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Experimental Investigation on the Engine Performance and Exhaust Emissions of Emulsified Palm Biodiesel Blends on a Diesel Engine

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Abstract. World energy demand, which is amplified multi-fold day-by-day due to the transportation, urbanization, industrial revolution and electricity generation give severe environmental consequences. The effective solution to steer clear of this problem is by using biodiesel-water emulsification. In the present study, pure diesel, diesel-biodiesel blend (B20) and emulsified diesel-biodiesel blend with different percentage of water 5% (B20E5), 10% (B20E10), 20% (B20E20) and 30% (B20E30) were prepared to be operated in a diesel engine to study engine performance in terms of brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE), and emissions in terms of nitrogen oxides (NO_x), carbon dioxides (CO₂) and hydrocarbons (HC). Emulsifiers Sorbitan Monoleate (Span 80) and Polyoxyethylene Sorbitan Monoleate (Tween 80) were used to prepare emulsion fuels. The engine was run at constant engine speed 2500 rpm and three different loads, 20%, 40% and 60%. The results showed that highest BSFC reduction of 6.68% achieved by B20E5. The B20E30 give highest improvement in term of BTE which is 32.56% compared to diesel. A total of 17.29% reduction of NO_x gained by B20E30 compared to conventional diesel. Therefore, the emulsification of biodiesel blend is suitable as an alternative technique to improve engine performance and emissions.

1. Introduction

Energy is available in different forms such as mechanical energy, electrical energy, sound energy, chemical energy, thermal energy, potential energy etc. which is transferable from one form to another through energy transformation processed [1]. World energy demand, which is amplified multi-fold day-by-day due to the transportation, urbanization, industrial revolution and electricity generation give severe environmental consequences [2, 3]. Therefore, the world is moving to another direction towards renewable, clean, cost-effective, biodegradable and easily available energy for future environment. Biodiesel has fast becoming a major role in lessening the dependency on petroleum fuel [4]. Biodiesel is considered as promising fuel with properties that low percentage biodiesel-diesel fuel blends will operate smoothly in a conventional compression ignition engines without modifications [5]. Because of the similarity of their properties between diesel and biodiesel, it can be used as viable alternative without major alteration to the storage and distribution infrastructure [6, 7]. On top of that, comparing to the conventional diesel, the risk of handling, transporting and storing of biodiesel is much lower [8]. The understanding of each and every properties is the main fundamental for evaluating and improving the



performance and emissions of the diesel engine. Biodiesel can be used alone or mixed in any portion with conventional diesel [9, 10].

There are several sources that used as feedstock for biodiesel such as soybean, rapeseed, canola, cottonseed, sunflower and palm oil. Among the feedstock, oil palm yield the highest oil which is 13 times better compared to soybean and rapeseed as shown in Figure 1.

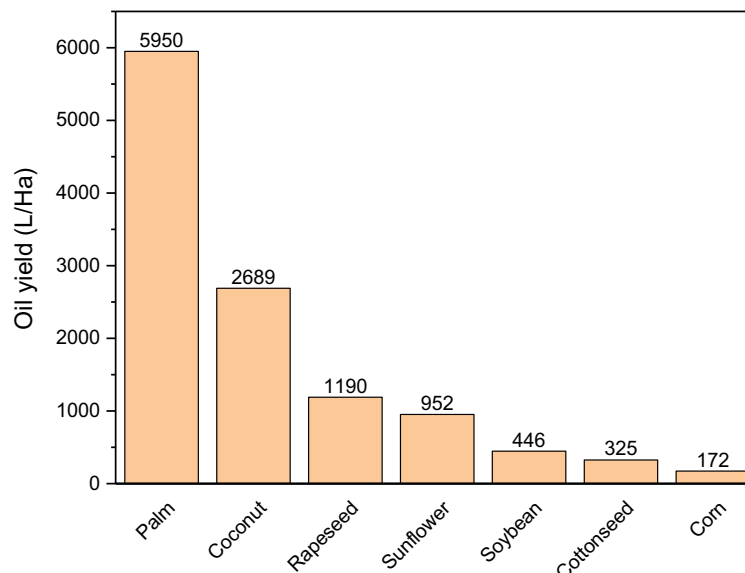


Figure 1. Average oil yields for major oil sources [11].

The properties and characteristics of biodiesel fall within fairly narrow band and similar to those of neat diesel. Biodiesel has lower energy content, but higher in oxygen content compared to fossil fuel. In term of emission, biodiesel release lower carbon monoxide (CO) and hydrocarbon (HC), but higher nitrogen oxides (NO_x) compared to conventional diesel. One of the methods to reduce emission is by using emulsion fuel. Emulsion fuel is a blend of fuel and water with surfactant as an emulsifier to reduce the surface tension between those two. One of the effective and most economic strategy to reduce exhaust emission of diesel engines is by introducing water into the combustion chamber [12].

Ramalingam et al. [13] studied the engine performance and emission characteristics of direct injection, naturally aspirated single cylinder four stroke Kirloskar engine using emulsified B20 Thevetia Peruvian oil blends with 5 and 7.5 percentage of water with different loads. The results showed a slight increase in brake thermal efficiency (BTE) and a clear improvement in exhaust gas temperature (EGT) for both percentage of water. There were 10% reduction of NO_x for 7.5% of water and 8% reduction for 5% of water. Similarly, a significant reduction of HC due to its improvement of air-fuel mixing during micro explosion occurrence in higher loads enhanced the combustion process. They also concluded that the smoke opacity decreased compared to B20 biodiesel caused by faster combustion reaction.

Perumal and Ilangkumaran [14] evaluated the combustion characteristic, engine performance of a single cylinder four stroke engine operated with biodiesel blend pongamia oil B20 emulsified with 5% and 10% of water with different load. There is a slight increase in peak cylinder but the heat release is reduced for the emulsified biodiesel compared to pure diesel. The raised in peak pressure cylinder is due to self-ignition temperature caused by longer ignition delay and higher density of the fuel. the experimental results conclude that all of the emissions parameters test by Perumal and Ilangkumaran [14] is reduced meaningfully compared to B20. HC showed some reduction trend due to the complete combustion helped by lower ignition delay. The total of 32% reduction of NO_x is obtained by using 5% of water compared to B20. The increased in brake specific fuel consumption (BSFC) when the water proportion is introduced is likely attributed to micro explosion of water particles and enrichment of fuel mixing. Typically the presence of water in the fuel lessen the heat content due to the vaporized water droplets during combustion. Therefore, the EGT is likely to decrease notably.

A series of test conducted by Naik et al. [15] to study the performance and emissions of canola oil biodiesel-diesel blend emulsified with water at various engine operating conditions. The test was conducted using air-cooled four stroke two cylinders HATZ 2G40 engine at 1000-3000 rpm engine speed. The engine performance and exhaust emissions parameters were compared to petroleum diesel. It is found that NO_x for emulsified biodiesel blends with 10% is decreased about 35% and the smoke opacity is decreased 15%. Conversely, CO and HC emissions for 10% of water is 20-40% and 20-60% higher respectively. They concluded that the improvement of BTE about 3-4% for emulsified fuel may resultant to micro-explosion during the combustion period. There is no significant change in BSFC.

Elsanusi et al. [16] investigate the effects of emulsified fuel characteristics with different percentage of water in a compression ignition engine with three engine speed (1000 rpm, 2100 rpm and 3000 rpm). The result showed that the EGT is indirectly proportional to the ratio of water. When the proportion of water in the fuel is increased the EGT is decreased. The maximum reduction of EGT is 40C achieved by B40E15 at engine speed 2100 rpm. NO_x , HC and smoke opacity is decreased 30%, 70% and 30% respectively. On the contrary, CO emission is increased when the water is introduced to the blends. The highest increased BTE is 7% obtained by B40E15 compared to conventional diesel.

Raheman and Kumari [17] analysed the combustion characteristics and engine performance parameters by using emulsified jatropha biodiesel-diesel blends in a water cooled, direct injection four stroke single cylinder coupled with hydraulic dynamometer. The blends use 10% of biodiesel emulsified with 10 and 15 percentage of water. It is found that the ignition delay is longer for emulsion fuels compared to B10. This result may attributed to the vaporization of water. Among the fuel tested, fuel containing 10% of water has the highest BSFC. When further proportion is added, the BSFC decreased. This is due to formation of finer spray during the injection. The exhaust gas parameters such as NO_x , CO_2 and CO showed some improvement compared to biodiesel blend and conventional diesel.

The aim of this study is to analyze the effect of water present in the form of emulsion with blended palm oil methyl ester (POME) biodiesel blend to the engine performance and emissions. The engine performance and emissions were measured throughout the experiment and the results were compared to neat diesel.

2. Materials and Methodology

POME was produced by palm oil plant which has been grown in entire Malaysia. Palm oil methyl ester (POME) was supplied by a local commercial company from a processing plant located in Selangor, Malaysia. Diesel fuel was provided by a commercial company. By using the method utilized by previous study [18], Tween 80 and Span 80 will be used as surfactants with 1% each by volume. The amount of surfactant is acceptable for the stability of the emulsion fuels as the proportion increase further, the stability will be drop due to rapid coalescence [19]. The objective of adding the surfactant is remove the tension between POME and water [18]. The external force is used to prepare emulsions fuel. Water with three different levels of concentration is prepared (5%, 10%, 20% and 30%). The water then will be mixed in B20 biodiesel-diesel blends. A digital overhead stirrer IKA RW20 at a speed of 800 rpm is used to stir the blend for 15 minutes. A total of six types of fuel were prepared namely B0, B20, B20E5, B20E10, B20E20 and B20E30. The formulation of emulsion fuels is shown in Table 1.

The experimental engine test was conducted on a water-cooled, naturally aspirated, compression ignition four-cylinder (Mitsubishi 4D68) diesel engine which direct fuel injection were used. The total displacement of the engine is 1998 cc. The engine was installed to a 150 kW eddy current dynamometer. The detail specifications of the test bed were given in Table 2. Gas analyzer Kane 900 was used to obtained emissions data. To ensure the accuracy of the measurement, the device was calibrated by the company before the test was conducted. The engine had been running for approximately five minutes to guarantee the emissions measured by the device is from the certain type of fuel. The schematic diagram and photo of the experimental arrangement is given in Figure 2 and Figure 3.

Table 1: Formulation of emulsification of biodiesel

| Fuel | Diesel (%) | Biodiesel (%) | | | |
|--------|------------|---------------|-----------|--------------|-------------|
| B0 | 100 | 0 | | | |
| B20 | 80 | 20 | | | |
| | B20 (%) | | Water (%) | Tween 80 (%) | Span 80 (%) |
| B20E5 | 95 | | 5 | 1 | 1 |
| B20E10 | 90 | | 10 | 1 | 1 |
| B20E20 | 80 | | 20 | 1 | 1 |
| B20E30 | 70 | | 30 | 1 | 1 |

Table 2: Test engine specifications.

| | |
|---------------------------|---|
| Engine model | Mitsubishi 4D68 |
| Number of cylinder | In line 4 |
| Type | Direct injection |
| Rated brake power, (kW) | 64.9 at 4500 rpm |
| Maximum Torque, (Nm) | 177 at 2500 rpm |
| Bore, (mm) | 42.7 |
| Stroke, (mm) | 93 |
| Engine displacement, (cc) | 1998 |
| Compression ratio | 22.4:1 |
| Combustion chamber | Swirl chamber |
| Cooling method | Water cooled |
| Dynamometer | Model ECB-200F SR no. 617, type eddy current, 150kW |
| Data acquisition device | DEWE-800, windows xp |
| Software | DEWESOFT and DEWECA-DEWETRON |

The engine was started and warmed up using conventional diesel. After the engine was stabilized and run at working condition, the data such as engine speed, fuel consumption and load were evaluated. The emissions parameters such as NO_x, CO₂ and CO were measured using the probe installed in the exhaust. The reading was measured thrice and the average value were calculated. The engine were operated at three different loads (20%, 40% and 60%) at constant 2500 rpm engine speed for every type of fuel.

3. Results and Discussion

3.1 Fuel Properties

The fuel properties of the biodiesel is tested first before operated on the engine. It is important to ensure that the properties are in acceptable range [20]. The tests properties such as density, kinematic viscosity and calorific value were repeated three times and the average of the three results were used. Table 3 shows the method and apparatus used, and the results of the measurement properties of the fuel.

The density values of the diesel, biodiesel blend and emulsion fuels were measured by using ASTM D1298 by using Portable Density/Specific Gravity Meter. It is found that when POME is blended together with the conventional diesel, the density is increased. Obviously, further increased is noticeable when the water is introduced to the blends. The density of the fuels is directly proportional to the percentage of the water. Kinematic viscosity is measured at 40C by using ASTM D445 using

CANNON-Fenske Routine Viscometer. Similarly, the increasing trend is followed by kinematic viscosity. In the contrary, when the water is added to the fuel, the calorific value is decreased. The calorific value is measured by using Oxygen Bomb Calorimeter using standard ASTM D4809.

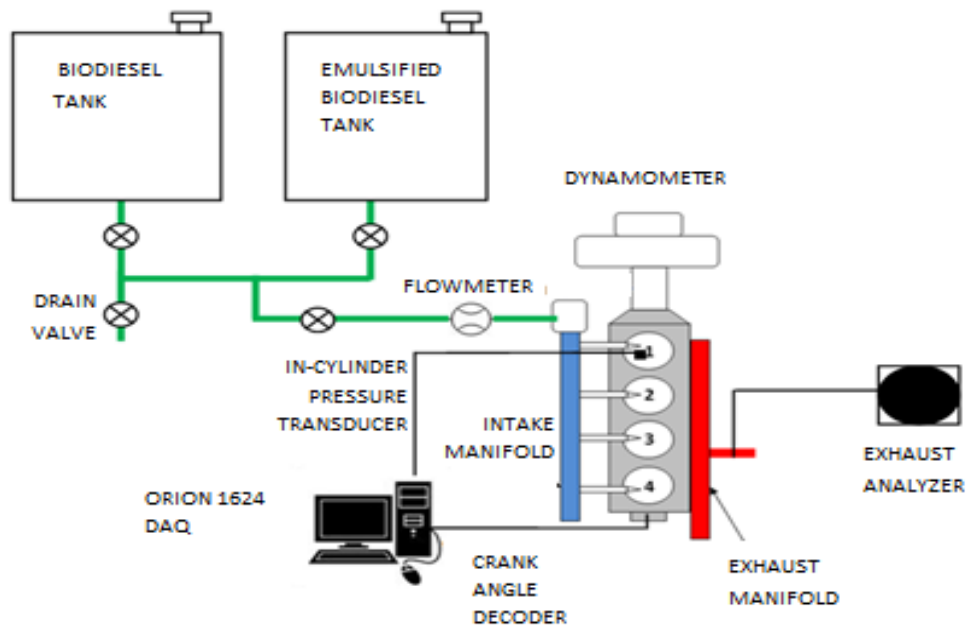


Figure 2. Schematic diagram of experimental arrangement.

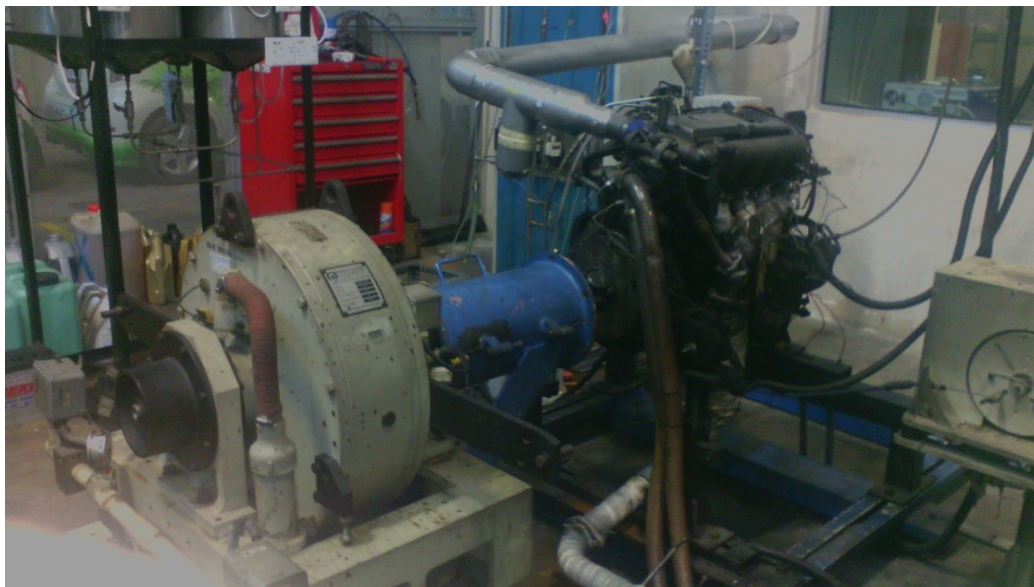


Figure 3. Experimental arrangement setup.

Table 3. Measured properties of blended fuels.

| Property | ASTM Method | Apparatus Used | B0 | B20 | B20E5 | B20E10 | B20E20 | B20E30 |
|--|-------------|---|------|-------|-------|--------|--------|--------|
| Density (kg/m³) | D1298 | Portable Density/Specific Gravity Meter | 820 | 854 | 860 | 871 | 877 | 890 |
| Kinematic viscosity @ 40°C (mm²/s) | D445 | CANNON-Fenske Routine Viscometer | 3.8 | 3.91 | 4.02 | 4.38 | 4.72 | 5.24 |
| Calorific value (MJ/kg) | D4809 | Oxygen Bomb Calorimeter | 42.5 | 42.05 | 41.66 | 38.67 | 35.94 | 31.03 |

3.2 Engine Performance

Figure 4 illustrate the variation of BSFC for all types of fuel against 20%, 40% and 60% of load. Obviously, the BSFC is decrease when the load of the dynamometer is increased. This is likely may attributed by conversion of burning efficiency of the fuel and better combustion conditions at higher engine power. The trend shows that when conventional diesel is blend with POME biodiesel, the BSFC is decreased for all load. This is due to higher oxygen contents in the biodiesel. When the water is introduced around 5% of the fuel, the BSFC is lower or similar to the biodiesel blend. Notably, when the water is further increased, the BSFC is starting to increase. This is caused by lower heat content of the emulsion fuels. This happened to all percentage of rated load. At lower load, the BSFC is decreased about 6.68%. The lowest BSFC obtained by biodiesel blend B20 at 40% of rated load which is 0.467 kg/kWh. Compared to pure diesel, BSFC for B20E30 increased about 38.10% at 40% load and about 27.79% at 60% load. Higher BSFC means that more fuel is used to produce power.

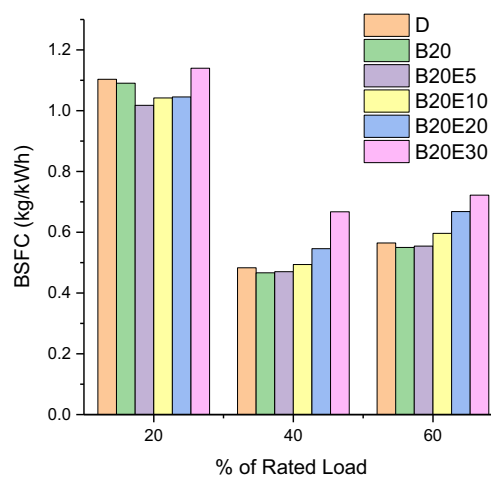
**Figure 4.** Variation of BSFC against percentage of rated load.

Figure 5 shows the variation of BTE of all type of fuel at various engine loads. Apparently, the thermal efficiency is increased from low load for all fuels, followed by a slightly decrease. The BTE for all fuel at low load are 7.68%, 7.85%, 8.48%, 8.49%, 9.58% and 10.18%. Due to the high content of oxygen in biodiesel, the BTE of biodiesel is slightly higher than diesel. The higher in oxygen content promotes burning efficiency during combustion period. The maximum increase of thermal efficiency achieved by B20E30 at low load which is 32.56% compared to conventional diesel fuel. This is followed by B20E20 by 24.72% at low load. Correspondingly, the micro-explosion phenomenon of emulsion fuel enhances air fuel mixing, hence will improved the combustion process [21]. Generally, the

introduction of water in diesel fuel blends can improved the BTE in diesel engines. The increase in BTE is caused by effect of micro emulsion phenomena during the combustion period in the combustion chamber [14, 19, 21, 22].

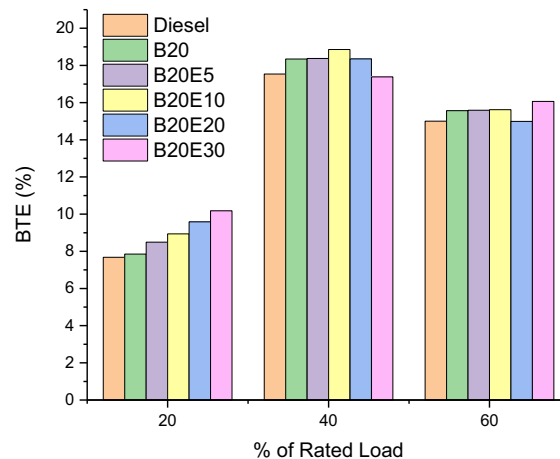


Figure 5. Variation of BTE against percentage of rated load.

3.3 Exhaust emissions

The formation of NO_x influenced intensely by in-cylinder temperature, injection patterns and oxygen concentration. The higher the temperature and oxygen concentration, the higher the quantity of NO_x emitted from the exhaust. It is observed that the NO_x formation is raised with the increased rated load for all type of fuels. This is due to the rich fuel supply for the higher load, hence increase the amount of heat released. The result in Figure 6 showed that when the POME is blended into the diesel fuel, the NO_x emission increased with regard to pure diesel at 70.37%, 13.53% and 5.77% respectively at load 20%, 40% and 60%. The raised in NO_x may attributed from higher oxygen content from biodiesel. Moreover, biodiesel has longer chain length and higher amount of unsaturated fatty acids, hence enhanced the production of NO_x . Generally, the presence of water in the blends decreased the formation of NO_x . This is due to the heat energy absorption by water vapour during combustion. B20E30 shows the maximum of 17.29% reduction of NO_x compared to baseline fuel at 40% of rated load at 2500 rpm engine speed. The reduction may likely contributed by low temperature during the combustion [23-25]. As a conclusion, the introduction of water by emulsion into the combustion chamber is an effective strategy to reduce greenhouse gas (GHG) [26, 27].

The variation of CO_2 emission is presented in Figure 7. CO_2 is considered as a major GHG that gives effect to the global warming, and therefore it is important to ensure that the amount is maintained at acceptable level. Typically, CO_2 is related directly to the combustion process efficiency. The lower the combustion process efficiency, the higher the carbon dioxides emissions. In addition to that, the carbon dioxides emission is directly proportional to BSFC and conversely proportional to NO_x emissions [28]. The CO_2 emissions varies from 1.9% vol to 3.5% vol, 4.8% vol to 8.4% vol and 8.8% vol to 13.7% vol at 20%, 40% and 60% of rated load respectively for different types of fuels. The increased of carbon dioxide emissions over the load is caused by the rich fuel supplied to the combustion chamber. The higher of CO_2 for B20 compared to conventional diesel may attributed to high viscosity causing lower volatility, large droplets and poor atomization that leads to slow burning [29]. It is noticeable that the CO_2 emissions is increased dramatically when the water is presence and later further increased in ratio. This is due to the higher BSFC. The maximum increment of 77.00% of CO_2 obtained by B20E30 at engine speed 2500 rpm at 40% load. The increase in CO_2 is due to the oxygen number because the presence of water during combustion [30-32].

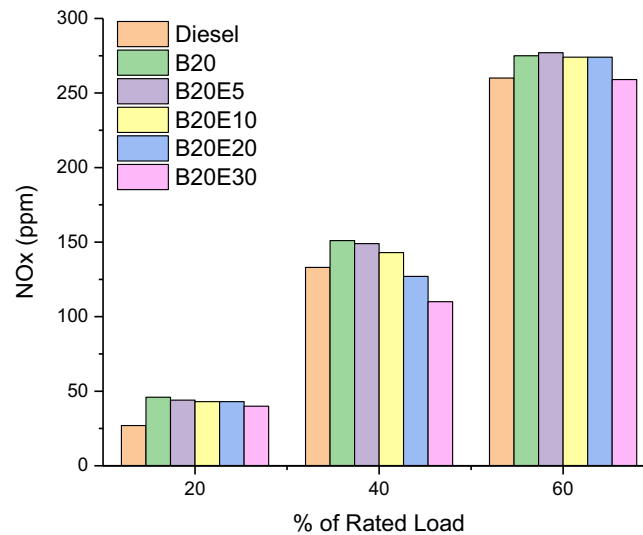


Figure 6. Variation of NO_x emission against percentage of rated load

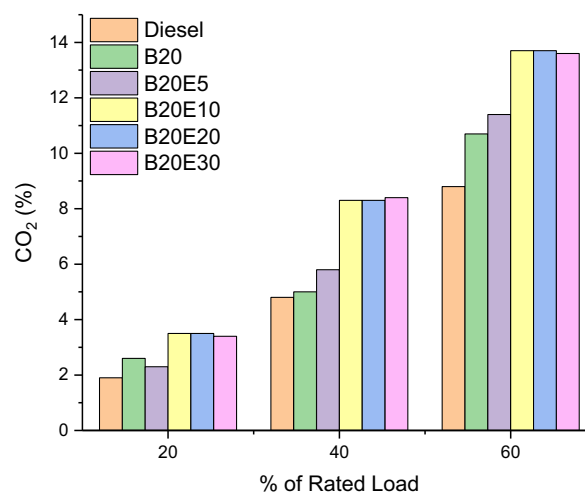


Figure 7. Variation of CO₂ emission against percentage of rated load

In the present study, the variation of hydrocarbons emission is indicated in Figure 8. The HC emission majorly depends on the power of the engine, the completeness of the combustion, fuel spray pattern and the nature of the fuel [33]. The exhaust emits lower HC emissions with an increase in engine power due to the higher combustion temperature. Typically, biodiesel tend to produce less HC emissions compared to neat diesel. This is due to the oxygen content in the biofuels and improved combustion efficiency. It can be observed that the HC formation is reduced when the higher load is placed on the engine. This likely may attributed by combustion efficiency, lower ignition delay and in-cylinder temperature. The increased in water proportion contribute for further increase in HC emission formation. This is due to the increase of ignition delay and higher fuel consumption, hence increase HC formation [34-36]. The maximum increase of 22.51% of HC emission obtained by B20E30 at 40% load compared to the baseline fuel. Therefore, the introduction of water in the fuel blend is not appropriate for reducing the HC emission.

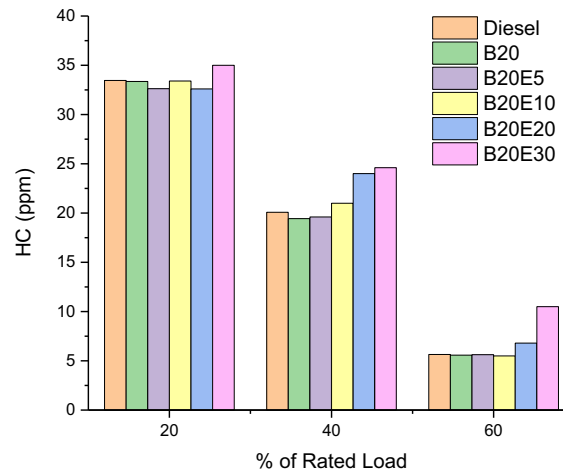


Figure 8. Variation of HC emissions against percentage of rated load.

4. Conclusion

Emulsified POME biodiesel-diesel blend with 5%, 10%, 20% and 30% water content were prepared and carried out for engine performance and emission characteristics. The engine is a direct injection water-cooled multi-cylinder compression ignition engine. The results were compared to conventional diesel. From the evaluation, a number of conclusions can be made which are follows.

1. Emulsion fuels showed higher kinematic viscosity than the diesel and B20 diesel-biodiesel blend and it can be concluded that the more water content in the fuel, the higher the kinematic viscosity.
2. The highest BSFC reduction of 6.68% achieved by B20E5 at 20% of rated load and engine speed 2500 rpm compared to diesel fuel. The emulsion fuels shows very promising in term of BTE. The B20E30 give highest improvement in term of BTE which is 32.56% compared to diesel. At high load, B20E30 achieved the improvement of 7.10% with regard to diesel.
3. As the emission parameters was considered, emulsification is the best alternative to reduce the NO_x emission. A total of 17.29% reduction of NO_x gained by B20E30 compared to conventional diesel at 40% load and 2500 rpm engine speed. Conversely, the introduction of water in fuel blend is not suitable to reduce CO_2 emission. The maximum of 77.00% of CO_2 was increased significantly. As the HC was considered, B20E5 showed a comparable result to baseline fuel.
4. The B20E5 has been considered as the optimum fuel as the engine performance and emission characteristics showed comparative result with regard to diesel.

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