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Engine performance and emission of compression ignition engine fuelled with emulsified biodiesel-water

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Abstract. The depletion of fossil fuel and environmental pollution has become world crucial issues in current era. Biodiesel-water emulsion is one of many possible approaches to reduce emissions. In this study, emulsified biodiesel with 4%, 6% and 8% of water contents were prepared to be used as fuel in a direct injection compression ignition engine. The performance indicator such as brake power, brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) and emissions such as NO_x and particulate matter (PM) were investigated. The engine was set at constant speed of 2500 rpm and load from 20% to 60%. All the results were compared to B5 (blend of 95% petroleum diesel and 5% palm oil biodiesel) biodiesel. At low load, the BSFC decrease by 12.75% at 4% water ratio and decreased by 1.5% at 6% water ratio. However, the BSFC increases by 17.19% with increasing water ratio to 8% compared to B5. Furthermore, there was no significant decrease in brake power and BTE at 60% load. For 20% and 40% load there was some variance regarding to brake power and BTE. Significant reduction in NO_x and PM emissions by 73.87% and 20.00% respectively were achieved with increasing water ratio to 8%. Overall, it is observed that the emulsified of biodiesel-water is an appropriate alternative fuel method to reduce emissions.

1. Introduction

The global energy consumption has been increasing multi-fold due to rapid population growth and economic development. This scenario occurred after the commencement of industrial revolution in the late 18th and early 19th century. Currently, fossil fuels are the primary source that powers our modern world and the reserves are likely to be depleted in 2052 [1]. This issue has led to increased exploration for alternative renewable energy. Recently, biodiesel has been considered as an important renewable energy source because of its potential to fulfill the energy demand, and reduce greenhouse gas emissions [2, 3]. In different parts of the world, depending upon climatic and agricultural conditions, different feedstocks are chosen for biodiesel production. As the world′s second largest producer of palm oil in the world, biodiesel from palm oil based appears to be a practicable long-term solution for Malaysia [4]. Several studies reported that pure diesel and palm oil methyl ester (POME) blends produce comparative results in terms of engine performance. A series of tests done by Ndayishimiye and Tazerout [5] to study the performance and emissions of preheated POME. They concluded that 27% of (BTE) was improved when using palm oil and diesel blends compared to that of the engine operated with conventional diesel.

Diesel emulsion is one of many possible approaches to reduce emissions of both oxidises of nitrogen (NO_x) and PM from diesel engines [6]. It was found that the presence of water vapor in reactants influences the physics and chemical kinetics of combustion [7]. A recent study by Raheman and Kumari [8] showed that the addition of water in the form of emulsion improves combustion efficiency and emissions. The engine torque, power and BTE increase as the water percentage in the emulsion increases. Sudrajad, Hirotsugu [9] conducted a series of experiment on a single cylinder water cooled diesel engine by using 10% of water blended with pure diesel. They found that the brake specific fuel consumption (BSFC) was decreased and the there was reduction in carbon monoxide (CO), nitrogen monoxide (NO) and sulphur dioxide (SO2). Subramanian [10] compared the effects of water–diesel emulsion and water injection into the intake manifold on performance, combustion and emission characteristics of a direct injection diesel engine under similar operating conditions and found that the BTE is reduced at all outputs below diesel values with water injection due to poor combustion. Hydrocarbon (HC) and CO levels are lower at low loads with water injection as compared to the emulsion. Nguyen, Dan [11] investigated the effects of double injection on combustion, performance and emissions of Jatropha water emulsion in a diesel engine. They found that a drastic increase in the ignition delay, combustion duration, and a shift in the combustion center toward the later combustion stage, as well as increased exhaust gas temperatures, and reduced brake thermal efficiency compared with the Light oil. Ithnin, Ahmad [12] tested the water-in-diesel (W/D) fuel with different water percentages (5%, 10%, 15% and 20%) on a direct injection air-cooled diesel engine. NOx and PM are found to be reduced for all types of W/D.

The aim of the present work is to study the effect of presence of water in the form of emulsion with blended biodiesel-diesel fuel B5. The engine performance parameters and emissions were measured experimentally and the results evaluated compared to blended fuel B5.

2. Material and method

2.1. Engine Experimental Setup

The experimental setup consists of four cylinder diesel engine, an engine test bed and a gas analyzer. The schematic diagram and real picture of the experimental setup is shown in figure 1 (a) and (b). Two separate fuel tanks equipped with stirrer and fuel valve systems were arranged to carry out the experiments, one is for diesel-biodiesel fuel and the other one is for emulsified biodiesel-water.

The engine used for testing was naturally aspirated four-stroke direct injection water-cooled Mitsubishi 4D68 inline four-cylinder engine that utilizes a high pressure common rail fuel system, variable geometry turbocharger and dual overhead camshafts. The basic specifications of the engine are shown in table 1. A Kistler 6041A piezoelectric pressure transducer was installed to the first cylinder of the engine through glow plug adapter to measure the pressure inside the cylinder. The speed of the engine is measure using a non-contact proximity sensor Kistler type 2613B while torque is measured using strain gauge bases load cell.

Table 1. Technical features of the test engine.

Engine model	Mitsubishi 4D68
Number of cylinders	4
Rated output, (kW)	64.9 at 4500 rpm
Maximum Torque, (Nm)	177 at 2500 rpm
Bore/stroke, (mm)	42.7/93
Engine displacement, (cc)	1998
Compression ratio	22.4:1
Combustion chamber	Swirl chamber

Table 2. Properties of B5 fuel [13].

Properties	B5
Density at 15°C (kg/l)	0.842 - 0.846
Viscosity at 40°C (mm^2/s)	4.136 - 4.549
Flash point (^{o}C)	75.0 - 81.0
Cloud point (^{o}C)	14 - 16
Pour point (^{o}C)	9 - 12
Sulphur content (mg/kg)	0.17 - 0.18
Cetane number	54.8 - 61.5
Higher Heating Value, HHV (MJ/kg)	44 - 47

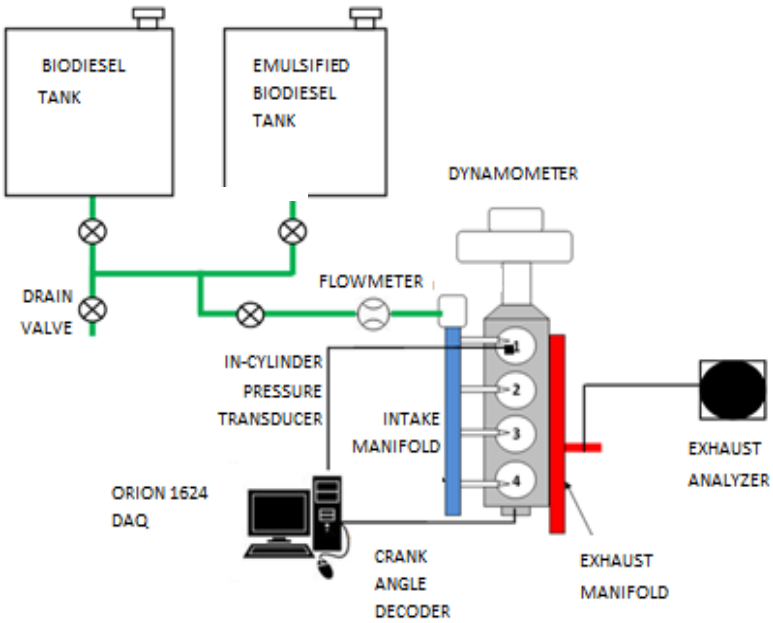
The test engine was coupled to a 150 kW eddy current type water-cooled, dynamometer controlled by Dynalec controller. The thermocouples used in measuring the necessary temperature at different locations during the test were the K type thermocouples. Fuel flow rate and airflow were measured by AIC fuel flow meter model 1204 HR 2000 and CENTERTEK blade anemometer respectively. Kane 900 gas analyzer was used to measure NO_x and PM emissions. The high speed data acquisition system consists of DEWE5000 is connected to the DEWESoft and DEWECa software for data logging.

2.2. Preparation of Emulsified Biodiesel

Palm oil based B5 biodiesel, 5% palm (*Elaeis guineensis*) and 95% diesel is readily available at most petrol stations in Malaysia since 2011 [14]. The properties of biodiesel B5 have been shown in Table 2 [13]. There are two distinctive emulsification techniques for water and oil; water-in-oil (W/O) and oil-in-water (O/W). However it is mostly restricted to use two-phase water-in-oil (W/O) technique for internal combustion engines compared to oil-in-water (O/W) technique [14].

The emulsified fuel was prepared using a mechanical homogenizing stirrer machine. The fuels were blended by using a homogenizer device at a speed of 800 rpm for 15 min. Lin and Wang [15] showed that when the rotational speed increases (in the range from 300 rpm to 1400 rpm), the stabilization increases as well. However, when the rotational speed was further increased (>1000 rpm), only a small effect on stabilization was observed. Emulsion stability increased with stirring time up to 15 min, beyond which the stability decreased with further increase in stirring time due to the drop-out of emulsifier from oil-water interface [16].

By using the method that utilized by Aziz, Jusoh [17], both surfactant Span 80 and Tween 80 were added into the mixture of biodiesel B5 and water to increase the affinity and reduce the interfacial between the water and oil phases. The test fuels were biodiesel (B5), B5 emulsified with 4% water (BW4), B5 emulsified with 6% water (BW6), and B5 emulsified with 8% water (BW8). The quantity of the each surfactant was set at 1 % of the total volume.



(a)

(b)

Figure 1. (a) Schematic diagram of experimental set up and (b) real picture of experimental setup.

3. Result and discussion

3.1. Engine Performance

The brake power generated by the engine under different load conditions starting from 20% to 60% at constant speed 2500 rpm is illustrated in figure 2. As the load increases, the brake power produced by the engine also increases for all blends of fuel. At 60% load, the power generated for fuel B5 is slightly higher than other water-emulsified fuels. This is due to the higher energy value of B5

compared to emulsified biodiesel. The power generated for fuel B5, BW4, BW6 and BW8 at 60% load were 28.067 kW, 27.63 kW, 27.7 kW and 27.95 kW. The trend has resulted from the energy value of the fuels. From the results it is concluded that the power produced by emulsified fuels were comparable to that of B5 at higher load.

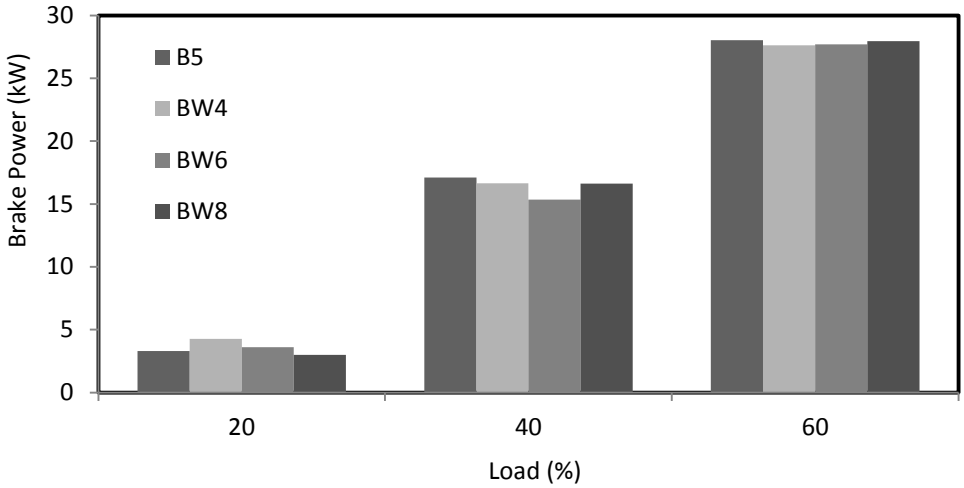


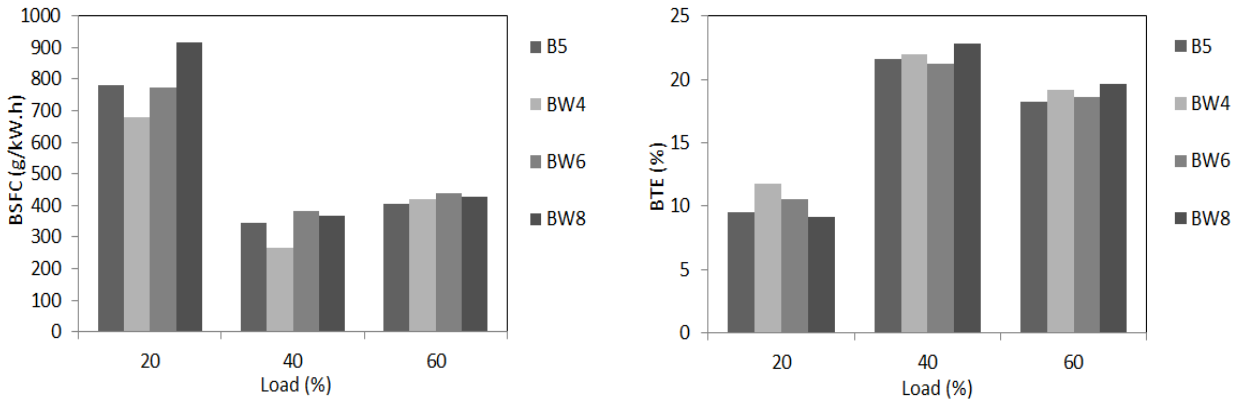
Figure 2. Comparison of brake power vs.Load.

The variation of brake specific fuel consumption (BSFC) with respect to load is presented in figure 3(a). The BSFC was found to decrease with increase in load for all tested fuels. This is due to the higher percentage increase in brake power with load as compared to the increase in fuel consumption. From the graph, it can be noticed that the BSFC were the lowest at 40% of load. That is because the engine were operating at its optimal condition.

Figure 3(b) shows the variation of BTE with respect to load for different fuels. HHV is used to evaluate the BTE. There was no significant variation of BTE with respect to emulsified biodiesel. In general, thermal efficiency increased within the engine speed until it reaches a maximum value, beyond which the thermal efficiency decreases. As known at low speeds, the time available for heat to be transferred to the cylinder walls is relatively long, and hence significant amount of heat loss occurs. As speed increases the brake power increases, leading to a higher BTE. However, increasing friction and inertia of moving parts due to high speed lead to decrease in BTE [18, 19].

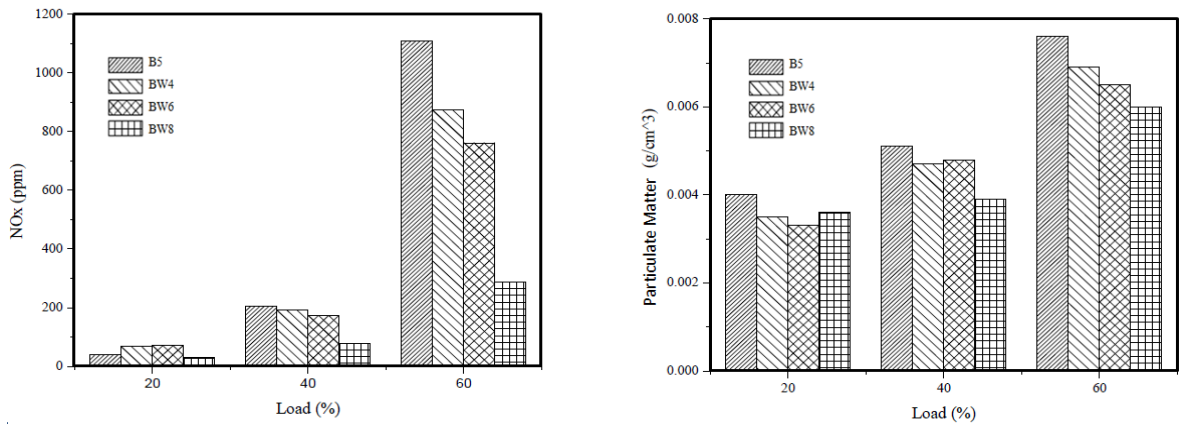
3.2. Emissions

Figure 4(a) shows the comparison of NO_x vs. Load. The NO_x emissions were increased when the load increase. By utilizing water in emulsified biodiesel, the NO_x emissions were decrease significantly. The main reason is that the heat absorption by water vaporization causes a reduction in the peak ignition temperature which then reduces the NO_x formation [20]. The maximum reduction is 73.87%. The variation of PM emissions with respect to load is illustrated in figure 4(b). It can be identified that the PM emissions reduced when the water percentage increased. This was attributed to the enhancement of combustion due to the presences of micro emulsion [21]. The maximum reduction for PM was 20.00%.



(a) (b)

Figure 3. Comparison of BSFC (a) and BTE (b) vs. load.



(a) (b)

Figure 4. Comparison of NO_x (a) and PM (b) vs. Load.

4. Conclusion

Emulsified biodiesel containing 4%, 6% and 8 % water were prepared and tested for engine performance and exhaust emissions in a 4-cylinder diesel engine. The results were compared with biodiesel blends (B5) as base fuel. Based from the results, several conclusions can be made which are follows;

1. The result shows no significant differences between the engine brake power and BTE measured for all emulsified biodiesel compared to B5 at 60% load.
2. At low load, the BSFC decrease by 12.75% at four percentage water ratio. However, the BSFC increases to 17.19% with increasing water ratio to 8% compared to B5.
3. The NO_x and PM emissions were reduced up to 73.87% and 20.00% respectively at 8% of water.

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