine overhaul.

In terms of CO emissions, it showed that, as road speed increases, the CO emission significantly decreases. As the percentage of blended biodiesel increased, the CO emission was slightly decreased.

This might be due to palm oil biodiesel fuel's greater cetane number, which has strong igniting qualities. However, after the engine overhaul, the CO emissions increased compared to before the engine overhaul.

Figure 7 shows the NOx emissions with different road speeds at certain APP comparing B10, B20 and B30 of blended biodiesel. When the road speed increases, the value of NOx decreases for all APPs. Different percentage of blended biodiesel does not affect NOx emissions. However, after the engine overhaul, the NOx emissions were much lower compared to before the engine overhaul. This might be due to the presence of additional oxygen molecules and a greater cetane number.

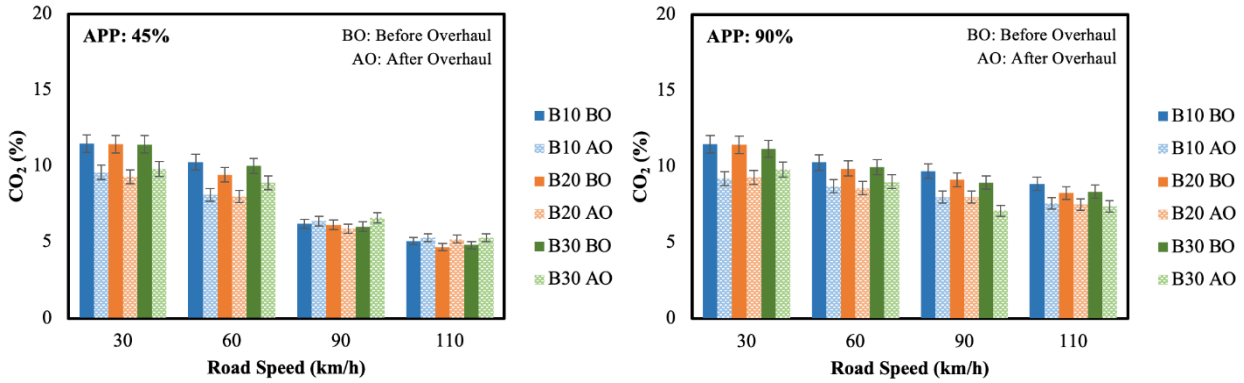

Fig. 5. Carbon Dioxide (CO_2) comparison between B10, B20 and B30 before and after engine overhaul

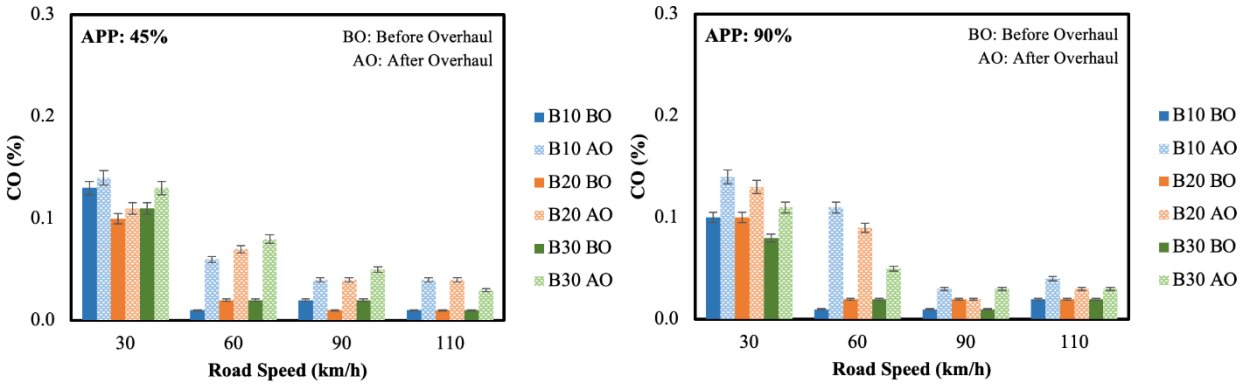

Fig. 6. Carbon Monoxide (CO) comparison between B10, B20 and B30 before and after engine overhaul

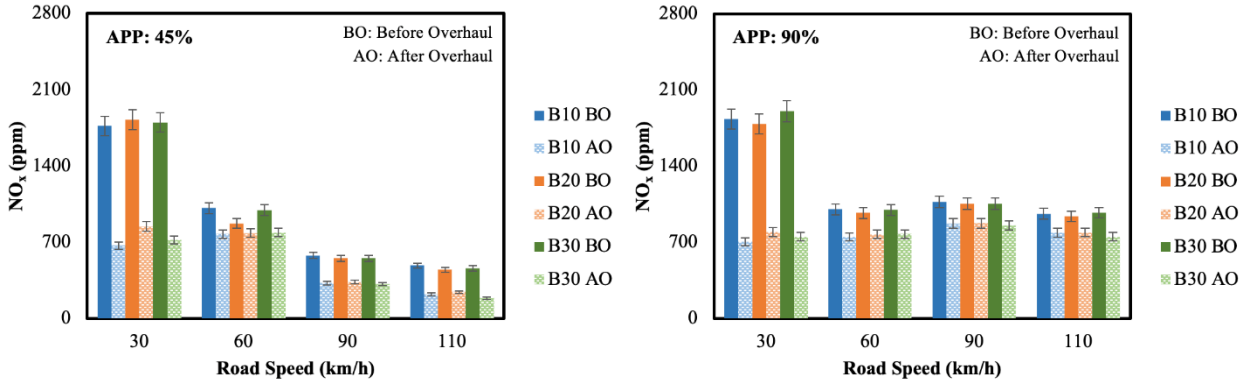

Fig. 7. Nitrogen Oxide (NOx) comparison between B10, B20 and B30 before and after engine overhaul

4. Conclusions

In conclusion, increasing the percentage of palm biodiesel in the blended biodiesel from 10% to 30% in Euro 5 diesel fuel does not drastically change its engine performance and exhaust emission. The higher percentage of blended biodiesel produced slightly lower brake power and increased fuel consumption. The emissions of CO_2 and CO decreased as road speed increased and slightly decreased with a higher percentage of blended biodiesel. The emission of NOx also decreased as road speed increased. This study showed after engine overhaul, the engine performance and emissions of vehicles fuelled with blended biodiesel improved. This study also proved that engine performance and exhaust gas emission using blended biodiesel B30 with Euro 5 diesel are reasonable.

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