Analysis of Particulate Matter Emissions and Performance of the Compression Ignition Engine Using Biodiesel Blended Fuel

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Abstract-As the world becomes more urbanized, the market for petroleum products increases. The supply of crude oil-based products such as diesel, gasoline, and natural gas is limited. Furthermore, natural resources are finite and their reservoirs are located in certain parts of the globe. Countries with low to no fossil fuel resources are experiencing a scarcity of petroleum products, necessitating the exploration of alternative energy resources. In this research, tests regarding the exhaust particulate emission, sound pressure level, and performance have been carried out using samples from diesel and biodiesel (waste cooking oil) blended fuel. Two fuel samples have been used, B25 (biodiesel 25% and 75% diesel) and 100% diesel as a baseline in a CI engine at constant RPM of 1350 and variable loads of 0.0 to 1.6 at an interval of 0.2Kg-m. The results show that particulate emissions are reduced by about 7.29% when using biodiesel blended fuel, whereas brake-specific fuel consumption of biodiesel blended fuel has decreased as brake power increased, and brake thermal efficiency increased as brake power increased. The sound pressure level was measured from different locations of the engine (back, front, left) and for varying load. The results show that B25 produces less noise than D100 in each case.

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Keywords-biodiesel (waste cooking oil); pollution; Diesel engine; particulate emissions; noise

I. INTRODUCTION

Greenhouse gas (GHG) emissions contribute to global warming and harm the environment [1, 2]. A higher quantity of pollutant emissions come as a result of fossil fuels [3]. The Compression Ignition (CI) engine was developed soon after the Spark Ignition (SI) engine and has become quite popular. To reduce environmental pollutant emissions, bio-ethanol has been used in the CI engine, fulfilling the demand of diesel fuel, increasing job opportunities, and conserving natural energy resources [4]. Biodiesel blend NBD25 is a mixture of neem oil methyl ester (25% vol.) and mineral diesel (75% vol.) and can be used as fuel. Nickel oxide nanoparticles were dosed in NBD25 blend at four levels in [5]. JBD100 biodiesel produces a lower level of carbon monoxide (CO), hydrocarbons (HC), and smoke emissions with notable increase in NO_x and carbon dioxide (CO_2) emissions [6]. Methane gas can be produced from wastewater, animal waste, and city garbage landfills. This gas can be produced by the gasification process of wood.

Biofuels [7] are generally considered environment-friendly because they emit fewer GHG emissions than conventional fuels. Fatty Acid Methyl Ester (FAME) is also referred to as pure biodiesel (B100). The lower concentration of biodiesel is known as "biodiesel blend", with B25 representing a mix of 25% of biodiesel in diesel fuel [8, 9]. Biodiesel is the most emerging and green fuel due to its similar properties to the ordinary diesel fuel. It is capable to blend in any proportion with diesel fuel [10, 11]. It is also defined by the time it takes to pass out the liquid from some specified size orifice so it is known as thick oil [12]. The physicochemical properties of gasoline, can affect engine the efficiency and emission characteristics. Biodiesel does not have the same property values with diesel fuel, so researchers blend biodiesels in various proportional ratios to diesel fuel [13, 14]. The use of biodiesel increases agricultural value and income, allowing for greater freedom of energy use and reduces the need for imported petroleum goods [15, 16]. Examples of greenhouse gasses are Methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O). These gases are responsible for global warming [17].

Due to the increased smoke associated with high fuel-air ratios, the brake specific fuel consumption of the CI engine increases at high loads, the mechanical efficiency decreases at lower loads, and the Brake Specific Fuel Consumption (BSFC) increases [18, 19] due to its higher oxygen contents, higher cetane number and proper spray timing. The emission of CO_2 (2.3%), CO (22%), NO_x (0.97%), and smoke (6.54%) decreased comparatively at 50% load in [20]. A few properties of biodiesel fuel significantly affect brake power, e.g. kinematic viscosity, calorific value, and lubricity [21]. An increase in the temperature of the combustion chamber improves thermal efficiency with a limited quantity of methanol and ethanol. It has been observed that vegetable oil blends give lower thermal efficiency than diesel fuel [21, 22]. Meanwhile, smoke opacity, brake specific particulate emissions, and particle geometric mean diameter drop as the quantity of soluble organic components increases, and biodiesel blends showed more variance [23].

II. RESEARCH METHODOLOGY

In this study, two fuel samples have been tested in a CI engine and parameters like engine performance, exhaust gas emissions, and noise emissions were analyzed. Initially, fuel properties have been tested on ASTM standards. Engine performance, exhaust gases, and sound pressure level tests have been analyzed on variable loading conditions and constant speed. The used engine specifications are shown in Table I.

A. Engine Exhaust Particulate Matter Emission

The results of PM (Particulate Matter) emissions from a diesel engine have been taken while running diesel fuel and biodiesel (waste cooking oil) blended fuel. The engine emissions depend on speed, load, fuel properties and injection timings. The load on the engine can be controlled by using a dynamometer coupled with the engine shaft directly. The instrumentations installed in the test bed were manually controlled. In this work, 3 particle sizes (PM 1.0, PM 2.5, and PM 7.0) were considered.

TABLE I. USED ENGINE SPECIFICATIONS

Stroke	80mm
Output (12hr rating)	4.4kw/2600r/min
Displacement	0.353L
Compression ratio	21-23
Mean effective pressure	576kpa
Piston mean speed	6.93m/s
Specific fuel consumption	278.8g/kwh
Specific oil consumption	4.08g/kwh
Cooling water	1360g/kwh
Injection pressure	14.2+0.5Mpa
Valves clearance	Inlet valve 0.15-0.25mm
Maximum engine power	7.7kw
Maximum engine torque	80Nm

B. Engine Performance Analysis

During the experiments, two fuel tanks were connected to the diesel engine test bed. Fuel was delivered to the engine through a single pipeline. Both fuel tanks were linked by a common line, and flow could be regulated by two separate valves. Based on fuel selection, one tank was filled with diesel fuel (D100) and the other with biodiesel blended fuel. Engine torque, brake strength, brake thermal efficiency, and brake specific fuel consumption were measured in the engine output. Variable loads were applied to calculate separate rpm on each load.

C. Engine Noise Emissions

The noise level (sound pressure level) of the CI engine was calculated when using diesel and biodiesel blended fuels at different loading conditions and constant speed.

III. RESULTS AND DISCUSSION

A. Particulate Matter Emissions

A CI engine is known as being high fuel-efficient and robust, but unfortunately, it is responsible for high PM emissions. Biodiesel (waste cooking oil) on the other hand, generates less PM emissions. However, there are different reasons of PM production from a diesel engine. Incomplete combustion of diesel fuel due to temperature variation of fuel is one of these reasons. It is observed that, overall, diesel fuel is mainly responsible for PM generation in PM 1.0, which is a higher particulate matter on idling condition of diesel fuel D100. Biodiesel blend B25 produces less PM emissions as compared to diesel fuel.

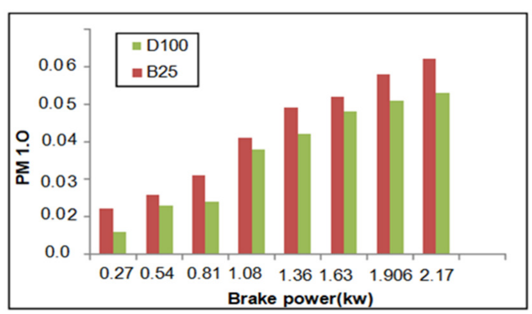

Fig. 1. Comparative results of exhaust PM1.0 emissions.

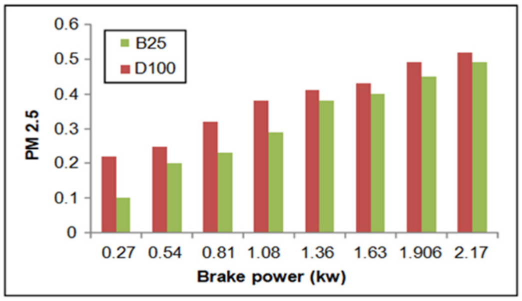

Fig. 2. Comparative results of exhaust PM 2.5 emissions.

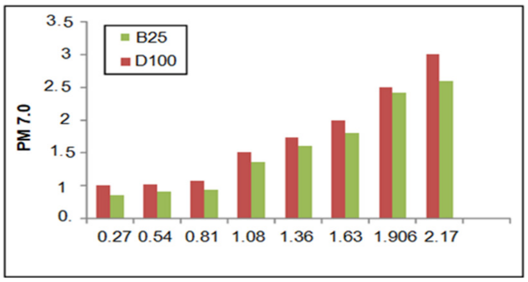

Fig. 3. Comparative results of exhaust PM 7.0 emissions.

B. Brake Thermal Efficiency

The thermal efficiency of the brake was studied next. As the calorific value of the biodiesel decreased, the fuel consumption increased for the same power output as shown in Figure 4.

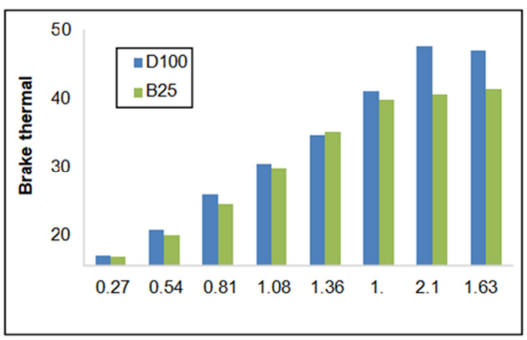

Fig. 4. Comparative results of brake thermal efficiency.

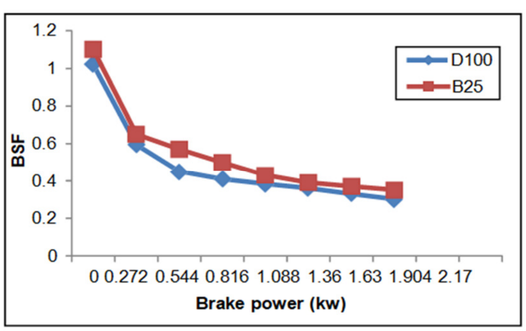

Fig. 5. Comparative results of brake specific fuel consumption.

In comparison to B25, the thermal brake performance of D100 has been increasing with increased load of the engine from 0.2KW to 1.6KW as shown in Figure 5. BSFC varies depending on engine load, rpm, and biodiesel blending ratio. It was discovered that brake B25 has higher BSFC than D100 because B25 has high oxygen content, which results in a lower heating value. The lower density and lower heating values of the fuels need higher mass of fuel for the same energy output from the engine. It was observed that density and calorific value have a high impact on the degree of UN saturation.

C. Sound Pressure Level

At a constant 1350 rpm, the sound pressure level results were calculated with variable brake loads such as 0.27212, 0.54424, 0.81636, 1.08848, 1.3606, 1.63272, 1.90484, and 2.17696 as shown in Figure 6. In comparison to the back and left sides of the engine, the front side has a higher sound pressure level. The results show that when using D100 in the engine, the sound pressure level is higher than when using the biodiesel blend B25. As a result of the higher oxygen content in gasoline, the cetane number is a key parameter to understand when it comes to ignition delay. During compression ignition, the cetane number plays an important role, as the higher cetane number gives a shorter ignitions delay. B25 has a lower sound pressure because there is more oxygen available.

(a)

(b)

(c)

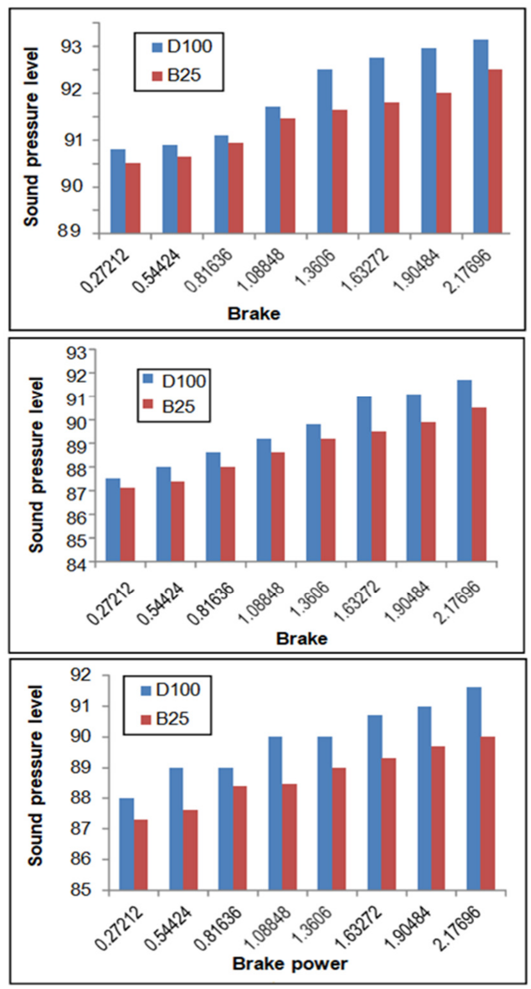

Fig. 6. Comparative results of sound pressure level at (a) the front side of the engine, (b) the left side of the engine, the back side of the engine.

IV. Conclusion

In this research, two fuel samples have been used, B25 (biodiesel 25% and diesel 75%) and D100 (100% diesel), which was the baseline in the CI engine, at constant 1350 rpm with variable loads from 0.0 to 1.6 at an interval of 0.2Kg·m. Exhaust particulate emissions, sound pressure level, and performance tests have been carried out. The results of the current study are:

- D100 has lower brake specific fuel consumption than the B25 and higher BTE.
- The results show that the use of biodiesel (waste cooking oil) causes a decrease in sound pressure level.
- The use of B25 reduces exhaust particulate emissions of the compression ignition engine by 7.29%.

Regarding future work, nanoparticles (aluminum oxide and silica oxide) can be added in biodiesel blends to analyze further their performance in the compression ignition engine.

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