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Exhaust Emission Particulate Matter Characterization of Biodiesel-Fuelled Diesel Engine

M. A. Kalam, A. M. Ashraful, M. H. Mosarof, H. H. Masjuki, I. M. Monirul, and H. K. Rashedul

Department of Mechanical engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia

Abstract: Comparative investigations were performed on the particle matter emitted from a DI diesel engine utilizing palm biodiesel. In this experiment, palm biodiesel PB10 (90% diesel and 10% palm biodiesel), PB20 (80% diesel, 20% palm biodiesel) and diesel fuel samples exhaust were investigated at different working condition (25% and 50% load at 1500 rpm constant speed). Observation of this experiment, it is clearly seen that at low load condition particle matter concentration of palm biodiesel exhaust was decreased than that of diesel fuel. At no load and 25% load condition PB10 biodiesel blend exhibited 2.2 times the lower PM concentration than that of diesel fuel. On the other hand, elemental carbon (EC) and organic emission for PB10 showed decreases trend as varies 4.2% to 6.6% and 32 to 39%, respectively, while elemental carbon percentage increased by 0.85 to 10% respectively. Similarly, metal composition of PB10 biodiesel blend increased by 4.8 to 26.5% respectively. SEM images for B10 and B20 demonstrated granular structure particulates with greater grain sizes compared with diesel fuel. Finally, the experimental outcomes showed that the blend composition and degree of unsaturation of the methyl ester present in biodiesel influence on the particulate matter formation.

Key words: particulate matter, elemental carbon, organic carbon, EDX analysis, SEM analysis

1. Introduction

Nowadays, the global is aggressively starving for energy as the main source of modern industrial life but remarkably depended upon imported petroleum oil. Unfortunately, the quantity of these resources is limited and expected to consume within one century. Biodiesel has several advantages as a renewable energy resource. Biodiesel is released the dependency on crude oil and is reduced environment pollution [1]. Biodiesel has a favorable combustion emission profile compared to diesel, such as low emissions of carbon monoxide, particulate matter and unburned hydrocarbons [2, 3]. Generally, biodiesel comes from vegetable oils, because their agronomic origin, are capable to reduce CO_2 emission to the environment with respect to import petroleum fuel [3, 4]. Renewable energy would be the best alternative in that case, and that is where researches started paying attention to bio-fuel to reduce the impact of the environment pollution as well as the fast consumption of non-renewable energy resources [5]. Internal combustion engines have two kinds of particles, i.e., solid and volatile particles. Diesel particulate matter (DPM), sometimes also called diesel exhaust particles (DEP), which contains soot and aerosols like ash particulate, sulphates, metallic abrasion particles and silicates [5]. The diesel exhaust main particulate fraction contains fine particles due to their small size; these particles can penetrate deep into the lungs. DPM released to the ambient air in the form of total carbon (total carbon = elemental + organic carbon). The sensitivity of measuring techniques and parameters is higher in the determination of particle size and number, compared to the quantity of particulate mass emissions [6]. Diesel particulate matter includes solids such as elemental carbon and ash, also contains liquid condensed hydrocarbon water, and sulfuric acid, these

Corresponding author: Dr. Md. Abul Kalam (M.A. Kalam), Associate Professor, research areas/interests: Biofuel, Biodiesel and Automotive engines. E-mail: kalam@um.edu.my

are obtained by PM sampling. The PM regulation mainly depends upon emitted particle mass. However, more attention has been paid to particle size in term of air quality, as it is believed that toxicity increases with decreasing particle size [7]. Environmental impact considered as one of the effect that caused by diesel engine, due to the emission of PM and others gases pollutant. Therefore, the main aim of this study was to evaluate exhaust polluted PM concentration, PM size distribution, PM-bound carbon emission and elemental composition of the PM emitted from a single-cylinder diesel engine fuelled with biodiesel.

2. Experimental Methodology

2.1 Fuel Characteristics and Properties

The experimental study was carried out on three types of fuel samples: diesel fuel (DF), PB10 (10% palm biodiesel and 90% diesel) blend, and PB20 (20% palm biodiesel and 80% diesel) blend. Table 1 shows the main physicochemical properties of the tested fuels. On the other hand, due to biodiesel concentration in the fuel blends, other parameters such as density, viscosity, oxygen content and molecular weight showed an increment in their value. In this analysis, we utilized commercial diesel as a reference fuel and we expected that progressions observed has affected by the addition of the biodiesel rate in the fuel blends.

2.2 Engine Parameters and Sampling Procedure

In this analysis utilized single cylinder, overhead cam system diesel engine. The engine test rig is pictured in the Fig. 1. In addition, the detailed engine specifications are listed in Table 2 Measurements of the engine mean temperature and pressure, thermocouples and pressure sensors was equipped with the engine test bench. An REO-DC A controller connected through a desktop computer to the engine used to monitor the engine test conditions. The engine was operated under different load conditions at about 25% and 50%. Fuel flow was measured using KOBOLD ZOD positive-displacement type flow meter. REO-dCA Data Acquisition System collects the data automatically. An Avldicom 4000 exhaust gas analyzer outfitted with an optical opacimeter chamber utilized. Measurement carried out during 5h operation (each fuel) and make sure enough PM collected for measurement morphological analysis. Glass microfiber filters with a diameter of 47 mm was used to collect the particulate matters. This filters held PM accompanied by other sediment segments.

Table 1 Physicochemical properties of diesel fuel, and biodiesel blends.

Properties	Unit	Fuel			ASTM D6751 limits
		OD	PB10	PB20	
Density at 15 C	Kg/m³	829.6	834.25	838.9	--
Viscosity at 40 C	mm²/sec	3.08	3.31	3.55	1.9-6.0
Calorific Value	MJ/kg	45.95	45.5	44.1	---
Higher heating value	MJ/kg	44.3	43.79	43.47	---

2.3 Characterization of Particulate Matter, Elemental Carbon Analysis and Energy Dispersive X-Ray Analysis

Scanning mobility particle Sizer (SMPS 3934) was

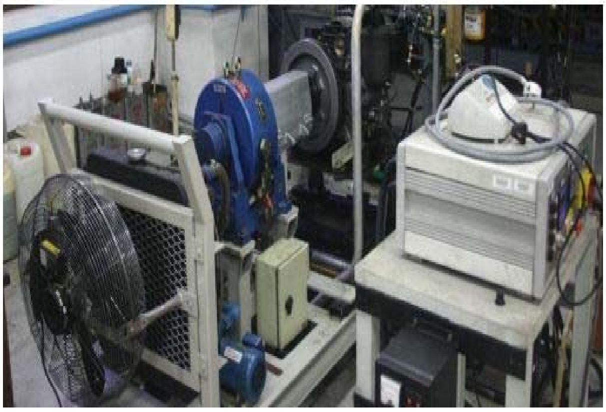


Fig. 1 Engine test rig.

Table 2 Detail specification of test engine.

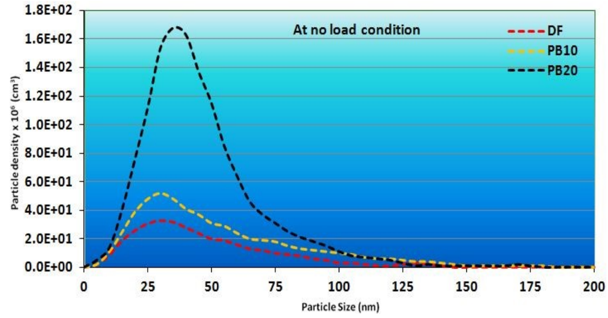
Specification	Description
Configuration	1-cylinder, 4s NA
Bore X stroke	92 mm × 96 mm
Nominal rated power	7.7 kW at 2400 rpm, 10.5 Ps
Max torque	8.8 kW at 2400 rpm, 12 Ps
Fuel injection pressure	200 kg/cm²
Cooling system	Radiator water cooling system

used to determine the particle size distributions. Scanning mobility particle sizer measures 12-604 nm ranges of particle size distribution, with a resolution of ±0.5 nm at 15 nm to ±30 nm at 500 nm. Total organic carbon analyzer (TOC-5000A) was used for the determination of elemental carbon (EC), organic carbon (OC) and total carbon contents in the exhaust gases. Exhaust samples were placed in the sample plate and manually put into the burner (900°C) and supplied sufficient oxygen to make complete burning. After complete burning H_2O and CO_2 had been formed and H_2O was separated by draying device. While, non-despersive infrared gas analyzer was used to determine CO_2 content. However, the carbon contents of the sample determined by data processing technique and calculations. Secondly, one quarter of filter was heated at 350°C for 1.5 hours to eliminated OC and then this sample placed in the elemental analyzer to determine elemental carbon (EC). Another piece of filter paper then placed in the elemental analyzer to determine total carbon (TC) without any preheated process. Finally, OC content had estimated by the subtraction of TC to EC content. Energy dispersive X-ray (EDX) spectroscopy has been broadly used to detect the elemental compositions of the surfaces of single airborne particles [8]. An Inca Penta Fet x3 EDX unit (Oxford Instruments) was employed for the identification and semi-quantitative analysis of the collected PM filter. The particle size was measured by scanning electron microscopy (SEM, model 3400Nat 3000×magnification). The elemental composition of the fuel samples was analyzed by Energy Dispersive X-ray (EDX) equipment at 5000 × magnification (Horiba EmaxEDX) attached to the microscope. Three samples were measured, each scanned at three different locations.

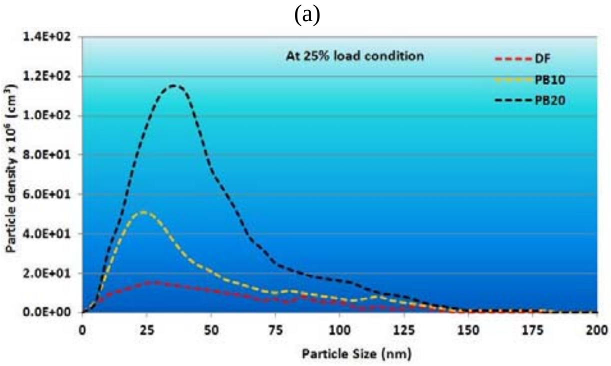
3. Results and Discussion

3.1 Particle Matter Emission Concentrations and Ingredients

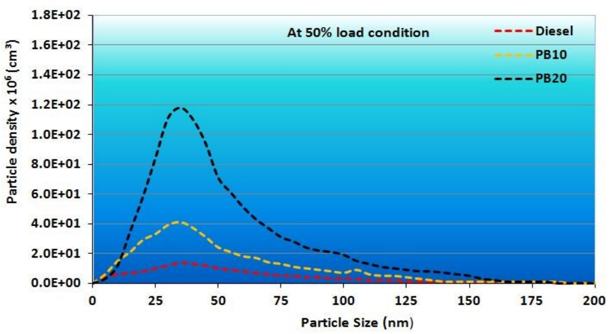
Fig. 2 represents the emission concentration of the particle size and number distribution of particulate matter from diesel engine. Among the different load conditions, had the lowest particulate matter emitted, when using diesel fuel (DF). Peak particle concentration at no load condition for PB20 is 1.68E+02 and peak particle concentration at 25% load condition is 1.15 E+02. Between no load and 25% load condition, particle matter concentration in PB10 exhausts decreases 2.2 times, i.e., peak particle concentration in the PB10 exhaust at no load condition is 5.2E+01 and peak particle concentration at 25% load condition is 5.1E+01. For PB20 biodiesel shows the highest peak particle concentration for all loads and always occurs in 30 nm to 50 nm size range.



(a)



(b)



(c)

Fig. 2 Emission concentration of the particle size and number distribution.

On the other hand, diesel fuel exhaust shows the lowest peak particle concentration at higher engine load conditions. Highest peak found in diesel fuel exhaust at no load condition is 3.3E+01, but exhaust curves remained below than biodiesel exhaust curves. Palm biodiesel is free from aromatic and unsaturated components and the main reason for the reduction of primary particle size when palm biodiesel blend was used in the diesel engine. Shobokshy et al. (1984) reported that the PM concentration of diesel-biodiesel blends increased with increasing engine load [9]. Dwivedi et al. (2006) found similar trends when they examined the PM emission in B20 biodiesel exhaust gases [10]. They reported that PM emissions of B20 biodiesel exhaust (17-48 mg/m³) were lower than those of diesel exhaust (22-59 mg/m³). Sharp (1996) reported that using biodiesel B20 in a diesel engine reduced PM by approximately 30% compared to the PM in diesel fuel [11].

3.2 Analysis of Pm-Bound Carbon Emission

From the carbon emission concentrations Fig. 3 it was observed that the EC and OC trends were similar for all fuel blend (DF, PB10 and PB20) at all load conditions. Observation of the experimental results it can be explained that, the emission of carbon concentration (EC, OC and TC) were the lowest when PB10 biodiesel was used in comparison with the DF and PB20. The EC emission reduction rate for PB10 was varied as follows: at no load to 50% load condition is 6.6%, 4.2%, and 5.3% respectively compare with diesel fuel. On the other hand, OC emitted from the biodiesel blend PB10 was lower than the EC emission. The results of this study showed that the OC emission from the biodiesel exhaust (PB10 and PB20) was lower than that of DF, while PB20 exhibited higher EC emission. OC emission rates reduced for PB10 was varied as follows: at no load condition is 33.9%, at 25% load condition is 32%, and at 50% load condition is 39.3% respectively. OC emissions from pure biodiesel combustion contain mainly fatty acid methyl esters, which associated with the fuel composition. OC

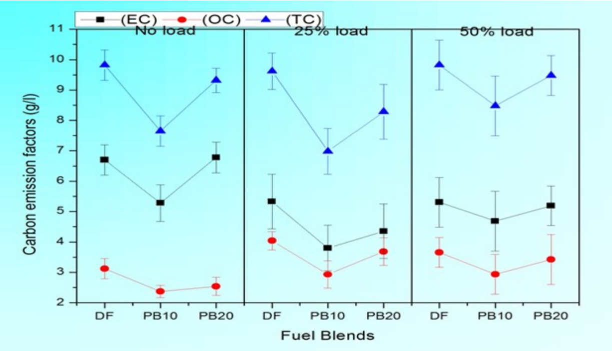


Fig. 3 Emission concentration of PM-bound carbons.

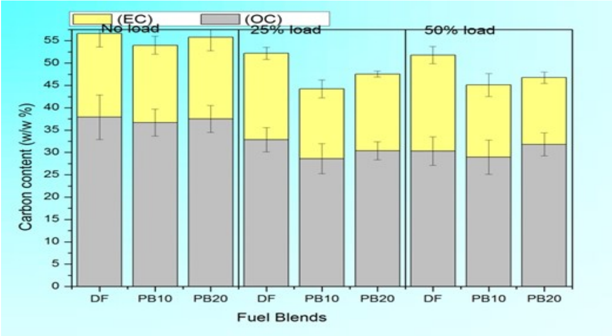


Fig. 4 PM-bound carbon emission factors.

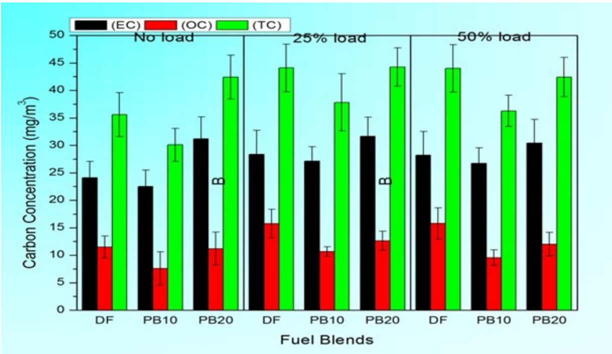


Fig. 5 The carbon content of PM emitted from diesel exhaust.

emissions dominated in biodiesel blends, whereas EC emissions dominated in DF [12]. From Fig. 4 showed that, EC, OC and TC emission factors reduce from the diesel engine exhaust when used PB10 and PB20 fuel. The use of PB10 could reduce EC, OC and TC emission factors by 8.6-27.4% (average 17.95%), 4.7-25.8% (average 15.66%) and 7.28-26.7% (average 17.23%) respectively. Similarly, the use of PB20 could reduce EC, OC and TC emission factors by

1.19-17.4% (average 8.66%), 5-18.5% (average 10.6%) and 1.76-13.5% (average 5.37%) respectively regardless of engine running condition. From Fig. 5 demonstrate that the carbon content emitted from the diesel engine. The mean total carbon content (TC = EC + OC) in the PB10 fuel exhaust was 10.5- 32.16%, while the mean ranges of EC and OC content from the engine exhaust were 3.1-12.96% and 7.4-24.7% respectively regardless the engine running conditions. Similarly, the mean total carbon content (TC = EC + OC) in the PB20 fuel exhaust was 3.1-34.9%, while the mean ranges of EC and OC content from the engine exhaust were 1-7.6% and 2.3-0.3% respectively regardless the engine running conditions. Therefore, investigation of the experimental results showed that blending different percentage of biodiesel with petroleum diesel results in important reductions in emissions of particle carbon species. These reductions are associated with the differences in fuel compositions; petroleum diesel mainly contains saturated and aromatic hydrocarbons while biodiesel fuel contains fatty acid methyl esters [13].

3.3 Elemental Analysis of the Particulate Matter

Fig. 6 demonstrated that the elemental analysis of PM samples obtained from diesel and biodiesel blends obtained by energy dispersive X-ray (EDX) spectroscopy. EDX data from interested spot consist of Carbon(C), Oxygen (O), sulphur (S), Zinc (Zn), Silicon (Si) and metals concentration. The percentages of C, O, S, Zn, Si and metals component of the particle composition of diesel exhaust PM emissions is 73.8%, 16.9%, 4.6%, 0.8%, 3% and 0.9% respectively. On the other hand, the weight percentages of C, O, S, Zn, Si and metals component of the particle composition found from the biodiesel is 77.4%, 15.8%, 0.9%, 1.4%, 3.2% and 1.3% respectively at the same condition. The overall observation of the elemental analysis, have been shows that the amount of carbon percentage increases

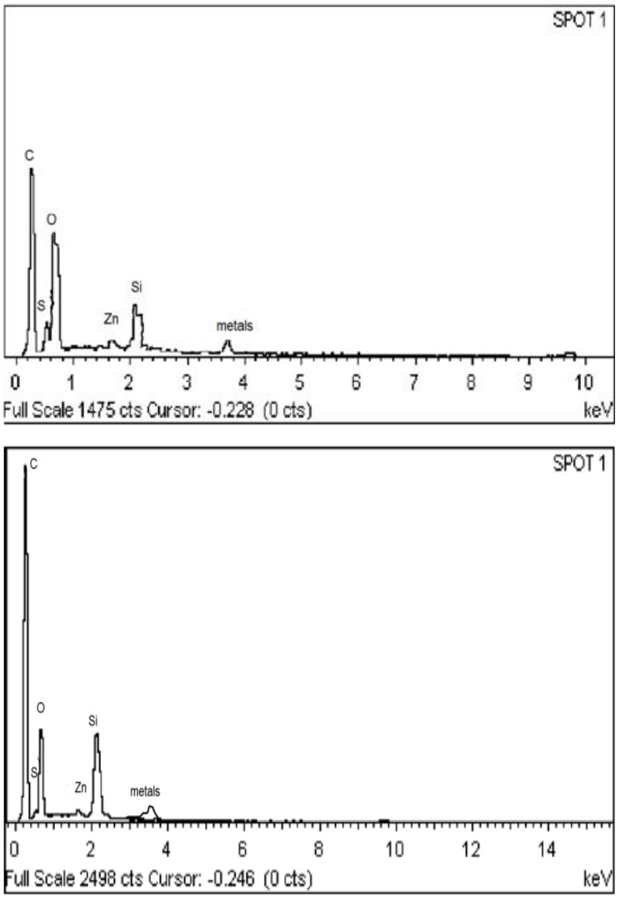


Fig. 6 Elemental analysis for a) diesel (b) biodisesl particle matter.

by 4.65% when biodiesel used in the diesel engine. On the other hand, elemental composition such as O and S composition of the exhaust gases reduced at about 6.5% and 80% respectively, while the metal composition of the exhaust gases was increases by 30%. The wellspring of different components, (for example, Si) may be from an inorganic component exhibit in biomass. A few authors have specified that the sulphur that shows up in the residue originates from the lubricating oil or fuel mix, as in the diesel case [14]. On the other hand, at low load condition, combustion temperatures are generally lower, which intimates that for low ignition proficiency and a huge portion of fuel infused into the combustion chamber goes out as fumes without complete burning. Due to those reason, the main sources for metal presence in exhaust particles.

3.4 Scanning Electron Microscopy (SEM) Analysis

Fig. 7 SEM images of all particulate samples collected can be observed clearly for all exhaust fuels. On observing the experimental results it can be seen that as the engine load increased, an increasing amount of particulate matter was trapped deep in the filter fibers. Due to the higher engine load condition, a higher combustion heat was generated in the combustion chamber, which resulted in higher particulate emissions due to the higher degree of heterogeneous combustion [15]. Under the low load condition a fine layer of agglomerates was found for PB10 compared to the DF and PB20 samples, whereas PB20 showed higher particle matter accumulation under the same load condition. When the load increased by 25%, the particulate agglomeration of PB10 sample decreased sharply and showed lower agglomeration than DF and PB20 samples. DF particle agglomeration under the 25% load condition produced similar particle agglomeration to the PB10 sample. Under 25-50% load conditions, PM deposition from DF and PB20 increased rapidly, while particle deposition from PB10 increased but remained lower than that from DF and PB20. Under this operating condition, DF and PB20 shows the highest particulate deposition and PB10 the lowest. For DF, particle accumulation increases as the load increases and the fine particles content increases by about 17.63% compared with biodiesel (PB10) under the 50% load condition. For biodiesel (PB10) particle accumulation, the particle diameter increased under the 50%load condition and was 8.70% higher compared to the low load condition. However, as the engine load increases the deposition of particles increases. Therefore, there is a proportional relationship among these parameters. On comparing the SEM images of diesel, PB10, and PB20, more fine particles are found in diesel. Zielinska et al. (2003) reported that at low engine load conditions, a higher organic carbon content was emitted from the engine exhaust [16].

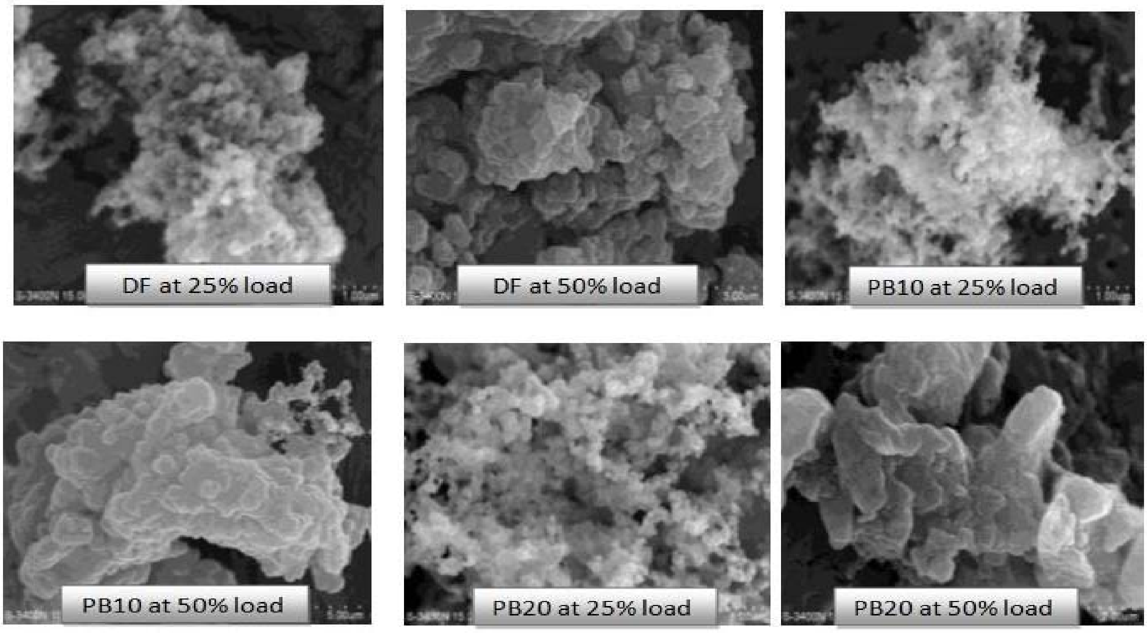


Fig. 7 SEM images for all particulate samples.

4. Conclusions

Analysis of particle matter concentration at low engine load conditions, i.e., no load and 25% load, PB10 gives lower particle matter concentration. Between no load and 25% load condition, particle matter concentration in PB10 exhausts decreases 2.2 times. While, PB20 biodiesel shows the highest peak particle concentration for all loads and always occurs in 30 nm to 50 nm size range. Reduces elemental carbon (EC) was varies 4.2% to 6.6% respectively for PB10. While, organic carbon (OC) emission rates reduced was varied 32%-39%, respectively due to effects of combustion temperature. Oxygen, sulfur, silicon, and calcium contents decreased with increases in engine load. Carbon percentage increased by 0.85-10% with an increasing biodiesel percentage in the fuel blend. From the morphological point of view, it was observed that as the engine load increased, the particulate agglomeration of PB10 sample increases sharply and showed lower agglomeration than DF and PB20 samples. Palm biodiesel does not significantly affect the average size of PM emitted compared to diesel. Finally, conclude that using blends of diesel and biodiesel from vegetable oil clearly affects the chemical composition of gas phase organic species emitted by diesel engine without modification. Details PM, EC and OC emission profile obtained from this research, will serve as a useful tool for climate change modelers, improving the assessment of future scenarios related to the use of alternative fuels.

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