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Performance and Emissions Characteristics of Diesel Engine Fuelled by Biodiesel Derived from Palm Oil

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Abstract. Bio fuels based on vegetable oils offer the advantage being a sustainable, annually renewable source of automobile fuel. Despite years of improvement attempts, the key issue in using vegetable oil-based fuels is oxidation stability, stoichiometric point, bio-fuel composition, antioxidants on the degradation and much oxygen with comparing to diesel gas oil. Thus, the improvement of emissions exhausted from diesel engines fueled by biodiesel derived from palm oil is urgently required to meet the future stringent emission regulations. Purpose of this study is to explore how significant the effects of palm oil blending ratio on combustion process that strongly affects the vehicles performance and exhaust emissions. The engine speed was varied from 1500~3000 rpm, load test condition varied by Dynapack chassis dynamometer from 0~50% and palm oil blending ratio from 5~15vol% (B5~B15). Increased blends of biodiesel ratio is found to enhance the combustion process, resulting in decreased the HC emissions with nearly equal of engine performance. The improvement of combustion process is expected to be strongly influenced by oxygenated fuel in biodiesel content.

Introduction

In Malaysia, Green Technology and the Climate Change Council (MTHPI) involved in reducing the CO_2 emissions up to 40% between 2005 and 2020. For that reason, the vehicle run by Bio-diesel Fuel (BDF) has been a potential option. Shortage in the hydrocarbon fuel sources and the future stringent emission regulations have been a formidable challenge to the most prominent worldwide automotive industries. Therefore, the alternative sources of fuel are receiving a lot attention in the automotive industry.

The key issue in using vegetable oil-based fuels is oxidation stability, stoichiometric point, bio-fuel composition, antioxidants on the degradation and much oxygen with comparing to diesel gas oil. However, the application of the BDF in the diesel engines offer not only attractive and more economical fuel but also creates problems of higher emissions compared with petroleum based diesel. BDF diesel engines still have problem of emitting NOx and Particulate Matter (PM) into the atmosphere because of the oxidation stability, cetane number, stoichiometric point, bio-fuel composition and antioxidants on the degradation extremely viscous [1-4]. Thus, the improvement of emissions exhausted from BDF engines is urgently required to meet the future stringent emission regulations. It was reported that the implementation of boost pressure, swirl velocity and injection pressure has a great effect on the mixture formation, ignition delay, turbulence, ambient density and ambient pressure, and then affects to the flame propagation, combustion characteristics and emissions elements. Biodiesel has higher cetane number than diesel fuel, no aromatics, almost no sulfur, and contains 10 to 11% oxygen by weight. These characteristics of the fuel reduce the emissions of carbon monoxide (CO), hydrocarbon (HC), and particulate matter (PM) in the exhaust gas. In addition, higher of viscosity and specific gravity are found to increase the fuel quantity, injection timing, and spray pattern will strongly influence the degree of initial premixing and combustion process. For that reasons, numerous emissions studies using bio diesel and its blends shows emissions concentration (CO, CO2, HC, PM, NOx as well as deposit) varies depend on source of bio-diesel and engine combustion system.

Hamsaki et. al. had fuelled a direct injection diesel engine with palm oil methyl ester (PME) and summarized that NOx and smoke emissions from PME are lower than those from petroleum base diesel fuel[5]. Kalam and Masjuki also investigated the preheated crude palm oil (CPO) into the test engine. The results show that preheated CPO fuel gives higher NOx emission compared with diesel fuel[6]. The thermal effect of the entrained air on ignition is dependent on the ambient temperature and oxygen concentration Thus, combustion process and exhaust emissions are more clearly observed by examining the characteristics of fuel spray at the different engine speed and variants test load conditions. In this research, the observation and advanced monitoring of oil palm blended fuel, engine speed and test load conditions plays an important role in-depth understanding of the combustion process, combustion characteristics, exhaust emissions and engine performance. It is expected that this work will provide the knowledge of the effects oxygenate fuel on combustion characteristics, emissions and performance. It is suggested that the interaction between oxygenated fuel spray and surrounding gas is important for the combustion efficiency and exhaust emissions. Ignition is important as it is first stage of combustion and emission formation.

Experiment set up

Fuel- The study used three kinds of BDF derived from CPO which provided by Universiti Tun Hussein Onn Malaysia (UTHM) biodiesel pilot-plant. The particulars of the tested fuels are detailed in Table 1. The fuels tested were a grade II diesel (STD) and blends of B5, B10 and B15 palm oil with the diesel fuel. The ordinary gas oil with the grade II diesel designated as a reference standard fuel (STD). Thus, the results for all the BDF conditions were compared with baseline operating conditions of standard diesel (STD). In this research, the kinematic viscosity of palm oil blend was measured by Viscolite 700 model VL700-T15. The density properties was measured by Metter Toledo Diamond Scale modeled JB703-C/AF. The water content in biodiesel sample measured by Volumetric KF Titrator model v20. The flash point measured by Pensky-Martens PMA 4. The engine fuel consumption are acquired with a precision ONOSOKKI volumetric fuel flow meter, and are pegged between the fuel tank and the fuel pump.

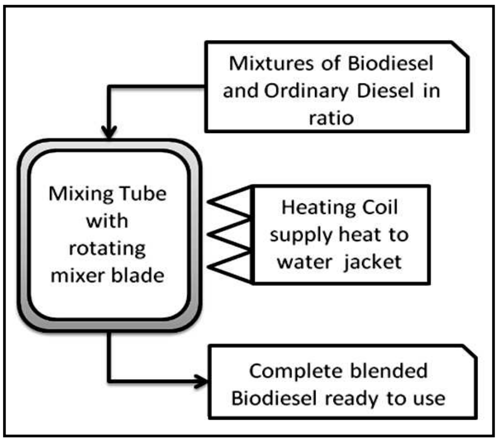
Table 1: Properties of the tested fuels

Fuel type	Properties			
	Density (g/cm³)	Kinematic Viscosity (Cp)	Flashpoint (°C)	Water Content (ppm)
STD	0.833736	3.0	80.0	79.6
B5	0.837048	3.0	91.5	120.1
B10	0.837664	2.9	92.0	158.6
B15	0.840428	3.0	93.5	219.0
B20	0.841172	3.1	94.5	294.7
B25	0.841716	3.0	97.0	363.3
B30	0.845852	3.2	97.5	397.1
B35	0.844816	3.4	99.5	426.9
B40	0.848236	3.2	100.0	558.0

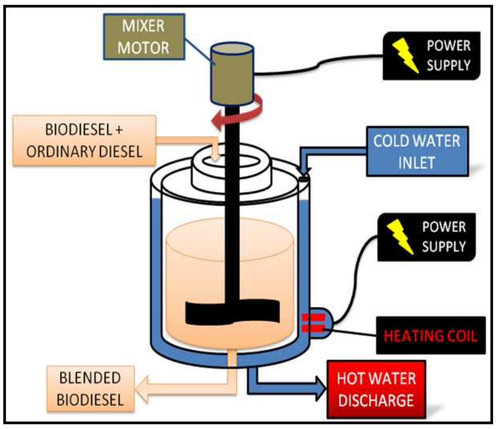
Table 2 : Engine specifications

Engine	Mitsubishi
Model Code	S-L049GV-NTD
Engine Model	4D56 (turbocharger)
Engine type	Serial 4 cylinder OHC turbo
Fuel type	Diesel
Fuel system	Distribution type jet pump
Bore/stroke (mm)	91.1/ 95
Maximum power	85 ps (62.52 kw) / 4200 rpm
Maximum Torque	20.0kg-m(196 N-m)/2000rpm
Displacement	2476 cc
Compression Ratio	21.0
Supercharger	TURBO
Vehicle Weight	1590 kg

A block diagram of blending process and schematic view of blending process are shown in Fig.1(a) and Fig.1(b), respectively. The purified palm oil methyl ester was then blended with STD in various concentrations for preparing biodiesels blend. During blending process, the laboratory scale blending machine was operated at 60^0C and the mixture was stirred at 70^0C for 1 hour. The rotating blade speed was adjusted to maintain the same speed at 270 rpm.



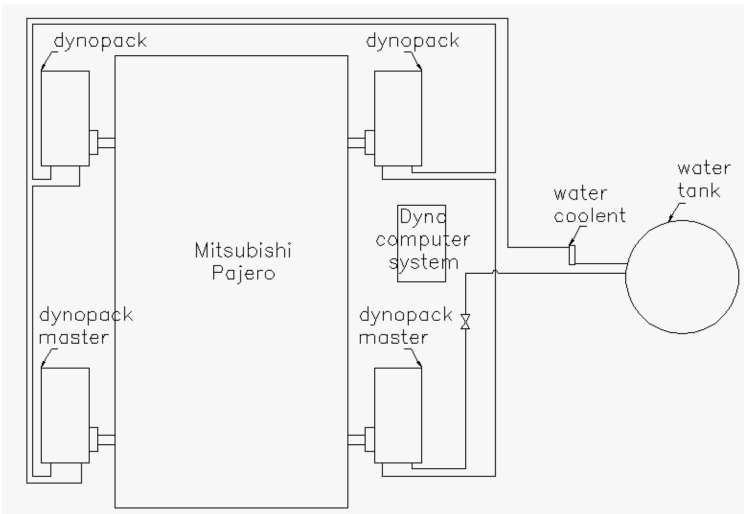
(a) Block diagram blending process



(b) Schematic of blending process

Fig. 1: Illustrating the blending process of producing oil palm blended fuel

Engine - In order to study the effect of the biodiesel blends on the engine operation, a series of measurements were conducted on a test commercial vehicle (Mitsubishi Pajero) intended for automotive application. The experimental programme was carried out using a four-cylinder four stroke-cycle DI diesel engine (Mitsubishi S-L049GV-NTD). Table 2 summarizes the engine specifications including the operating parameters and fuel injection system. The engine is equipped with turbocharged, capable of maximum power of 62.52 kW (4200 rpm) and having a compression ratio of 21:1. During experiment, a unmodified engine and injection rail system were used to inject STD fuel (a density of 836kg/m^3 and lower heating value of 42.7MJ/kg) into the combustion chamber. Fuel consumption test is essential for evaluating the fuel consumption pattern of an engine operation.



(a) Schematic diagram of experimental set up

(b) Test vehicle and chassis dynamometer set up

Fig. 2: Experimental set up (Automotive laboratory, UTHM)

A schematic view of the experiment set up is shown in Fig.2. All tests were performed on a Dynapack Chassis Dynamometer (eddy current dynamometer, max power 850HP). The chassis dynamometer was used to simulate the wide range engine application similar to actual behavior while operation on the road. The engine together with drive shaft and chassis are directly mounted to chassis dynamometer through the wheel hub connector (testing without tyre). Data presented here were obtained at an engine speed of 1500, 2000, 2500 and 3000 rpm. the dynamometer unit loads was held fixed at 0% and 50% thus covering the typical and middle load range of the combustion regime. Measurements vehicle performance data comprised power (kW), flywheel torque (Nm) together with the exhaust emissions observation. Auto-check 5-Channel Gas Emission Analyzer was used for hydrocarbon (HC), oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO) and smoke opacity emissions measurements. The sampling probes of smoke meter and gas analyzer were mounted centrally at the end of the engine exhaust pipe. In this research, different fuels are used for running similar engines under similar operating conditions; any marked difference in results is due to the characteristics of the fuel alone. To compensate for these differences, the measurement were made with repeating method, the experiment are sampled for more than 3 cycles at the same operating condition. Further analysis and presentation of these data is based on average of these 3 cycles.

Result and Discussion

The effect of biodiesel blending ratio on the combustion, exhaust emissions and performance was investigated at the base STD fuel for BDF of 5 (B5), 10 (B10) and 15vol%(B15) for engine speed of 1500, 2000, 2500 and 3000 rpm. The test load condition was the same at 0% dynamometer unit load for the all engine operations. Fig. 3 clearly demonstrates the emissions and fuel consumption versus blending ratio under different engine speed. Increase in blending ratio up to 15vol% for all engine speed is found to decrease modestly of O_2, HC and smoke opacity emissions with increasing fuel consumption. It seems that the increasing blending ratio exhibit relatively weakens in fuel ignitibility, and therefore prolongs the ignition delay of pilot fuel. This behavior results in lower due to the lower heating value of oil palm blend fuel, despite significantly higher combustion pressure and temperature. Thus, lower HC emissions and smoke opacity might be the explanation for the higher combustion temperature.

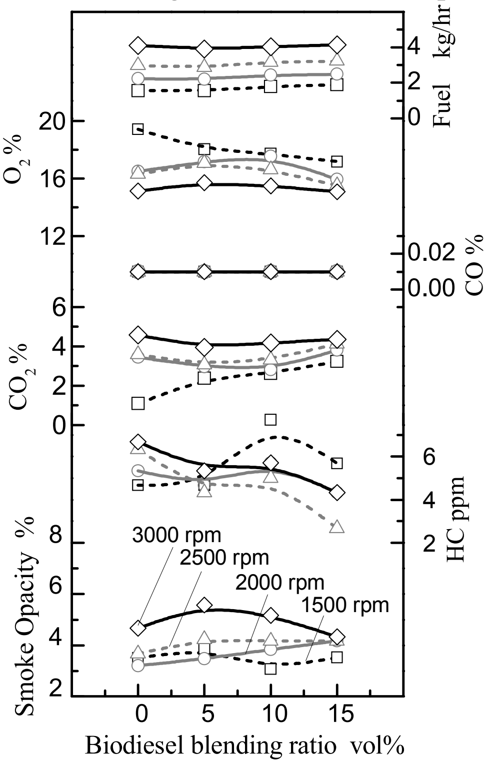


Fig. 3: Effects of palm oil blending on emissions without load conditions

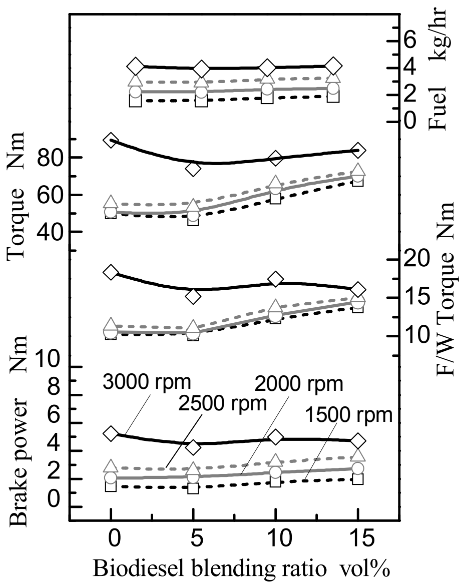


Fig. 4: Effects of palm oil blending on engine performance analysis without load conditions

Changes in the oil palm blending ratio with different engine speed are clearly observed by examining the engine performance and fuel consumption presented in Fig.4. The variations of combustion process represent from the exhaust emissions behavior are attributed to the elucidation for the difference combustion performance. As seen in Fig. 4, the brake power is similar as compared to the standard diesel and variant percentage BDF during zero load operation. This may be attributed to complete combustion because of oxygenated fuel. The complete combustion and fully utilized high oxygen content in fuel associated with the increasing torque and fly wheel torque with the slight changes of the fuel consumption.

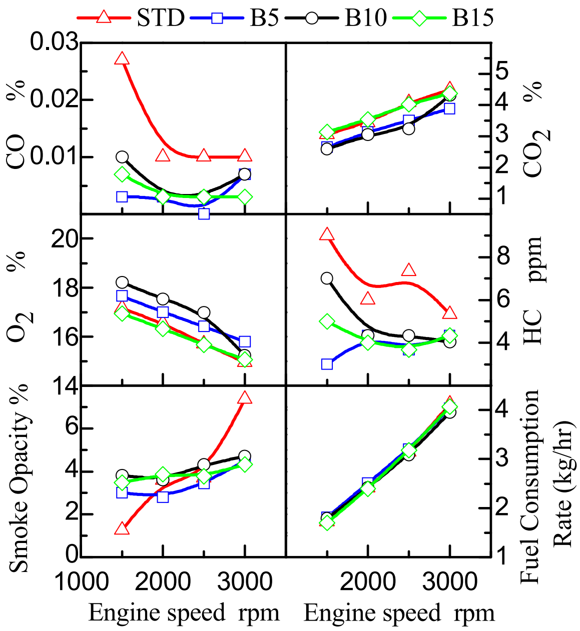


Fig. 5: Effects of palm oil blending and engine speed on emissions under medium load (50% test load condition)

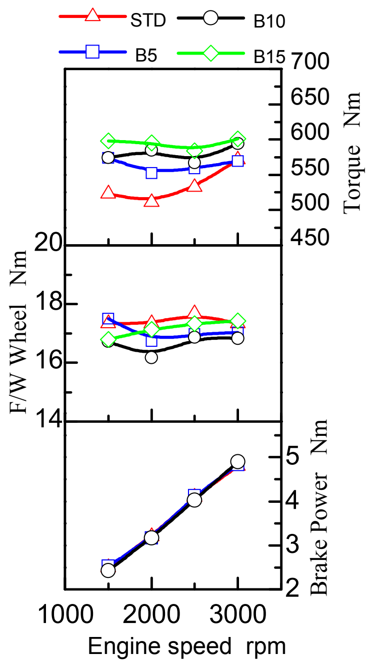


Fig. 6: Effects of palm oil blending and engine speed on engine performance under medium load (50% test load condition)

Next, the effects of engine speed on exhaust emissions and performance are discussed in this section. The effects of engine speed on the combustion, exhaust emissions and performance was investigated in a manner similar to that employed to the study the effect biodiesel blending ratio. However, the test loads was identical for the 0% and 50% dynamometer unit load. To investigate the effect of engine speed on combustion process, engine speed of 1500, 2000, 2500 and 3000 rpm were employed at all fuel of STD, B5, B10 and B15. The influence of palm oil blending on performance and combustion characteristics were investigated at the base of STD fuel combustion development. Fig. 5 depicts the variation in the emissions such as smoke opacity, HC, O_2, CO,CO_2 and fuel consumption with different engine speed and variant BDF percentage. As seen in Fig.5, the blended palm oil fuels under all engine speed conditions depicts the reduction of exhaust emissions. The emission decreased monotonically with the increasing BDF percentage. This behavior could be associated with a difference in the overall combustion process thus predominantly influences to the emission reduction. This correlation suggests that the higher oxygenated fuel in chamber responsible for the complete combustion and decreased emission with similar fuel consumption. Thus, the HC emissions decrease in magnitude associated with the better combustible mixture preparation and fuel-air mixing.

Next, the influences of engine speed are investigated on the point of engine performance. As seen in Fig. 6, increasing the engine speed throughout the entire BDF percentage behavior exits the less amount of the smoke opacity compared with the base condition. Fig. 6 demonstrates the effects of the palm oil blending and engine speed on engine performance under 50% load operating condition. It is clearly shown that the blended palm oil fuels promotes the higher torque at low speed region but there is not much difference in fly wheel torque between the BDF and base condition STD fuel. On the contrary, there is little influence of BDF on engine performance such both torque and flywheel torque especially under high speed engine of 3000 rpm. This kind of engine performance under high engine speed exhibits the same combustion process for palm oil blend fuel and reference fuel. It seems that the rate of oxygenated fuel is expected not to be strongly influenced by BDF percentage in the range of 5 to 15% under high engine speed condition.

Conclusion

The study used three kind of BDF (biodiesel) derived from different CPO (B5, B10, B15) in order to investigate the diesel engine performance and emissions for load test of 0% and medium (50%), and at engine speed was adjusted at 1500, 2000, 2500 and 3000 rpm. The results of the study may be summarized as follows:

1. As compared with base condition of reference (STD) fuel, all BDF blending ratio promotes the reduction of HC emission at variant engine speed and both engine loads. This behaviour could be associated with the oxygen content in biodiesel fuel, despite significantly the more oxygen present during combustion will raise the heat release rate and burning temperature during combustion process. However, there is little influence of oxygenated fuel on emission reduction at the range of biodiesel between 5 to 15vol%.
2. The engine performance is not expected to vary significant with the changes of BDF percentage ratio during medium and without load test conditions, at which time the performance is expected to be strongly influenced by the low calorific values of the blended fuel. The benefits may not be seen due to small amount of oxygenated fuel range for B5, B10 and B15.

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