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The performance of a single-cylinder diesel engine fuelled with egusi based biodiesel

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Abstract. The rapid depletion of fossil fuels coupled with the awareness of environmental issues and escalation of petroleum prices have led to intensive efforts in the search for renewable and environmentally friendly alternative fuel. Biodiesel is one such fuel. The main objective of this study is to evaluate the performance and emissions characteristics of a single-cylinder diesel engine fuelled with egusi biodiesel and compared against the conventional diesel and palm oil based biodiesel available in the Malaysian market. The oil extraction from whole Egusi seeds is obtained through Soxhlet extractor and went through transesterification process. The egusi based biodiesel is prepared for B7 (7% egusi biodiesel, 93% diesel) so that a direct comparison can be made against the palm oil based biodiesel sold in the market (grade B7). A single-cylinder, four-stroke diesel engine with speed of 1200-2000 rpm is used to evaluate the engine performance. Egusi based biodiesel shows a comparable engine performance to that of conventional diesel and B7 palm oil. B7 Egusi oil reduces carbon dioxide (CO2) and carbon monoxide (CO) by 0.8-0.9 %, while unburnt hydrocarbon (UHC) and nitrogen oxides (NOx) by 75-80 % from that of diesel. It shows that the Egusi based biodiesel holds the potential as a biodiesel feedstock in the future.

1.Introduction

Biodiesel is defined as the mono-alkyl esters of fatty acids derived from vegetable oils or animal fats. Biodiesel is the alternative into renewable sources which has property almost similar to that of conventional diesel. However, biodiesel slightly differs in terms of having high incompressibility, density, viscosity, pour point, flashpoint, cetane number, near-zero aromatic compounds and no sulfur link. Biodiesel has a heat value of 10 -12 % lower than diesel on mass basis [1].

Egusi based biodiesel is produced from egusi melon (Colocynthis citrullus) and is among the 300 species of melon belongs to the family of Cucurbitaceae found in tropical Africa, as shown in Figure 1. It is cultivated for its seeds, which are rich in oil (53%), protein (28%), vitamins (A, B1, B2 and C) and a good source of minerals [2]. The seeds are not only edible but also used to produce fuel. The fruit is not edible as its white flesh is dry and bitter enough to be repulsive [3]. It grows vigorously in tropical, subtropical, arid desert, and temperate conditions [4].

Figure 1. (a) Egusi melon fruit, (b) whole seed, and (c) seed kernels [2].

The study on the potential of egusi melon seed as biofuel feedstock has been reported by Giwa et al. [5]. They investigated in their study the egusi based biodiesel, where the egusi melon seed was obtained from a local store in Lafenwa, Nigeria and imported to Malaysia. The oil quality properties of the crude egusi melon seed oil were analyzed prior to transesterification process, in accordance with Palm Oil Research Institute of Malaysia (PORIM) standard test methods for oil analysis, with the exception of the higher heating value (HHV). The quality of egusi melon seed oil is expressed in terms of selected properties, such as density, kinematic viscosity and calorific value, as shown in Table 1. The properties are comparable to other conventional vegetable oils and the values are within the acceptable range. Transesterification process is a way to reduce viscosity of the crude oil to be able to be run in conventional diesel engine [6]. A direct alkaline transesterification process is adopted because egusi oil has a remarkably low acid value [2].

Table 1. Properties of Egusi melon oil compared with different biodiesels [7,8].

Parameter	Diesel	Egusi Melon B100	Palm Oil B100	Jatropha B100	Karanja B100	Polanga B100
Density at 15°C (kg/m^3)	853.97	905.3	864.42	873	883	869
Kinematic viscosity at 40°C (mm^2/s)	4.33	6.58	4.71	4.23	4.37	3.99
Calorific value (MJ/kg)	45.273	39.37	39.837	42.673	42.133	41.397

Evaluation of the engine performance fuelled by biodiesel and its blends is based on the assessment of the performance parameters. The difference in the chemical composition and thermo-physical characteristics of biodiesels from different feedstock generates diversity in performance and emission characteristics of an engine. An engine using biodiesel produced torque generally 3-5% lower due to its lower energy contents than diesel [6].

Besides that, the performance of another biodiesel based on Karanja oil was tested on a single cylinder, four-stroke direct injection and water-cooled diesel engine with rated output of 7.5 kW at 3000 rpm [9]. It was found that, the variation of torque of the engine under different engine loads using different blends of Karanja biodiesel shows that torque increases with an increase in the loading. This is due the engine operated with a higher amount of fuel consumption. The torque produced for the case of B20 and B40 are 0.1–13% higher than that of diesel due to complete combustion of fuels, while B60 to B100 gave 4–23% reduction from that of diesel due to a decrease in the calorific value of fuel, with an increase in biodiesel percentage in the blends [9].

In addition, the engine power reduces when biodiesel was used. It is also reported that some power gain in an engine fuelled with biodiesel due to the higher density, higher bulk modulus and higher viscosity of biodiesel. Moreover, high density results in injection of increased mass of fuel, while high viscosity reduces the leakage. However, the higher mass fuel flow for the methyl ester is not sufficient to compensate for the approximately 12.8% lower heating value in comparison of diesel. In fact, it is reported that there is no significant difference in engine power between biodiesel and diesel [10].

There are many studies on the performances and emissions of compression ignition engines fuelled with pure biodiesel as well as it blends with diesel fuel have been conducted and are reported in the literature. Fuel characterisation data show some similarities and differences between biodiesel and diesel fuels. The sulfur content of diesel is 20 to 50 times of biodiesels. Biodiesel has demonstrated a number of promising characteristics, including minimization of exhaust emissions [11].

Another finding by Qi et al. [12] reported that the exhaust gas emissions of CO and UHC were reduced by using biodiesel. The reduction of CO and UHC is about 27% when compared to that of diesel, when both fuels were tested in a diesel engine at full load. This is because of better combustion of biodiesel inside the combustion chamber due to the availability of oxygen atom in biodiesel [12]. CO is predominantly formed due to lack of oxygen. Biodiesel fuel contains some amount of oxygen, which is a combustion promoter inside the cylinder. This leads to a higher air excess ratio for biodiesel than for diesel at speed characteristic at full load and results in better combustion for biodiesel. UHC emission increased due to several elements such as quenched flame, lean combustion, cold starting and poor mixture preparation. The higher viscosity of biodiesel may have provided better fuel spray penetration leading to efficient combustion process. This high viscosity may have also provided a good sealant between the piston rings and cylinder wall, hence improving engine compression as well as engine combustion [13].

Nitrogen oxides (NOx) emissions, on the other hand, are sensitive to oxygen content, adiabatic flame temperature and spray characteristics. The fuel spray properties depend on droplet size, droplet momentum and degree of mixing with air and penetration rate, evaporation rate, and radiant heat transfer rate. An amendment in any of those properties may affect the NO_X production. The average reduction of NO_X for biodiesel is about 5% lower than that of diesel [12]. However, there has been numerous reports suggested that biodiesel fuels tend to have an increase in NOx emissions because the advanced of combustion process [14,15].

This study aims to investigate the performance of egusi based biodiesel, where the egusi oil is blended with 93% volume of diesel to obtain B7 grade biodiesel. A direct comparison will be made between B7 palm oil based biodiesel available in the market and conventional diesel fuel. The performance discusses engine torque, power and emissions levels produced by the engine.

2.Experimental Setup

The first step of the study is to extract the egusi oil from its seed. Egusi whole seed sample is coarsely minced and the crushed whole seed is then placed in the thimble. Hexane was poured into round bottom flask. The mantle heater is set to 60 – 70°C. They are extracted for 8 hours. Excess hexane in the extracted oil is evaporated in rotary evaporator and is then filtered using double layer lab filter paper to obtain pure egusi oil. Then, the transesterification process was then performed using 0.55% Potassium Hydroxide (KOH) as the catalyst with molar ratio of 7:1 methanol to oil at 65°C. The pure egusi oil is preheated to 70℃ and is continuously stirred at 300 rpm for around 15 minutes. Mixture of methanol and KOH is then added into preheated egusi oil and they are stirred for 1 to 3 hours to ensure complete reaction. The transesterified egusi oil is then poured into separating funnel overnight. The mixture of two layers was observed, which upper layer represents the biodiesel while the latter is the glycerol. The glycerol was then removed from the funnel. The water wash process was performed onto the biodiesel to remove excess water and glycerol existed in the biodiesel. After that, the water was drained out from the biodiesel and the biodiesel is heated to 120°C to remove any present water. The final product is now called egusi oil methyl ester (EOME). The egusi oil is then blended with diesel with the ratio of 7% egusi and 93% diesel (which will be called B7 EO). B7 grade is created so that direct comparison can be made between B7 EO and B7 palm oil (B7 PO) based biodiesel available in the Malaysian market.

The performance of the engine with respective fuels (B7 EO and B7 PO) are analysed and are compared with each fuel. The experiment uses Yanmar single cylinder diesel engine, where the engine was tested from 1200 – 2000 rpm. The details of the engine testbed specifications are given in Table 2 and Figure 3 shows the engine testbed used in the experiment. The intake temperature and pressure are at ambient condition. Engine exhaust emissions were measured using automobile gas analyzer that measures unburnt UHC, CO, CO2 and NOx emissions. UHC and NOx emissions are measured in ppm while CO and CO2 are measured in percentage volume.

Table 2. Diesel engine specifications.

Engine type	Single cylinder, four-stroke diesel engine
Model	L48N6
Brand	Yanmar Engines
Engine Speed	1200 – 2000 rpm
Bore	70 mm
Stroke	57 mm
Displacement	219 cc
Maximum output	3.5 kW / 3600 RPM
Starting system	Electric starter/Recoil starter
Lubricant	Forced lubrication with Trochoid Pump
Dynamometer Type	Water brake

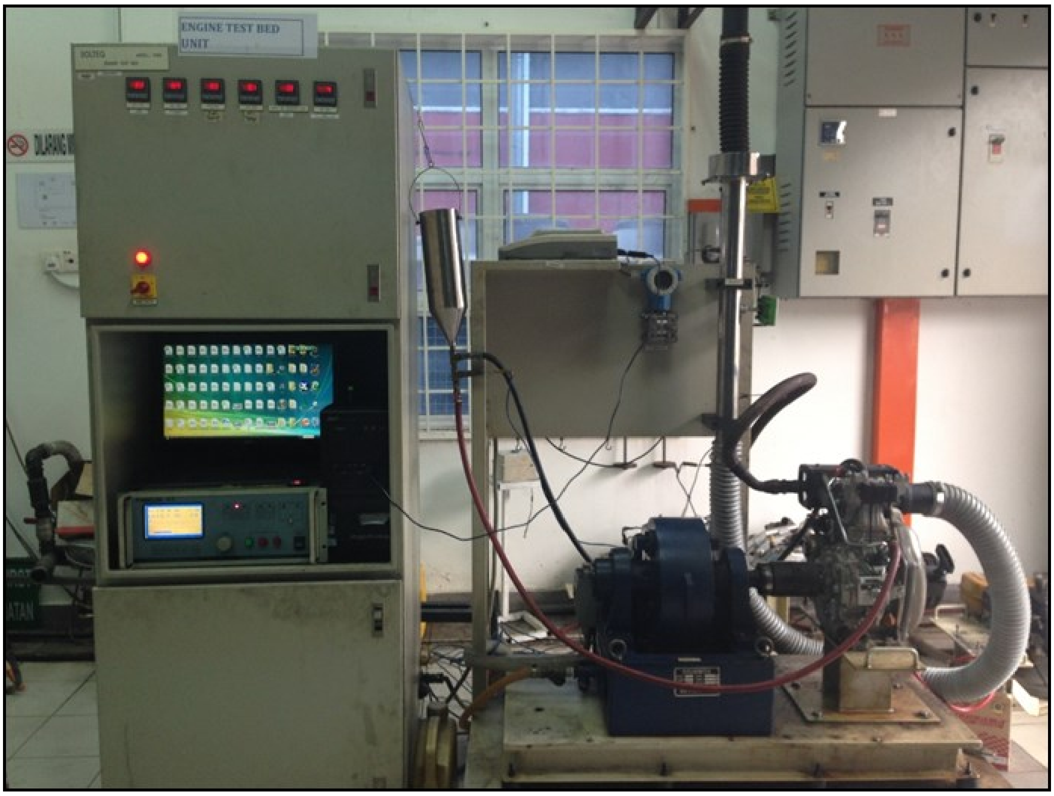

Figure 2. Engine test bed.

3. Results

For each of the fuels tested, the torque increases when engine speed is increased. From Figure 3, diesel generates a higher torque compared to B7 PO and B7 EO. B7 EO shows only a slight lower torque than diesel followed by B7 PO. [16] Diesel has around 42 to 46 MJ/kg energy contents compared to palm oil biodiesel and egusi oil biodiesel which is 39.84 MJ/kg and 39.37 MJ/kg respectively. These data explains the fact diesel gives more torque than biodiesel does [17].

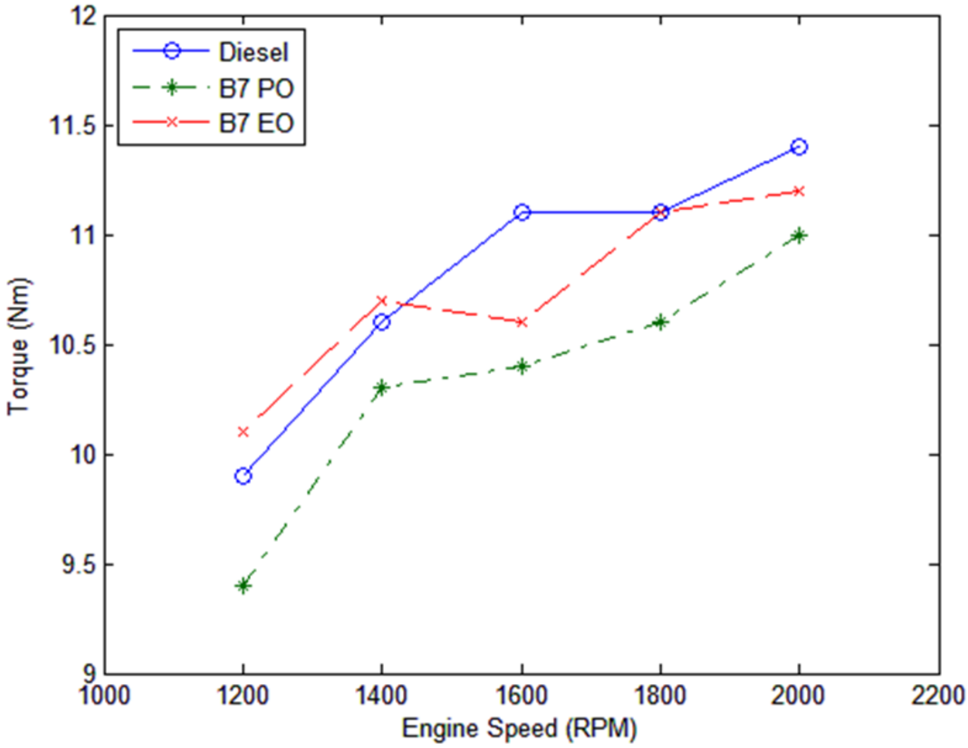

Figure 3. Comparison of engine torque for Diesel, B7 PO and B7 EO under different engine speeds at full load condition.

Engine power output for each fuel is increased as the engine speed increases as shown in Figure 4. B7 EO shows a remarkable potential as the fuel gives 1.75% more power output than diesel at 1200 rpm. However, as the engine speed increases, the diesel generates slightly higher power output compared to B7 EO. Throughout all engine speed tests, B7 EO surpasses the power output given by B7 PO. The engine supplies fuel on a volumetric basis and the density for B7 EO is higher than the B7 PO, thus the plunger in the fuel pump discharges more B7 EO biodiesel compared to that of B7 PO. The result shows that the power produced by B7 EO is almost the same as diesel and better than B7 PO in all engine speeds. This results in agreement with the study done by Makanju [16] as the torque and power are close to those conventional diesel fuel.

As for the emission tests, B7 EO improves the exhaust emissions better than diesel and B7 PO. Figure 5 shows the plots for CO2 emissions for diesel, B7 PO, and B7 EO at various engine speeds. Diesel gives the highest CO2 emissions among the fuels and the percentages are increasing when the engine speed increased. In contrast with B7 EO, the fuel emits less percentage of CO2, from 0.17% to 0.06% when engine speed is added. Meanwhile, B7 PO has about a slightly higher CO2 compared to B7 EO at a higher engine speed. This shows that the CO2 emission for B7 EO is better than that of B7 PO and diesel.

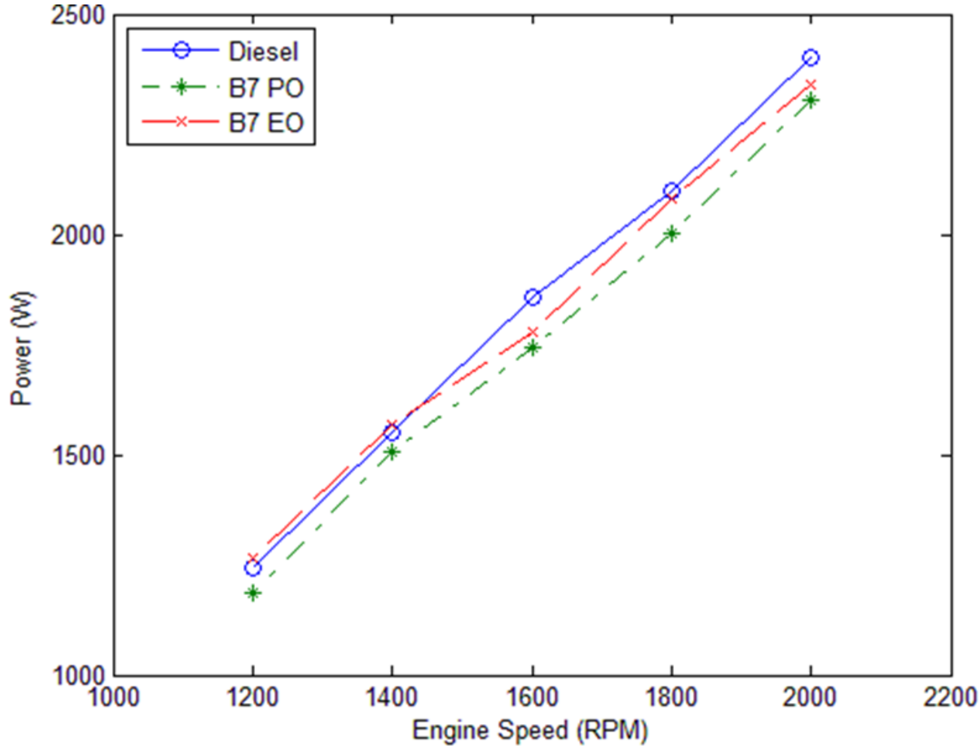

Figure 4. Comparison of engine power output for Diesel, B7 PO and B7 EO under different engine speeds at full load condition.

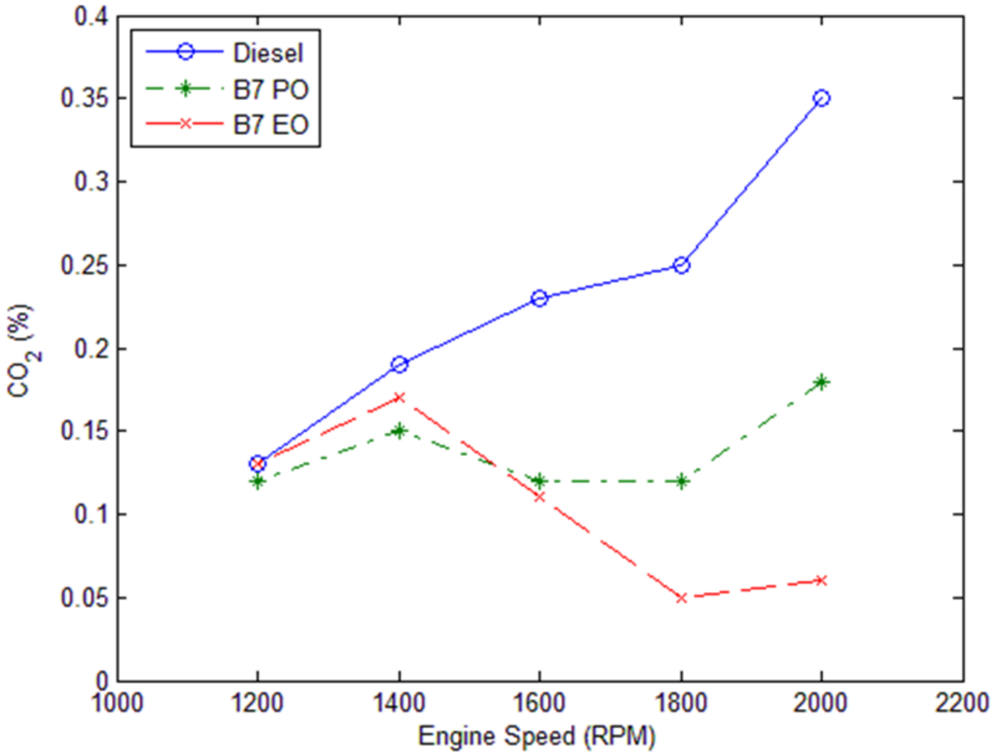

Figure 5. CO_2 emissions of diesel, B7 PO and B7 EO with respect to engine speeds.

In Figure 6, the CO emissions for each fuel are shown. Diesel shows an increase of CO emissions at increasing speed. The percentage of CO emission at the highest engine speed for diesel is 0.09%. Both B7 PO and B7 EO give zero CO emissions at lower speed. However, at 2000 rpm, B7 PO emits sudden increase of CO to 0.04%, while B7 EO always produces lower CO emissions compared to diesel in all engine speed tests. Biodiesel fuels contain some amount of oxygen, which is a combustion promoter inside the combustion chamber. This leads to higher air excess ratios for biodiesel than for diesel at full load condition and results in better combustion for biodiesels [18].

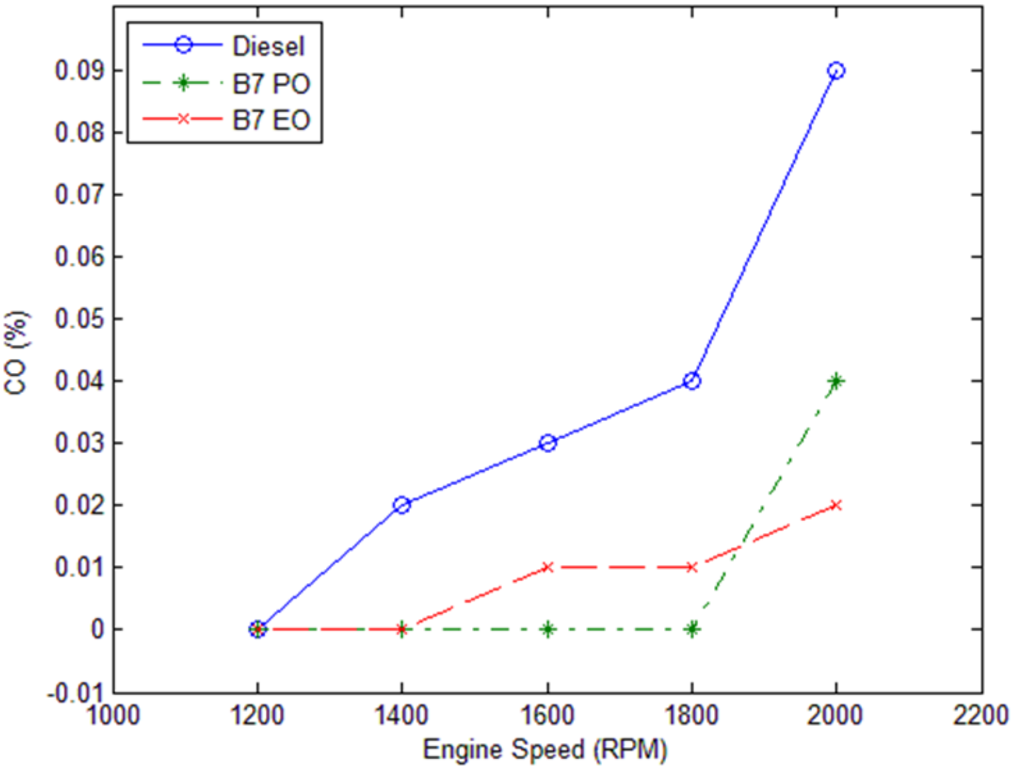

Figure 6. CO emissions of diesel, B7 PO and B7 EO with respect to engine speeds.

Figure 7 shows the UHC emissions with respect to engine speed for diesel, B7 PO and B7 EO. Diesel produces the most UHC, more than four times the value of UHC produced by B7 EO. The UHC emission between B7 EO and B7 PO is almost the same except at the highest engine speed, where the UHC for B7 PO is higher compared to B7 EO. The higher viscosity of B7 EO provides better fuel spray penetration (reduces wall wetting issue) leading to efficient combustion process. In addition, more oxygen contents of biodiesel also benefit the combustion process, which contributes to a cleaner burning.

NOx emissions of diesel, B7 PO and B7 EO are plotted in a graph shown in Figure 8. NOx emission shows reduction at 2000 rpm for each fuel tested. At lower engine speed, 1200 to 1400 rpm, B7 PO gives the lowest NOx emission. However, as the engine speed increases, B7 EO starts to emit less NOx. The physicochemical properties of biodiesel have significant effects on NOx emissions. An increase in NOx is said to increase with increasing viscosity at low temperatures. B7 EO holds the greater kinematic viscosity than B7 PO, thus explains the higher emission of NOx for B7 EO at lower engine speed.

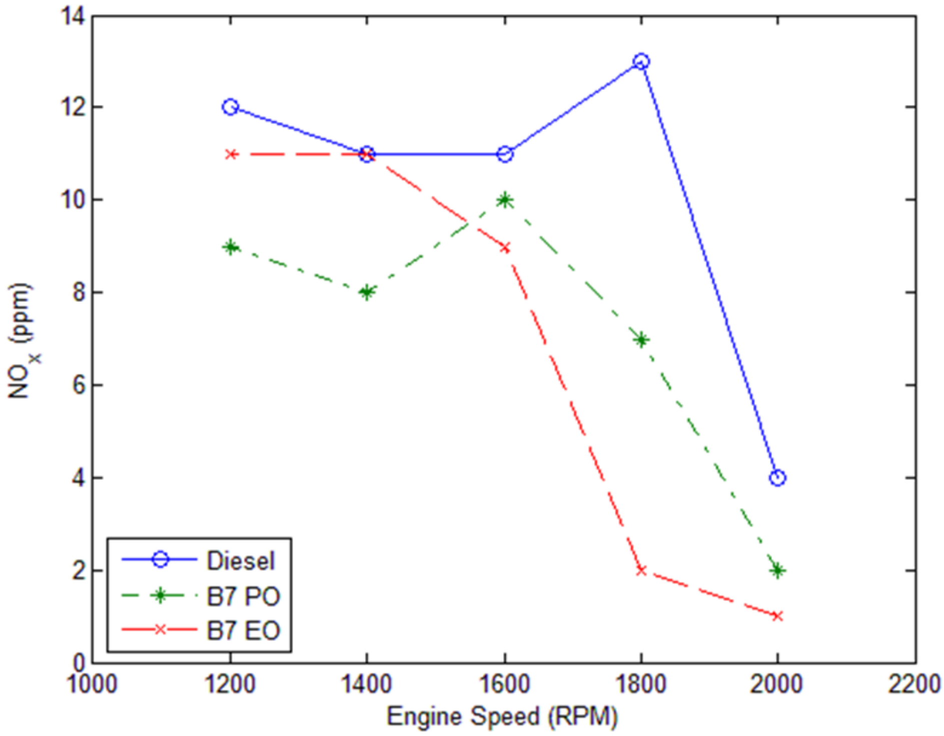

Figure 7. **NO_x emissions of diesel, B7 PO and B7 EO with respect to engine speeds.**

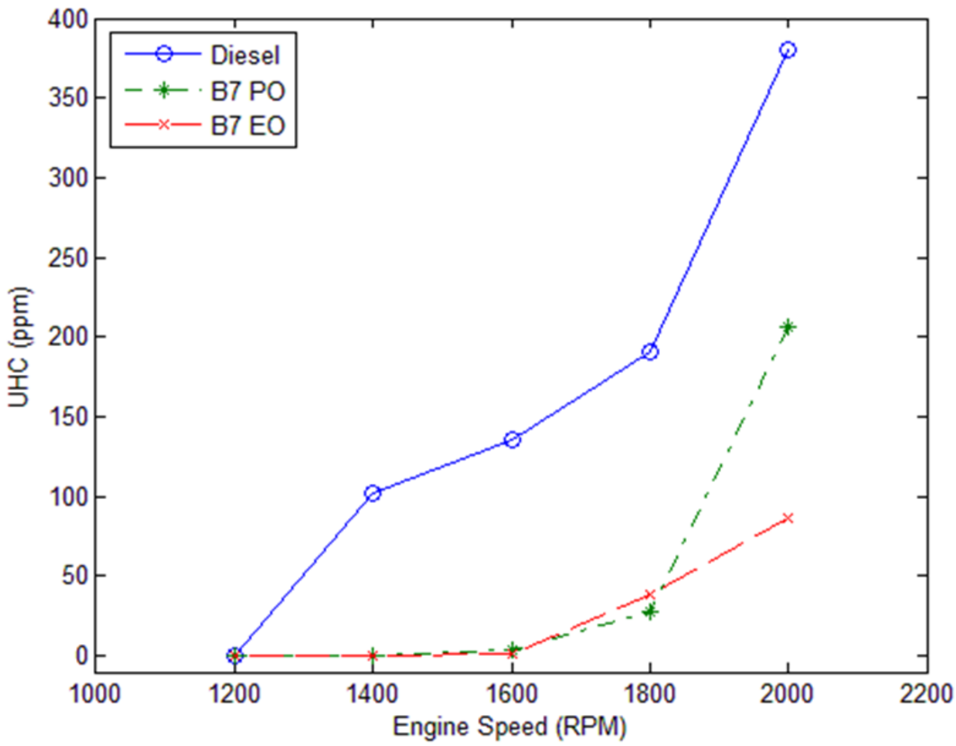

Figure 8. UHC emissions of diesel, B7 PO and B7 EO with respect to engine speeds.

4. Conclusion
This study investigates the performance of B7 EO and compared against the fuels that are readily available in the market, which are B7 PO and diesel. Due to the different properties of biodiesel and diesel, B7 EO exhibits different engine performance with the variation of engine speeds at full load condition. B7 EO shows a comparable engine power and torque to that of diesel. Besides that, B7 EO outperforms B7 PO in both engine power and torque tests.

When biodiesel is said to be environmentally friendly, B7 EO strongly supports the fact to be a greener fuel. B7 EO reduces the CO2 and CO by 0.8 to 0.9%, while UHC and NOx by 75 to 80% from that of diesel. Thus, egusi based biodiesel has been proven to significantly reduce the CO2, CO, UHC and NOx emissions. From this study, egusi based biodiesel holds the potential to be developed as the next biodiesel feedstock.

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