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Effect of Palm Oil Biodiesel Blends on Engine Emission and Performance Characteristics in an Internal Combustion Engine

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Abstract

Increasing global environmental issues and depleting fossil fuel reserves has necessitated the need for alternative and sustainable fuel. In this paper, the effects of biodiesel and its blend on engine emission and performance characteristics in an internal combustion engine were analyzed. Biodiesel derived from the transesterification of raw palm oil was blended with diesel fuel at different proportions designated as PO5 (5% Biodiesel and 95% Diesel), PO10 (10% Biodiesel and 90% Diesel), PO15 (15% Biodiesel and 85% Diesel), PO20 (20% Biodiesel and 80% Diesel), PO50 (50% Biodiesel and 50% Diesel), PO85 (85% Biodiesel and 15% Diesel), and PO100 (100% Biodiesel). A Lombardini 2-cylinder, four-stroke direct injection diesel engine with a compression ratio of 22.8 was developed using Ricardo Wave software in which diesel, palm oil biodiesel blends and pure biodiesel are used in the model, and the obtained results were analysed and presented. The simulation was done under varying engine speeds of 1200 rpm to 3200 rpm at full load condition. Biodiesel and its blends are more environment-friendly and non-toxic when compared to diesel fuel; it also improves the mechanical efficiency of the engines, and above all can also lead to a reduction in poverty among rural dwellers. The obtained results showed that brake specific fuel consumption and brake thermal efficiency increased with palm oil biodiesel blends as compared to diesel fuel which might be a result of biodiesel's lower heating value, and the increase in thermal energy may be a result of the oxygenation of the biodiesel blend as compared to pure diesel. In terms of brake torque, palm oil biodiesel blends were lesser than diesel fuel. The CO, HC, and NO_x emissions of palm oil biodiesel blends decreased significantly compared to that of pure diesel. From this study, palm oil biodiesel emits lesser emissions than diesel fuel and its performance characteristics are similar to diesel fuel. Therefore, palm oil biodiesel can be used without any modifications directly in a diesel engine. In addition, it can also be used as blends as an alternative and sustainable fuel, decreasing air pollution, and increasing environmental sustainability.

Keywords

Diesel Engine, Biodiesel, Palm Oil Biodiesel, Engine Performance, Emissions

1. Introduction

The world has been faced with environmental challenges such as pollution, greenhouse effect, acid rainfall, and ozone depletion in which gases emanating from the usage of fossil fuels are major contributors. Pollution and emission levels arising from the continued and increasing demand and usage of fossil fuels are having adverse effects on our environment. The United Nations Annual Climate Summit since 2016 and COPS 27 focused on reducing greenhouse gas emissions and the conservation of our environment in which the usage of eco-friendly clean or low carbon energy substitutes was one of the solutions proposed during the summits. Similarly, Kyoto Protocol [1]-[6] has prompted resurgence in the use of biodiesel throughout the world. Many countries around the world have passed legislations that diesel should contain a minimum percentage of biofuels. Biodiesel produced from nonconventional sources such as vegetable oils, fat, palm oil, soybeans, coconut and others offers a viable alternative fuel for diesel engines. In addition, these alternative biodiesel fuels are readily available in Nigeria and can be obtained locally in large quantities. The blending of pure diesel and even low percentages of biodiesel will contribute to the local economy of the nation and reduce poverty levels.

Yasin *et al.* [7] conducted an experimental analysis to ascertain the effects of exhaust gas recirculation (EGR) on a Diesel Engine Fuelled with palm biodiesel. They used a Mitsubishi 4D68 SOHC in-line four stroke, direct injection diesel engine equipped with diaphragm type EGR, the engine is water-cooled, and operated at low-speed and a maximum power of 64.9 kW and can operate up to 4500 rpm. Their aim was to reduce the NO_x emission, though many previous works have shown an increase in NO_x emission when the engine is fuelled with biodiesel. From their experimental results, using this diesel engine operating with palm oil-based biodiesel with EGR leads to a reduction in the brake power output, the engine torque, consumption and NO_x. In addition, they observed some increment in other emissions including CO_2, CO, and particulate matters, but there was a measurable increment in fuel consumption.

Bari and Hossain [8] run palm oil diesel on a 5 kW Cussons air-cooled single-cylinder indirect-injection diesel engine with a Ricardo comet-type-swirl combustion chamber installed using a DC motor generator with a swinging field for torque measurement and as a dynamometer to load the engine while emissions were measured with COSA 6000 gas analyser. Their result showed about

10% higher brake specific fuel consumption with POD compared to the pure diesel fuel, and brake thermal efficiency reduced with POD to about 5% lower due to the heating value of POD while CO and HC emissions reduced on average by 51% and 55% respectively using POD. The NO_x was observed to increase by 33% on the average compared to pure diesel fuel. They concluded that POD is a suitable alternative fuel for diesel engines.

Nagaraja and others [9] investigated the effects of the engine compression ratio (CR) on the emission and performance features of a diesel engine using preheated palm oil blended with pure diesel blends. They use a single-cylinder 4-stroke diesel engine at a constant speed of 1500 rpm at full load, using the preheated palm oil in the ratio of 5%, 10%, 15%, and 20% blends with pure diesel, using CR of 16:1, 17:1, 18:1, 19:1 and 20:1. Their results showed that preheated palm oil/diesel blend of 20% has improved emission and performance characteristics for the compression ratio of 20:1 at full load condition with reference to the other blends analysed in their research work.

Yasin *et al*. [10] carried out experiments on a Mitsubishi 4D68 4-inline multi-cylinder compression ignition (CI) engine fuelled with palm biodiesel blend (5% palm methyl ester B5), and 95% pure diesel fuel. They observed slight differences in brake power output and torque between B5 and diesel. The BSFC was observed to increase with the reduction in NO_x emissions, which is obtained when the engine is fuelled with B5. CO, CO_2, and UHC were observed to reduce the exhaust emission for B5 compared to pure diesel fuel.

Shote *et al*. [11] examined the characteristics of CO and NO_x emission from the combustion of palm kernel oil-based (PKO) biodiesel in a compression ignition engine. Their results showed that as the concentration of the PKO biodiesel increases in the blends, the carbon monoxide (CO) emissions reduce. They observed that about 35% is a significant reduction in the CO emissions as the concentration of methyl esters increased in the blends at 99.9% confidence. They also noted that over 80% of NO_x variation is a result of changes in the Flue gas temperature.

El-Araby *et al*. [12] studied the physio-chemical properties of palm oil-biodiesel-fuel blends such as viscosity, density, and flash point. They used the ASTM test method to experimentally evaluate the properties and thereafter developed a model to predict these properties. Their results showed that biodiesel fuel properties and that of pure diesel fuel are very close, and their model was validated using experimental data from other literature which showed good agreement.

Gad *et al*. [13] used palm oil methyl ester blended with diesel oil to operate a compression ignition engine. The test fuels were designated B20, B100 and PO20 (20% palm oil, 80% diesel oil). Performance results showed that the BSFC and EGT increased when biodiesel blends were used as compared to diesel fuel while BTE was reduced because of the low heating value of the biodiesel. The results show a reduction in HC and CO emission when using Biodiesel, this they attributed to the higher oxygen content, lower carbon content and higher cetane number of the biodiesel. However, the NO_x emission increased with an increase in engine load when biodiesel blends was used as compared to diesel oil which may likely be due to the increase in the quantity of fuel injected into the engine at a high load and the heat generated may have led to increasing combustion temperature responsible for the observed NO_x increase.

Shahabuddin and others [14] investigated the effect of addiction on the performance of compression ignition engines fuelled with Malaysia Palm Oil (biodiesel). From their experimental investigation, they concluded that biodiesel blend (B20) plus additive ("B20 + 1%") resulted in 1.73% and 9% higher brake power compared to only B20 and diesel fuel respectively, Fuel "B20 + 1%" consumes 26% and 6% lower SFC as compared to fuel B20 and OD respectively and Fuel "B20 + 1%" reduces CO, NO_x and CO_2 emissions as compared to other fuels.

Alghafis and Raouf [15] investigated the impact of injection timing and injection duration on engine brake power and NO_x using Diesel-RK simulation software. They operated the engine at different engine speeds of 1000, 1500, 2000, 2500, 3000 and 4000 rpm, at different injection timing of 10˚ CA-bTDC, 5˚ CA-bTDC and 0˚ CA-TDC and at different injection duration of 20˚, 25˚, 30˚, 35˚ and 40˚ CA. From their results, NO_x emission was reduced in the greater injection durations while the brake power decreased at those injection durations. Consequently, as the brake power increased the NO_x emissions increased.

Fasogbon *et al.* [16] analysed the combined effect of a catalytic reduction device with waste frying oil based biodiesel on NO_x emission. In their experiment, they used a four-stroke, air-cooled compression ignition engine operated at a constant speed of 19,000 rpm fueled with B0, B5, B20, B30, B70 and B100 coupled with a Megatech DG2 dynamometer varying the load from 25%, 50%, 75% and 100%. A PCA 3 Bacharach Gas Analyzer was used. Their results revealed that NO_x emission increased with an increase in load and reduced significantly with the use of the catalytic converted device.

In this study, performance and emission from an Internal Combustion Engine fuelled with palm oil biodiesel blended with diesel fuel designated as PO5 (5% biodiesel, 95% diesel), PO10, PO15, PO20, PO50, PO85, PO100 were investigated and compared with that of regular diesel under constant load with varying speeds.

2. Modelling

The simulation models are based on thermodynamic models and fluid dynamic models. The numerical simulation is carried out using Ricardo Wave commercial software. The fundamental governing equations used for the simulation of the software are as follows.

Conservation of Mass. The rate of change of mass within any open system is the net flux of mass across the system boundaries.

$$\text{mass} = \frac{\mathrm{d}m}{\mathrm{d}t} = \sum \dot{m} \tag{1}$$

Conservation of Energy

$$\text{enegrgy} = \frac{\mathrm{d}e_T}{\mathrm{d}t} = \sum mh + \text{sources} \quad (2)$$

Conservation of Momentum

$$\text{momentum} = \frac{\mathrm{d}mu}{\mathrm{d}t} = -A\frac{\mathrm{d}p}{\mathrm{d}x}\mathrm{d}x + \sum \dot{m}u - \text{sources} \quad (3)$$

The solution to the governing equations is obtained by the application of a finite difference technique utilizing the finite-volume approach to the discretization of the partial differential equations. The time-difference approach is based on the explicit technique, with the time step governed by the Courant condition.

The parameters, which were calculated in order to find the performance of the engine are: brake power, specific fuel consumption and the thermal efficiency. These parameters were calculated for each blend at different engine operational speeds. The engine used in this work has the specification shown in **Table 1**, and the properties of the fuel blends are shown in **Table 2**.

3. Simulation Results

3.1. Brake Specific Fuel Consumption

The brake specific fuel consumption is the mass flow rate of the fuel per unit power produced. **Figure 1** shows that BSFC was higher with biodiesel blends as compared to diesel. This shows that biodiesel blends consume more fuel than diesel at the same speed level. This phenomenon is a result of the increased density and lower heating value associated with biodiesel blends [17] [18]. However, all the fuel display the same trend by decreasing as the speed increases to 2000 rpm,

Table 1. Engine specification.

Cylinders (N)	2
Bore (mm)	75
Stroke (mm)	77.6
Displacements (cm^3)	686
Compression rate (–)	22.8:1
Cooling System	Liquid Coolant
Maximum Speed (rpm)	3600
Maximum torque (Nm) @ 2000 rpm	40.5
Injector Timing	$11^\circ \pm 1^\circ$
Injector Opening pressure (bar)	140 ± 15
Intake Valve open	16 degrees before TDC
Intake valve closed	36 degrees after BDC
Exhaust valve open	36 degrees before BDC
Exhaust valve closed	16 degrees after TDC

Table 2. Properties of palm oil biodiesel and diesel fuel.

Property	Diesel	Palm Oil Biodiesel
Density @ 15.5˚C (kg/m^3)	827.2	877.6
Viscosity @ 40˚C (mm^2/s)	3.323	5.5377
Viscosity @ 100˚C (mm^2/s)	1.245	1.998
Viscosity index	90	183.2
Pour Point (˚C)	0	13
Flash Point (˚C)	68.5	162.5
Cloud Point	8	12
Lower Heating Value [kJ/kg]	45272	39513
Cetane Number [−]	49	53.8

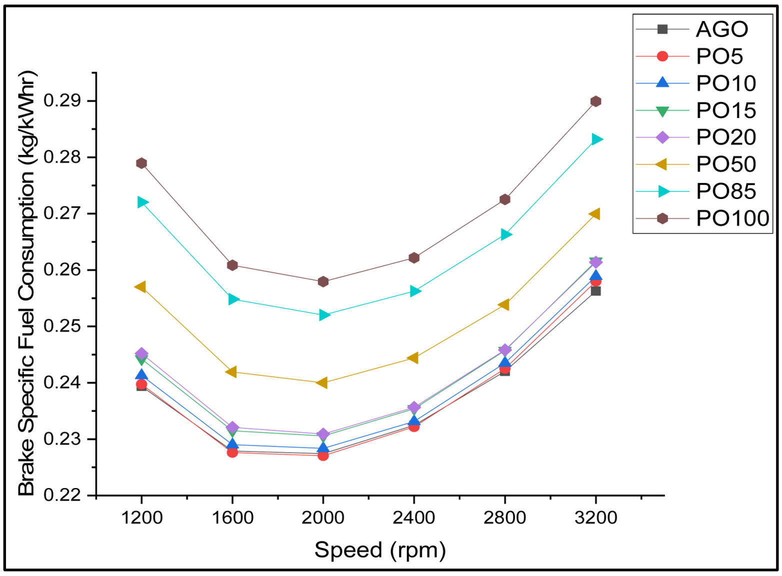

Figure 1. Brake specific fuel consumption against speed for fuel blends.

then as the speed increases there is similar trends cross all the fuel Blends. Hence the optimal fuel consumption was obtained at a speed of 2000 rpm.

3.2. Brake Thermal Efficiency

Figure 2 shows the variations in brake thermal efficiency for the fuel blends. At 2000 rpm biodiesel blends produced higher brake thermal efficiency. The brake thermal efficiency shows how well the engine converts the chemical energy contained in the fuel into useful mechanical energy. The obtained result is in agreement with other researchers who have worked on similar fuel blends in particular the work of Nair *et al.* [19] where they observed that variations in brake thermal efficiency result from the oxygen content of the fuel.

3.3. Brake Torque

In Figure 3, we observed that the brake torque decreases with an increase in

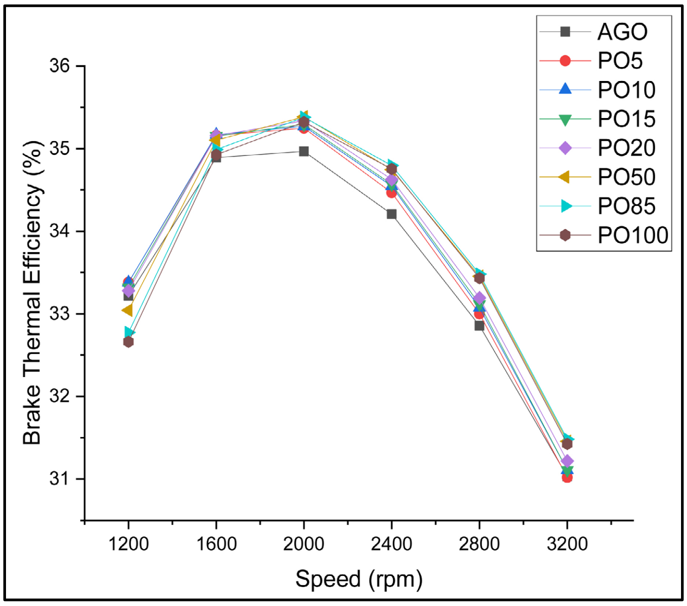

Figure 2. Brake thermal efficiency against speed for the blends.

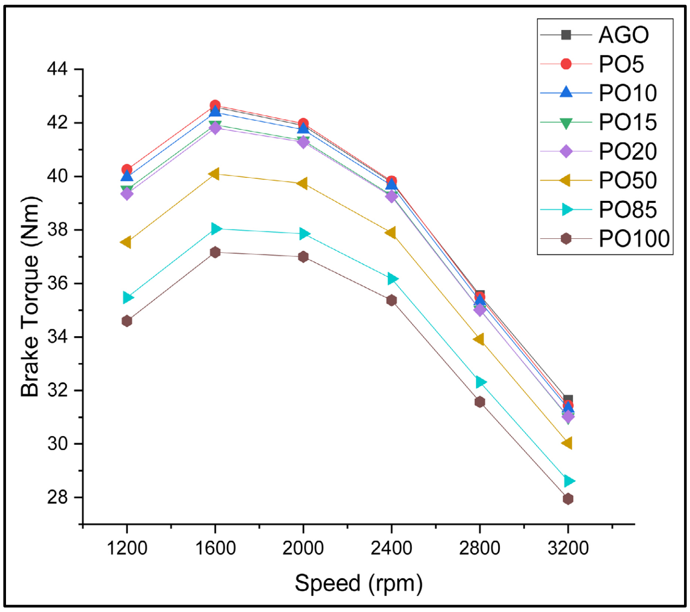

Figure 3. Brake torque against speed for fuel blends.

biodiesel blend ratio when compared to diesel fuel. This variation according to Paul *et al.* [20] noted that the variation in torque was due to the lower heating value of the fuel. The highest difference was observed for PO100, but for PO5 and PO10, there was no significant difference between the observed torque and that of AGO for all the operational speeds used. However, there is a general trend of the highest torque being observed by all the blends at 1600 rpm.

3.4. The Carbon Monoxide (CO) Emission

The emission of CO is usually a result of incomplete combustion or an improper mixture of fuel and air or a rich spot within the combustion chamber. Heywood, JB [21] explained that CO emission is controlled primarily by the Fuel/air equivalence ratio. The CO emission variations shown in **Figure 4** indicates that the biodiesel blends reduce CO emission when compared to diesel fuel at all engine operational speed, except for PO5, PO10, and PO15 where CO emission level at 2800 rpm and 3200 rpm were higher than that of the pure diesel fuel this may be due to the fact that as the speed increases more fuel is injected, and there is not enough residence time for proper mixture preparation and the injected fuel may have impinged on the piston crown and cylinder wall leading to the observed increase in CO emissions. Palm Oil biodiesel has higher oxygen content than pure diesel which leads to better combustion, thus reducing CO emission [22]. At 1200 rpm the CO emission reduces by 28% with PO100 as compared to diesel. Biodiesel blends are known to have higher oxygen content which enhances complete combustion.

3.5. The Unburnt Hydrocarbon (UHC) Emission

The unburnt hydrocarbon emission depends on fuel properties, the injection timing and duration and engine operational loads [23] [24] [25]. **Figure 5** shows that UHC emission decreases with biodiesel blends at all speed levels when compared to diesel fuel. This reduction is attributed to the higher cetane number and oxygenation characteristics of biodiesel fuel and its blends with pure diesel. However, all the blends display similar UHC emission characteristics, and this also indicates that the variation of speed does not really have much effect on the emitted UHC.

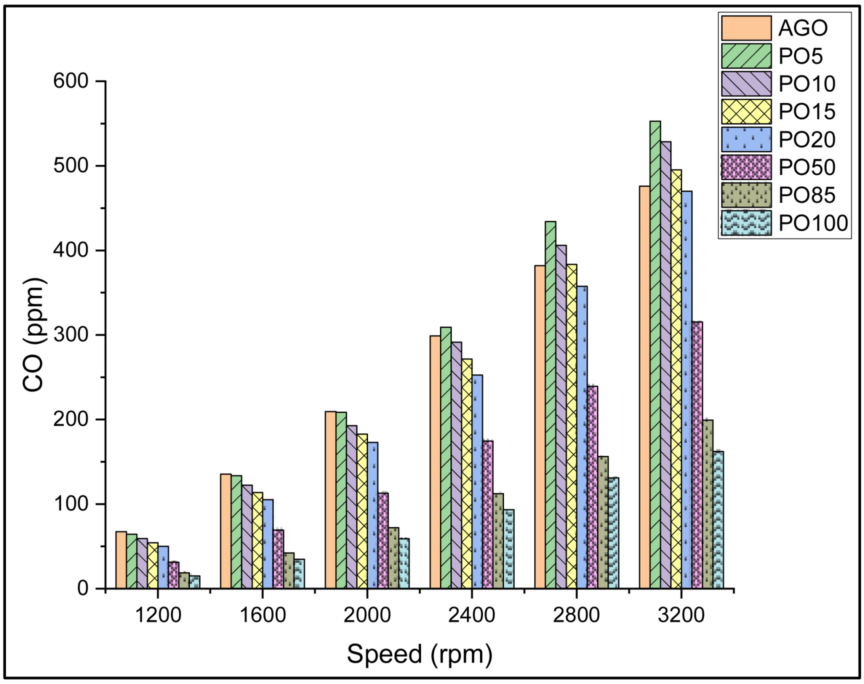

Figure 4. CO emission against fuel blends.

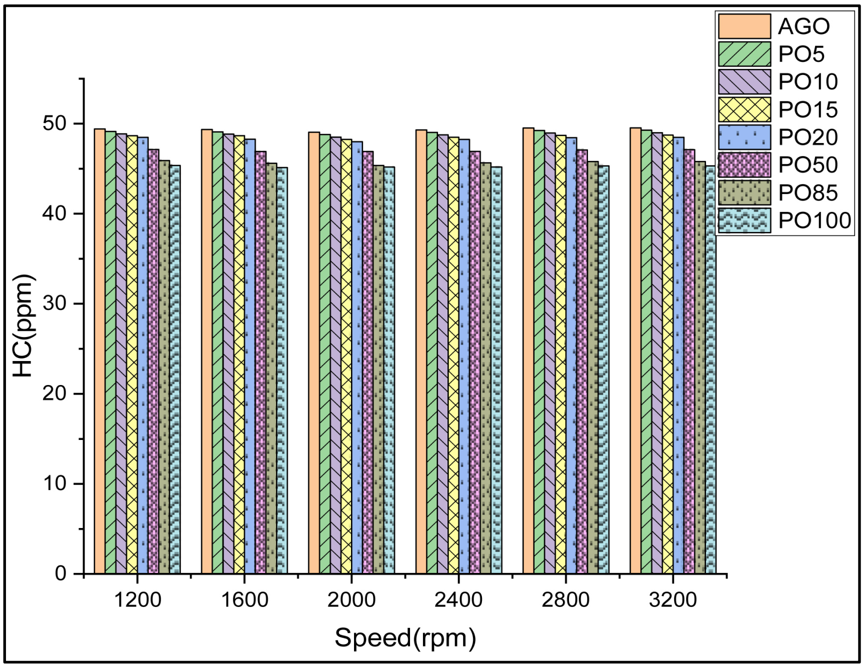

Figure 5. UHC emission against speed for fuel blends.

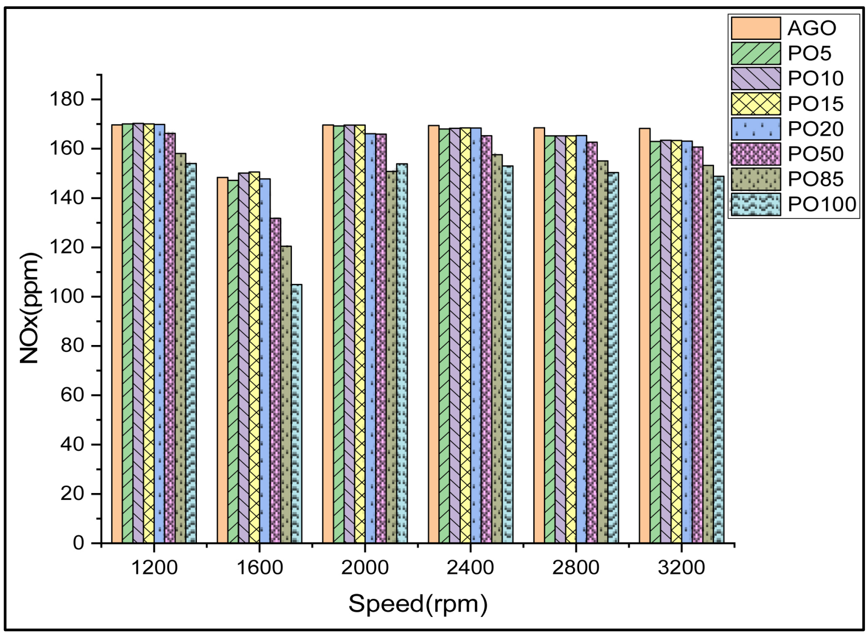

Figure 6. NO_x emission against speed for diesel and palm oil biodiesel blends.

3.6. The Nitric Oxide (NO_x) Emission

The NO_x is formed as nitrogen reacts with oxygen under high temperature in the cylinder. Figure 6 shows the variation of NO_x emissions of biodiesel blends and diesel against speed. It is observed that palm oil biodiesel blends are emitting less NO_x as compared to diesel. This phenomenon could be a result of the oxygenation nature of biodiesel which lead to lower combustion temperatures [26] [27].

4. Conclusions

In this study of palm oil biodiesel blends on performance and emission on diesel engines with blends of biodiesel, we can conclude that palm oil biodiesel blends are showing higher brake specific fuel consumption and brake thermal efficiency than diesel. The brake torque produced by the palm oil biodiesel blends displays lower values compared to the diesel fuel.

In addition, the CO, UHC, and NO_x emissions of palm oil biodiesel blends display a decreasing trend compared to the diesel fuel.

From this study, it can be seen that palm oil biodiesel is a viable alternative and sustainable fuel to diesel fuel, reducing emissions significantly without any modifications to the diesel engine configuration.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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