

Particulate Matter Emission Characteristics of a Biodiesel Fueled Engine at Idling Speed

I. Shancita, H. H. Masjuki, and M. A. Kalam

Abstract—Automotive and transportation sectors will be inclined towards the renewable or green energy in the near future. One of the green energy sources discovered recently is biodiesel. Biodiesel is a source of clean alternative fuel for internal combustion engines, which reduces the exhaust emissions significantly. Like diesel, biodiesel also emits exhaust particulate matter (PM), which is responsible for the black soot coming out from the diesel engine. However, it is not clear that what will be the size of PM formed during the idle speed of a biodiesel fueled engine. In this study, the characteristics of the exhaust particulate during the idling speed of a biodiesel fueled single cylinder diesel engine is analyzed. Biodiesel showed a positive result in terms of the concentration of emitted PM. However, particle sizes were smaller in case of biodiesel than diesel. Further studies should be carried out to improve the properties of biodiesel to ensure that the emitted particle sizes are not toxic to human health.

Index Terms—Biodiesel, idling, internal combustion engine, particulate matter emission.

I. INTRODUCTION

The ever increasing transportation demand has led to the utilization of fuel in a more efficient way. This issue has become a major concern because the fossil fuels continue to be depleted as their sources are diminishing and the price of fossil fuels keeps on increasing rapidly. Besides, the emissions from fossil fuels are the major source of environmental pollution [1]. It has been reported that the emissions from the diesel fuel may rise up to 39% by the end of 2030 if there is no regulation to limit these emissions [2]. Biodiesel has gained a mounting interest as one of the most promising answers towards the green energy source to replace reliance on fossil fuels. This is due to its potential to satisfy the energy demand, halt global warming effect and greenhouse gasses. Its primary benefits are it is biodegradable, renewable, environmental friendly and non-toxic. Biodiesel can be formulated from a diverse range of animal fats, vegetable oils or greases by dilution, pyrolysis, trans-esterification and micro-emulsion process. The biodiesel has very similar properties to the diesel fuel [3]-[6]. In the last few decades, the production of biodiesel and its performance in diesel engines have been investigated. The utilization of biodiesel in diesel engine as a blend has shown a great impact on engine performance and emissions. It was reported that biodiesel emits less PM, carbon monoxide (CO), hydrocarbons (HCs) and other emissions [7], [8]. However,

usage of alternative fuels like biodiesel in diesel combustion engines can also create impact on health. This is because of the combustion related emissions from the exhaust. Vehicle idling happens when the vehicle's engine is let off to run while the transmission is not engaged. Vehicle idling has impact on human health, environment and vehicle performance too. It is a source of air pollution because of PM emissions. It also emits pollutants such as nitrogen oxide (NO_x), carbon dioxide (CO₂) and volatile organic compounds (VOCs) [9], [10]. Emissions can be reduced from vehicles by turning off the engine when idle mode exceeds more than a few minutes [11].

Diesel particulates from diesel engine are a portion of the whole diesel exhaust. Two phases are put together, either gas or particle in which both of them are responsible for contributing to health risks. The gas phase in diesel exhaust emission comprises of a lot of hazardous air pollutants. Diesel particulates which are categorized as fine and ultra-fine are of the utmost health concern. Their composition may comprise of elemental carbon with absorbed composites [12], [13] PM emissions from biodiesel have been the most controversial issue due to its environmental and health anxieties. Studies in epidemiology revealed that air-borne PM has effects on a person's health. The effects include respiratory, heart diseases, and carcinogenic problems. Temperature and the type of feedstocks play an important role in the compositions of the biodiesel PM and the relation between PM characteristics and biodiesel combustion conditions are yet to be clarified. The exhaust PM size varies with engine load and speed conditions [11]. At the idle engine speed, the engine is normally operated without load. The biodiesel fueled engine normally produces lower size of particulate matter [14]. Therefore, this study is focused on how exhaust PM is formed at idle speed condition of biodiesel fueled engine as well as investigates the PM size, concentration etc. at idle speed condition of biodiesel fueled engine.

II. METHODOLOGY

A. Experimental Setup

An experimental measurement is conducted on YANMAR engine model TF120-M. An eddy current dynamometer was subjected to the engine and used to maintain the variation of loads at different speeds. Pure diesel (B0) and pure palm biodiesel (PB100) were used to conduct the study. Fig. 1 shows a schematic diagram of engine used for the experiment.

The engine was connected with test bed and a computer data acquisition system. Data acquisition system collects signal, rectify, filter and convert the signal to the data to be read. The data acquisition board was controlled to the laptop,

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where user can monitor, control and analysis the data using REO-dCA software. Using this software the engine was operated at idling conditions. When the engine was operated at idling conditions, engine performance and fuel consumption data were stored in the computer. For performance test, each fuel sample was tested three times and their results were averaged.

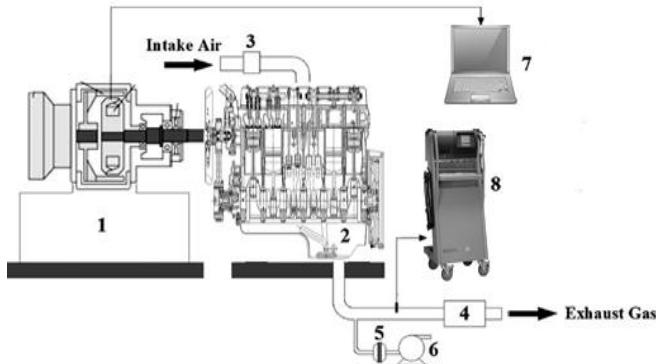


Fig. 1. Experimental layout (1: Eddy current dynamometer, 2: Diesel Engine 3: Air filter, 4: Silencer, 5: Particulate filter holder, 6: Sampling pump, 7: Dynamometer controller, 8: Portable exhaust gas analyzer).

The specification of engine was provided in Table I.

TABLE I: ENGINE SPECIFICATION

Engine model	YANMAR engine model TF120-M	
Type	1 cylinder, horizontal, water-cooled, 4-cycle diesel engine	
Combustion System	Direct injection	
Aspiration	Natural aspiration	
Cylinder Bore X Stroke (mm)	92 × 96	
Displacement (L)	0.638	
Continuous rated output	rpm	2400
	kW	7.7
At 1 – hr rated output	rpm	2400
	kW	8.8
Power take – off position	Flywheel side	
Starting system	Manual starting	
Cooling system	Radiator cooling	
Lubrication system	Complete enclosed forced lubricating	

B. Fuel Sampling

When you submit your final version, after your paper has been accepted, prepare it in two-column format, including figures and tables.

Some important properties of diesel and biodiesel were tested. They are listed below in Table II.

TABLE II: PROPERTIES OF DIESEL AND BIODIESEL

Parameter	Diesel	Palm biodiesel
Density (kg/m ³)	853.8	878.3
Viscosity (m ² /s)	3.223×10 ⁻⁶	4.410×10 ⁻⁶
Oxygen (wt %)	0	11
Sulfur (×10 ⁻⁶)	1135	64
Cetane number	45	58.3
Lower heating value (MJ/Kg)	42.59	38.39

C. Particulate Matter Sampling

PM samples can be collected by many methods. In this study the particulate matter was collected from a partial-flow exhaust gas using pump with constant flow rate. Quartz filter papers were installed at the beginning of diesel exhaust pipe to collect particulate matters. Filters for sampling were inserted in filter holder after the engine warmed up to 85 °C. At first, diesel was fueled into the engine to determine the standard parameters. To measure fuel consumption, exhaust gas temperature, power and speed of engine, sensors were installed and data were collected. Exhaust emissions and smoke were also measured using BOSCH BEA-350 exhaust gas analyzer. In Table III, specifications of exhaust gas analyzer are presented.

TABLE III: EXHAUST GAS ANALYZER SPECIFICATION

Equipment Name	BOSCH BEA-350 Exhaust Gas Analyzer
Measured HC	Parts per million (ppm)
Carbon monoxide	Percentage volume (%vol)
Carbon dioxide	Percentage volume (%vol)
Smoke	Percentage opacity (%opac)

D. Particle Size and Elemental Composition

Particle sizes were measured using SEM model -3400N at 5000x magnification. The acceleration voltage of the microscope while operating was 10 KV. Elemental composition of the sample has been analyzed by energy dispersive system at 5000x magnification (HORIBA EMAX EDX) attached to the microscope. Each sample was scanned at three different spots.

III. RESULTS AND DISCUSSION

A. Engine Performance

The engine was tested under 2 idling conditions at engine speeds of 1500 rpm and 2000 rpm. The operating conditions are listed in Table IV.

TABLE IV: ENGINE OPERATING CONDITIONS

Fuel	Mode	Engine speed (rpm)
B0	1	1500
	2	2000
PB100	3	1500
	4	2000

B. Engine Torque and Power

Fig. 2 represents the torque and the power of the engine at the two operating conditions for both of the fuels. From the figure, it can be observed that torque decreased slightly by approximately 3 Nm with increasing engine speed of 500 rpm. Torque of the engine can decrease due to two main factors. One is the lowered volumetric efficiency of the engine because of the increase in engine speed. The other factor is thought to be expansions in mechanical losses. On the other hand, reduction in engine power was found while using biodiesel (B100). This result is expected for B100 compared to diesel (B0) due to its respective lower heating value. Insignificant average power reductions of biodiesel compared

to diesel were found as 1.6% and 0.56% at 1500 rpm and 2000 rpm respectively.

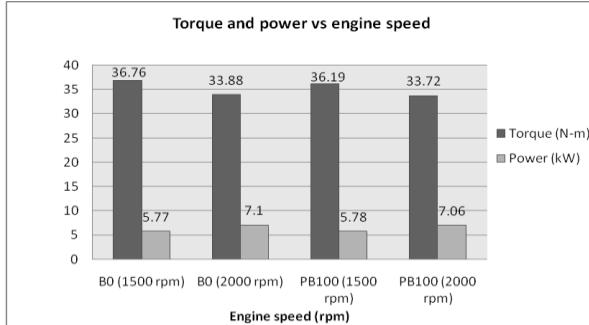


Fig. 2. Comparison of torque and power of diesel and biodiesel.

C. Engine Exhaust Temperature

Fig. 3 shows the variations of exhaust gas temperatures for the two different fuels. Diesel (B0) was found to have the highest exhaust gas temperature (EGT) value at all tested conditions. However, biodiesel showed a decrease in EGT by 15.8% and 2.01% at 1500 rpm and 2000 rpm respectively. The reduction is significant at 1500 rpm whereas there is only a slight decrease at 2000 rpm. Heating value, cetane number, density and kinematic viscosity, these four physicochemical properties have potential impact on EGT. Biodiesel showed lower EGT than diesel due to higher cetane number, higher viscosity and density and lower heating value. Lower EGT is an indication of good burning of fuel inside cylinder combustion chamber.

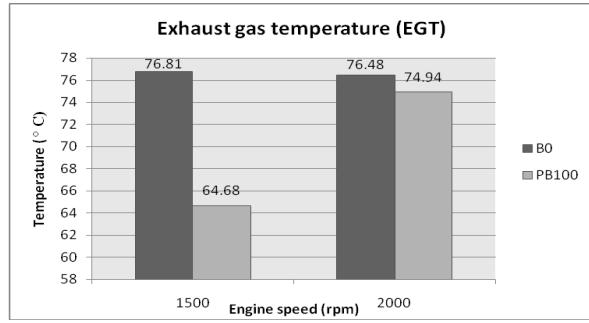


Fig. 3. Engine exhaust temperatures for diesel and biodiesel.

D. Diesel Particles Size

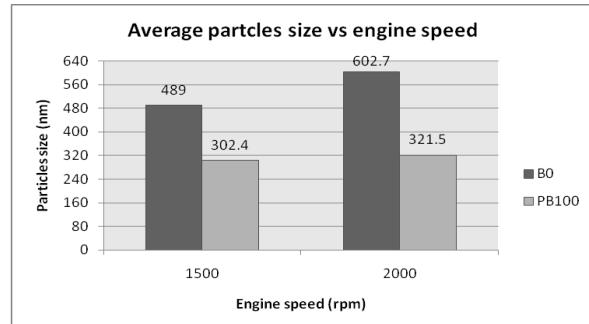


Fig. 4. Average particles size for diesel and biodiesel.

Presently, the PM regulation is mainly dependent on emitted particle mass and concentration. Many studies have been conducted and they proved that biodiesel produces less PM emission. However, more attention has been paid to

particle size in terms of air quality as it is believed that toxicity increases with decreasing particle size. Using biodiesel as alternative fuel is negative in terms of particle size. Fig. 4 shows the average diameter of particles with respect to engine speed. It can be noted that palm biodiesel (PB100) produced smaller diameter of particles in average compared to diesel (B0). The size of particles increased with engine speed for both fuels tested.

E. Effect of Pure Diesel (B0) on Particles Size

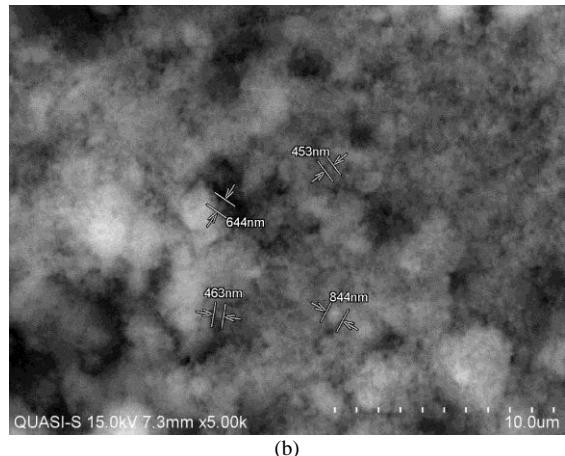
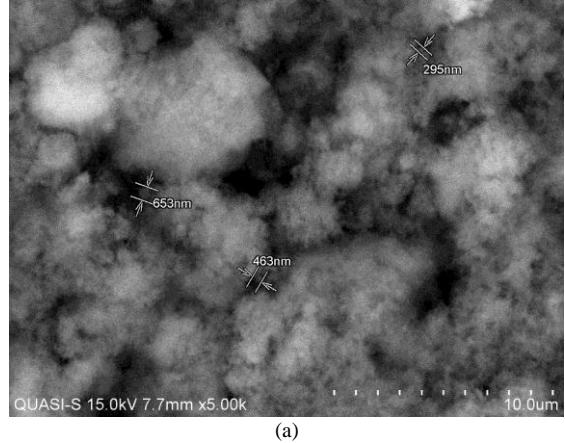


Fig. 5. SEM image for diesel PM at (a) 1500 rpm and (b) 2000 rpm.

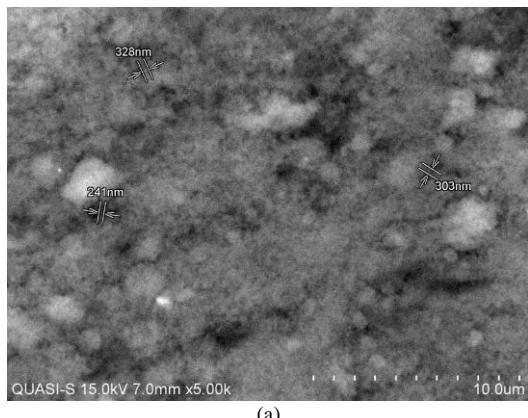
Fig. 5 represents SEM images of two different locations for diesel which has been taken at two different engine speeds. The average of particles size was about 489 nm at 1500 rpm and 602.7 nm at 2000 rpm. It can be seen from Fig. 5 that, size of the particle increased with increasing engine speed. Concentration of diesel particles also increased, with more accumulated particles can be seen in the image when the speed was increased.

F. Effect of Pure Biodiesel (PB100) on Particles Size

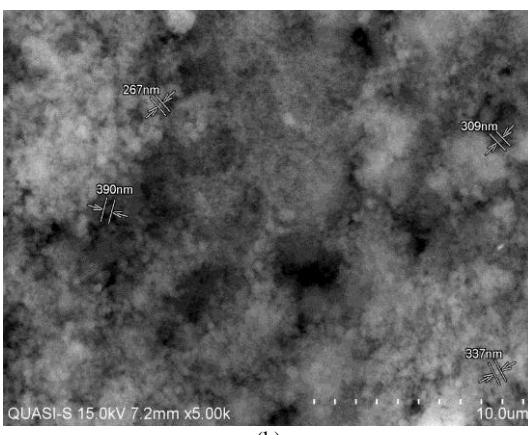
Exhaust particles and engine performance are affected by biodiesel. Biodiesel resulted a reduction in overall particle sizes compared to diesel. Fig. 6 shows particles distribution at different engine speeds for palm biodiesel. The average particle size was about 302.4 nm at 1500 rpm and 321.5 nm at 2000 rpm. As the speed increased, it can be seen that more accumulated particles were formed.

Particles of less than 50 nm diameter are usually referred to as the nucleation mode, which is the smallest group of particles. The formation of such particles is occurred either by

homogeneous nucleation in the atmosphere or by nucleation processes which is the result of emissions from high temperature sources and lead to the emission of primary nucleation mode particles. Because of the highly diffusive nature of such particles they have a relatively transient existence in the atmosphere and they readily transform into larger particles and also deposit quite efficiently on surfaces. This happens due to their low individual mass and high tendency to Brownian motion. The growth of nucleation mode particles is occurred primarily by vapor condensation process but is also influenced by coagulation process. Those processes lead to the formation of particles of the accumulation mode that are generally between 50 nm and 1 μ m in size. As they do not coagulate rapidly like fine and coarse particles, their further growth is inhibited and there are diffusion barriers to their growth by condensation [15]-[17].



(a)



(b)

Fig. 6. SEM image for palm biodiesel PM at (a) 1500 rpm and (b) 2000 rpm.

Biodiesel produces significantly smaller particle sizes in average due to its higher oxygen content and cetane number. High cetane number of biodiesel decreases the ignition delay time and the premixed combustion and influences the generation of more nucleation mode particles in the pre-combustion. The higher oxygen content of the biodiesel optimizes later diffusion combustion process and inhibits the transformation of particles from nucleation mode to accumulation mode.

G. Elemental Analysis of Particulate Compositions

Carbon is the main element in the particles that have been released from diesel engine; particles of carbon are coated by organic and inorganic substances. From EDX energy

dispersive system, the elemental compositions of the samples are as followed.

1) Elemental analysis of diesel particulate matter emission

Fig. 7 shows the composition of diesel PM at 1500 rpm and 2000 rpm. EDX data from 3 spots of each sample showed that the diesel PM consist of Carbon (C), Oxygen (O), and Fluorine (F) contents. The filter mainly consists of Carbon (C) and Fluorine (F) content, with only a small percentage of Oxygen (O) content.

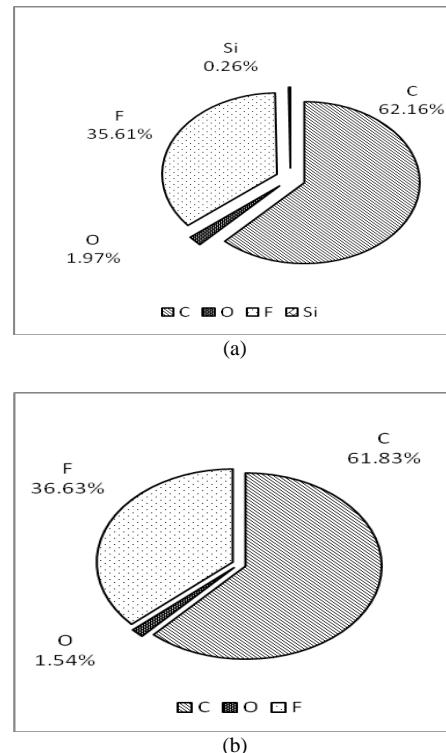


Fig. 7. Element composition of diesel PM at (a) 1500 rpm (b) 2000 rpm.

Carbon (C) and Oxygen (O) content in the PM decreased as the speed of the engine increased. Increasing engine speed cause better mixing of air and fuel to provide complete combustion, utilizing more Carbon (C) and Oxygen (O). Meanwhile, the Fluorine (F) content increased. Oxygen (O) percentage was low mainly due to the fact that they didn't settle on to the particles.

2) Elemental analysis of palm biodiesel particulate matter emission

The elemental composition of the palm biodiesel (PB100) did not contain any particulates of Silicon (Si). Fig. 8 shows the elemental composition for biodiesel PM at 1500 rpm and 2000 rpm. 3 spots that has been analyzed consisted of Carbon (C), Oxygen (O), and Fluorine (F) contents. The Carbon (C) and Fluorine (F) contributed the most in the biodiesel PM. Carbon (C) and Oxygen (O) content in the PM decreased as the speed on the engine increased. The trend was similar to the diesel PM. However, the Carbon (C) and Oxygen (O) in biodiesel PM were slightly lower than diesel PM at both conditions. This is given by the fact that biodiesel has a lower carbon content and high oxygen content which provided more complete combustion to give out less carbon in particles. Fluorine (F) content increased in biodiesel PM.

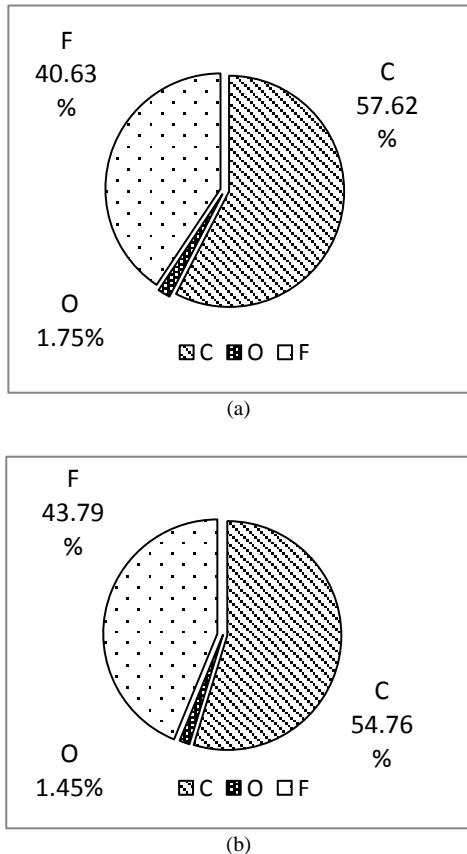


Fig. 8. Element composition of palm biodiesel PM at (a) 1500 rpm (b) 2000 rpm.

IV. CONCLUSION

In this study several operating conditions have been set under idling state at different speeds. Biodiesel has been selected due to its properties to reduce the amount of particulate matter from the exhaust emission of the engine. Details from SEM images has been provided; results have been compared with diesel fuel in terms of engine performance, regulated emissions, PM emissions and total size of the particles matter. Some conclusions can be drawn from this study. For example, biodiesel (B100) produces lower engine power than diesel fuel (B0) at all operating conditions. Biodiesel (B100) produces lower concentration of particulate matter (PM) than diesel fuel (B0) at all operating conditions. Biodiesel (B100) and diesel (B0) produce particle sizes in range of accumulation mode of nano-particles. Biodiesel (B100) produces significantly smaller particle sizes in average than diesel (B0) at all operating conditions. In terms of particulate composition, only Carbon (C), Oxygen (O), and Fluorine (F) contents are found in particles for both fuels. Biodiesel (B100) shows lower Carbon (C) and Oxygen (O) contents in the particles at all operating conditions than diesel (B0).

V. RECOMMENDATIONS

PM is one of the major pollutants emitted by diesel engines. The concentration of PM decreases when using biodiesel, however the size of particles are more refined and their sizes are becoming more toxic to the human health. Biodiesel

negatively affects the particles size but positively affects the particle concentration in the smoke. It is recommended that more studies should be done on biodiesel properties so that the particles size, that are emitted are much larger, and can be filtered. Though their concentration is found lower, but their sizes are gaining more attention. A recent study found that nano-particles are more hazardous to human health than larger particles and also affects atmospheric visibility. These particles also have a long atmospheric lifetime, typically 7–30 days, although they are subjected to removal by incorporation into rain and this can significantly shorten their atmospheric lifetime [14], [15].

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