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PM emission of diesel engines using ester-ethanol-diesel blended fuel

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Abstract

In this study, Palm Oil Methyl Ester (PME) was added to ethanol-biodiesel fuel in order to reduce the emissions. The percentage of ethanol is up to 20% in volume. Thus, the effects of ethanol on particulate matter (PM) components, soluble organic fraction (SOF) and dry soot (DS) using different type of fuel blends were investigated. Using a composite filter, the ester-ethanol-diesel characteristic such as mass concentration in term PM, SOF and DS were analyzed under different engine operating conditions using four cylinder engine. The results show that increasing ethanol in blended fuel will decrease the PM, SOF and DS at low and middle load. In addition, as the load is increased, the PM component such as SOF and DS also increase. Thus, ethanol-biodiesel fuel can reduce the emissions for low and middle load condition.

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Keywords: Palm Oil Methyl Ester (PME), PM emission, Soluble Organic Fraction (SOF), Dry Soot (DS).

1. Introduction

The development of alternative fuel were being focused since the shortage of petroleum resources in the 1970s due to global energy crisis[1]. In the past two decades, ethanol has been studied for engine testing application due to clean alternative fuel. Besides, ethanol can be produced from sugarcane, sorghum, corn, barley, cassava and beets [1]. There are several feedstock of ethanol that highly efficient and low cost processes such as agricultural crops, food and wood [2].

The emission of engines is affected by different type of fuel. For instance, ethanol fuels contain an oxygen component which is in the past research showed that it could significantly reduce the smoke and PM emission exhausted from diesel engine. The result from Spreen [3] showed the reduction in PM of 20-27% for 10% ethanol blends. Donahue and Foster [4] reported that local oxygen concentration in the fuel plume effect the improvement in emissions.

Many researchers concluded that the main factor affecting PM emission is the fuel oxygen content. For instance, the results obtain from Miyamoto et al. [5] show that when oxygen content is approximately 30% mass in diesel fuel, the smoke levels approaching to zero. However, in some cases, some of them concluded that the differences depending on the chemical structure or volatility of a given oxygenate [6]. The numerical modeling of the chemical kinetics has been

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investigate in the primary soot formation region [7]. Therefore, these study provide an information of the behavior of PM reduction usig oxygenated diesel blends.

In this study, in order to prevent separation of ethanol from diesel, the ester was added to the ethanol-diesel blends fuel which is act as a co-solvent. The ethanol percentage in blended fuel was up to 20% by volume were used in this experiment. Furthermore, the cetane number and viscosity for ester is higher than diesel and ethanol, thus it could balance the the ester-diesel-ethanol blended fuel in order to meet the requirement of diesel engine. In order to understand the effects of ethanol in diesel engine, more attention was paid on PM component, SOF and DS.

The performance and emission characteristic of diesel engines have intensively investigated from the different feedstocks in the last three decades. From the studies, biodiesel from different feedstock produce similar results [8-9] and quite small in term of performance differences [10-12]. In term of fuel lubricity [13-14], it enhances and caused reduction on emission. Thus, all the testing must meet American Society of Testing and Material (ASTM) specification designated in ASTM D-6751 and in Europe EN 14214. For some reasons, biodiesel will be an important alternative energy sources due to environmental friendly compared to mineral diesel.

2. Research Methodology

Engine tests were carried out on a bench-mounted and instrumented automotive diesel engine. A four stroke multi cylinder Mitsubishi 4D68 SOHC 2.0 liter was used in this study. Table 1 shows the details of the engine specifications.

Table 1. Specifications Of Mitsubishi 4D68 Diesel Engine

Descriptions	Specifications
Number of cylinders	4 in-line
Combustion chamber	Swirl chamber
Total displacement cm	1.998 cc (121.925 cu in)
Cylinder bore mm x Piston stroke mm	82.7 x 93
Bore/stroke ratio	0.89
Compression ratio	22.4:1
Fuel system	Pump distributor-type injection

A pressure transducer (*Kistler* 6041A), a water cooled piezoelectric pressure transducer was flush mounted with cylinder head to measure combustion pressure. The flush mounting was preferred in order to minimize the lag in the pressure signal and to avoid pipe connecting passage resonance. The test bench was equipped with Cole Palmer pressure gauges and K-type thermocouples for mean temperatures and pressure measurements in order to characterize and monitor accurately the engine's operating mode.

KANE gas analyzer complete with a 3 meter sampling probe was used for emissions measurements. The sampling probes of smoke meter and gas analyzer were mounted centrally at the end of the engine exhaust pipe. Kane gas analyzer has been used to measure and monitor the exhaust emission of the engine including NOx, carbon dioxide (CO), carbon dioxide (CO2) and unburned hydrocarbon. The engine was mounted with Kistler CAM crank angle encoder type 2613B connected to Kistler signal conditioner type 2613B2 for crank angle measurement and combustion characteristics. Crank angle encoder being connected to PC DEW-800 with connecting cable type 2613B3 using the signal conditioner.

A 150 kW eddy-current brake *ECB* dynamometer equipped with a Dynalec load controller was directly coupled by a shaft. The engine and dynamometer are mounted on a seismic steel bed (2.49 m x 1.3 m) to absorb the engine vibration emitted during the trial. Air flow and fuel flow rate were measured by a CENTERTEK anemometer and AIC fuel flow meter respectively. Figure 1 shows the diesel engine with four cylinders.

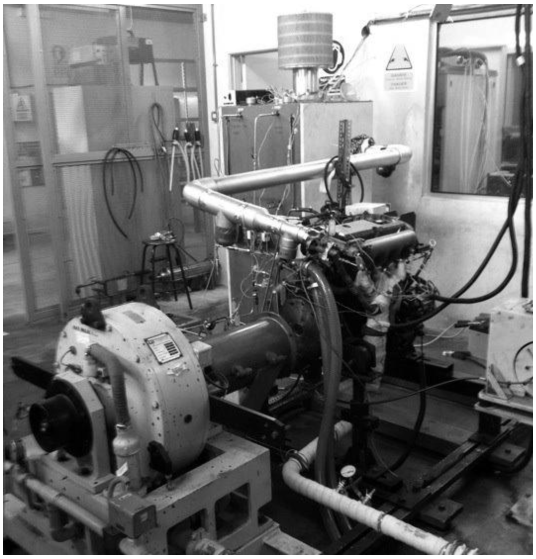

Fig. 1. Specification of Mitsubishi 4D68 Diesel Engine.

Table 2. Properties Of The Fuels

Properties	**Diesel**	**B20**	**B20 E5**	**B20 E10**	**B20 E15**	**B20 E20**
Flash point (°C)	70	110	43	48	45	49
Viscosity (mm²/s)	4.24	3.07	3.08	3.09	3.28	3.63
Density (kg/m³)	837	845	843	842	844	843
Cetane number	50	41.2	41.7	42.6	43.4	44.2

Before the experiment, the engine was run with diesel fuel for a period of 15 minutes to reach steady state condition. Engine performance and exhaust emissions tests were conducted from range of 20% to 60% load. The total mass concentration of the diesel PM on composite filter is measured by a high precision electric balance. The filters were weighted under controlled temperature and relative humidity. Using dichloromethane, SOF and DS can be extracted and the concentration can be measured.

3. Results and Discussions

3.1. Comparison of PM Total Mass

Fig. 2 shows the variation of PM mass concentration with the load fueled with the biodiesel blends. The engine was set at a constant speed of 2500 rpm. Due to the ethanol's low energy content, the power will decrease a little using the blended biodiesel fuel. From Fig. 2, with the increase of ethanol in blended fuels, the PM mass concentration for low and middle load is decrease, especially at the load of 20% , B20E20 reduces the PM 86.2% compared to the pure diesel fuel, B20E15 reduces the PM 68.9% and B20E10 and B20E5 reduces the PM 58.6% and 31.0% respectively. Thus, the more ethanol added to the fuel, the more PM reduction achieved at low and middle load.

However, at high load, the PM concentration act differently which is increase the mass concentration of PM. For instance, at 60% load, B20E5 reduces the PM 66.3% compared to diesel fuel, B20E10 reduces PM 64.75% and B20E15 and B20E20 reduces 34.4% and 18.0% respectively. The reason will be discussed in details through PM component analysis in the next section.

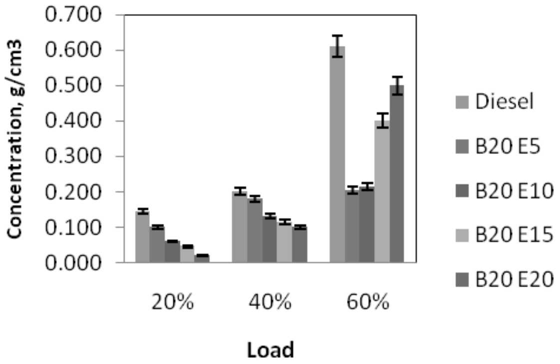

Fig. 2. PM concentration.

3.2. Dry Soot (DS) Concentration

PM is mainly composed of two components: DS and SOF. There is one method to separate the PM into SOF and DS according to the previous study [15]. Thus, in this study, PM emission are affected by ethanol content and these component need to be separated in order to investigate the effects in the diesel engine. Figure 3 shows the DS components in the PM with the load fuelled with diesel-ester-ethanol fuels. The DS in the PM decrease compared to diesel fuel and as the ethanol percentage in the fuel increase, the reduction of PM is more efficient for low and middle load.

For example, at 20% load, B20E5 reduces 14.3% PM while B20E10 reduces 42.85% PM and B20E15 and B20E20 reduces 57.15% and 85.7% PM respectively. This is due to the oxygen content present in the ethanol and ester that makes an improvement in the oxygen condition surrounding which benefit the combustion and also prevent DS formation in the fuel oxidation reactor.

However, for 60% load, B20E5 reduces 60.25% PM while B20E10 reduces 58.9% PM and B20E15 and B20E20 reduces 25.6% and 24.35% PM respectively. In a word, it can be seen that the increase of ethanol percentage in the blended fuel for 60% load, the DS component in the PM slightly increased.

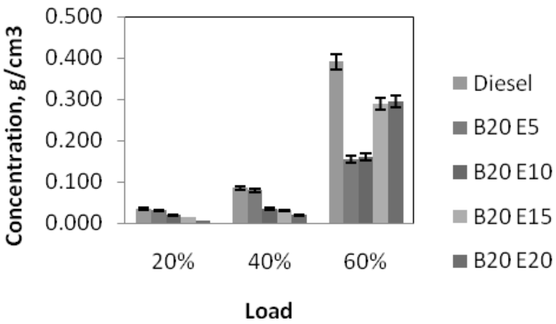

Fig. 3. DS concentration.

3.3. Soluble Organic Fraction (SOF) Concentration

The SOF in the PM is given in Figure 4. SOF characteristic is depending on the HC emission where the SOF component is caused by the unburned HC absorbed by DS. With the increasing the ethanol content in the blended fuels, the SOF tends to be reduced just for 20% and 40% of load. From the Fig. 4, for the 20% load, the value of B20E5 reduces 36.3% PM while B20E10, B20E15 and B20E20 reduces 63.6%, 72.7% and 86.4% PM respectively.

At 60% load, the SOF in the PM is increased as the ethanol content increased. This is due to the ethanol provides more oxygen component in the fuel and at higher load the ratio of fuel-air is high and produce high rate of oxidation. On the other hand, the evaporation latent heat of ethanol is much higher than diesel, thus decrease the temperature in the combustion chamber during the mixing formation. Therefore, it will not benefit for SOF reduction. At higher load, SOF becomes the main component in the PM and SOF is composed of unburned HC which is easy to be removed by using aftertreatment. Thus, by introducing the oxidation catalyst after treatment, PM can be reducing effectively.

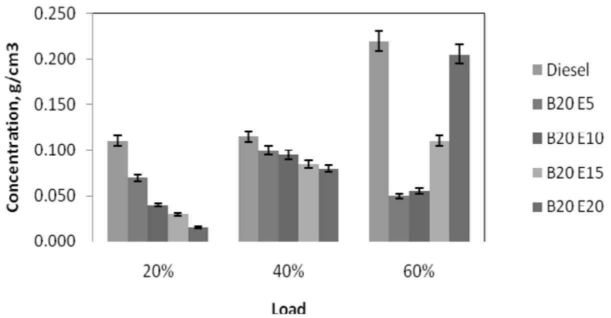

Fig. 4. SOF concentration.

4. Conclusions

The effect of ethanol in PM component for IDI diesel engine fuelled with PME and neat diesel using diesel engine were investigated. The analysis of this research can be summarized as follows;

1. Using the ester-ethanol-diesel blends, PM, SOF and DS can be reduced effectively at low and middle load but for high load it is not effective due to high content of oxygen present in the ethanol and also the ratio of air-fuel is very high.
2. As the ethanol contents in the blended fuels increase, the PM, SOF and DS also tends to decrease at 20% and 40% load.
3. For higher load which is 60%, with the increasing the oxygen component in the fuels, the PM, SOF and DS mass concentration increase.

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