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EMISSIONS ANALYSIS ON DIESEL ENGINE FUELED WITH PALM OIL BIODIESEL AND PENTANOL BLENDS

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ABSTRACT

This study examined the effects of pentanol, palm oil biodiesel blends of varying proportions on the emissions pattern in a constant speed diesel engine. The main intention of this study was to investigate the reductions in HC, CO, NO_X and smoke emissions when deploying four different fuels. The conversion of palm oil into biodiesel was achieved using the base catalysed transesterification process. The four different fuels evaluated were neat palm oil biodiesel (POBD100), pentanol blended with palm oil biodiesel by 10% volume (POBD90P10), palm oil biodiesel blended with pentanol (POBD80P20) by 20% volume and petroleum diesel. The experimental work concluded that by fuelling the diesel engine with palm oil biodiesel and pentanol blends, combustions were smooth. It was observed that the pentanol to palm oil biodiesel blend gave respective reduction of 9.3%, 3.8%, 6.6% and 2.7% in CO, HC, NO_X and smoke emissions when compared to neat palm oil biodiesel.

Keywords: pentanol, palm oil, biodiesel, emissions.

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ITRODUCTION

Escalating environmental issues coupled with depletion in petroleum resources have paved the way for global efforts to search for eco-friendly fuels (Amirnordin *et al*., 2013). Automobiles are widely acknowledged as the major source of greenhouse gas emissions. Diesel engines play a significant role in the power and automobile sectors of industry largely because of its durability and economy. However, diesel engines emit higher emissions when fueled with diesel. A lower emission alternative is needed to lessen the demerits of fossil fuel (Harmiwati and Rahmad, 2015). Biodiesel is made up of long chain alkyl esters produced by reacting lipids with alcohols (Lam *et al*., 2011). Biodiesel can be deployed in diesel engines without any modification. It can also be blended with petroleum diesel. In spite of its many advantages, the major drawbacks of biodiesel concern higher NO_X emissions, viscosity and density and lower calorific value (Jaat *et al*., 2014).

Many studies have proven that by appending higher alcohols to biodiesel much of the drawbacks are reduced (Karabektas *et al*., 2009; Murcak *et al*., 2013; Wang *et al*., 2015). Higher alcohols such as butanol, hexanol and pentanol are incorporated in biodiesel as an oxygenated additive (Rakopoulos *et al*., 2010). Blending, fumigation, emulsion and dual fuel injection are the existing techniques to append alcohols to fuel. Alcohols can be blended to liquid fuel in the range of 10%-30% by volume. Many

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studies have reported that the addition of alcohol to fuel improves the air and fuel mixing rate during combustion. It also reduces the kinematic viscosity of the fuel (Karabektas *et al*., 2009; Murcak *et al*., 2013; Wang *et al*., 2015). Rakopoulos *et al*. (2014) investigated the effect of butanol in diesel fuels. They found reductions in NO_X and smoke emissions when fuelled with butanol and diesel blends. This has been attributed to the increase in the oxygen content of the resultant fuel. Campos-Fernandez *et al*. (2015) examined the effect of appending pentanol to diesel in diesel engines. They reported that by appending pentanol, 2.1% and 3.5% reduction in HC and NO_X emissions were achieved respectively. Atmanli *et al*. (2016) examined the effect of blending pentanol to diesel by 10% and 20% on volume basis and found 7.8% reduction in NO_X emissions by appending 20% of pentanol to diesel. Additionally, smoke emissions dropped by 8%. Yuvarajan *et al*. (2017) investigated the effects of adding pentanol to cashew nut shell biodiesel in 1300 rpm diesel engine. They reported a significant reduction in all the emissions citing ample availability of oxygen as a cause. Dogan (2014) investigated the effect of adding butanol to diesel engine by 10% and 20% by volume. He found 4.4%, 5.4% and 2.9% reduction in NO_X, CO and HC emissions respectively. Li *et al*. (2015) employed pentanol as an additive to diesel and found significant reduction in NO_X and CO emissions at all loads. Gonca *et al*. (2016) examined the emission pattern of pentanol to diesel by means of pilot injection technique. They found a considerable reduction in NO_X and smoke emissions. Atmanli *et al*. (2014) investigated the effect of appending butanol with vegetable oil. They found 2.8% reduction in HC emissions and 1.7% reduction in CO emissions by appending 20% of butanol to biodiesel.

Based on the review of previous studies, it can be concluded that no study has been conducted on blending pentanol at various proportions to neat palm oil biodiesel to view its effects on emission pattern. In this study, pentanol is chosen as an oxygenated additive and is blended with palm oil biodiesel at 10% and 20% by volume. Pentanol has a better potential to blend with diesel and biodiesel. Compared to other alcohols, it has five straight chain carbons with higher energy density, cetane number and better stability when blended. It also requires lesser energy during production (Rajesh *et al*., 2015). In this study, the test fuels used are namely; neat palm oil biodiesel (POBD100), pentanol appended with palm oil biodiesel by 10% volume (POBD90P10), pentanol blended with palm oil biodiesel by 20% volume (POBD80P20) and diesel. They fueled steady state diesel engines. The emission characteristics for all the test fuels were investigated and compared to view the effects of pentanol as an oxygenated additive.

MATERIALS, METHODS AND REAGENTS

Palm Oil

Palm oil is a vegetable oil derived from the mesocarp of the fruit of the oil palms, primarily the African oil palm, *Elaeis guineensis* and to a lesser extent from the American oil palm *Elaeis oleifera* and the maripa palm *Attalea maripa*. Palm oil is naturally reddish in colour because of its high beta-carotene content (Harmiwati and Rahmad, 2015). It is not to be confused with palm kernel oil derived from the kernel of the same fruit, or coconut oil derived from the kernel of the coconut palm (Lam *et al*., 2011). The fatty acid composition of neat palm oil biodiesel is listed in *Table 1*.

TABLE 1. FATTY ACID COMPOSITIONS OF PALM OIL BIODIESEL

Fatty acids	POBD100 (% mass)
Palmitic C16:0	35.9
Stearic	6.1
Oleic	46.1
Linoleic C18:2	11.9
Linoleic C18:3	-

Pentanol

Pentanol ($C_5H_{11}OH$.) offers potential advantages when blended with diesel and biodiesel. It has five straight chain carbons with higher energy density, cetane number and better stability while blending compared to other alcohols. It also requires lesser energy during production (Rajesh *et al*., 2016). It is produced during fractional distillation of fossil fuels (Atmanli *et al*., 2016). Analytical grade pentanol is procured from local chemical suppliers (Thermo-Fisher chemicals). The physical and chemical properties of pentanol are listed in *Table 2*.

TABLE 2. PROPERTIES OF PENTANOL

Properties	Pentanol
Molecular formula	C_5H_{11}-OH
Viscosity at 40°C (mm s^{-2})	2.88
Flash point (°C)	49
Latent heat of evaporation (kJ kg^{-1})	308
C (%wt)	68.18
H (%wt)	13.64
O (%wt)	18.18

Conversion of Palm Oil to Palm Oil Biodiesel

The base catalysed transesterification process is carried out to convert the neat palm oil into palm oil biodiesel. A molar ratio of 6:1 (methanol to palm oil) and potassium hydroxide of 0.3% (wt/wt) is employed in the transesterification process. A sample containing 500 ml of palm oil is heated at atmospheric condition till the oil attains 60°C. A measured quantity of solution containing catalysts dispersed in methanol is then added and stirred at a constant stirring speed of 340 rpm for 45 min and kept untouched to allow the formation of two layers (palm oil biodiesel and glycerol). Palm oil biodiesel is then removed by a gravity separation technique.

Testing Facilities

A constant speed (1300 rpm), single-cylinder, four-stroke, air-cooled diesel engine is employed in this study. The technical specifications of the engine employed in this study are listed in *Table 3*. *Figure 1* shows the layout of the experimental set-up. Gas analyser (QROTECH type 402) is employed to compute the pollutants in the exhaust gas. Smoke concentration is computed by employing AVL 437 Smoke meter. The technical specifications of the gas analyser and smoke meter are listed in *Table 4*. Errors involved in the measurement of all the emissions are calculated by the procedure recommended by Moffat (1985). *Table 5* shows the properties of diesel, palm oil biodiesel and pentanol blends.

TABLE 3. TECHNICAL SPECIFICATION OF EXPERIMENTAL SET-UP

Make	Kirloskar
Stroke	4
Cylinder	Single
Rated power	4.2 kW
Rated speed	1300 rpm
Bore diameter (D)	87.5 mm
Stroke (L)	110 mm
Compression ratio	17.5:1
Injection timing	17°bTDC
Injection pressure	200 bar
Fuel pump plunger diameter	8 mm
Number of injector nozzle	4
Diameter of injector nozzle	0.32 mm
Cooling	Air cooled
Position	Vertical
Type	Eddy current dynamometer
Make	Benz systems
Dynamometer constant	2000
Supply voltage	240 ± 10% AC, 50 Hz, 1ϕ
Maximum excitation current	6 to 8 Amp

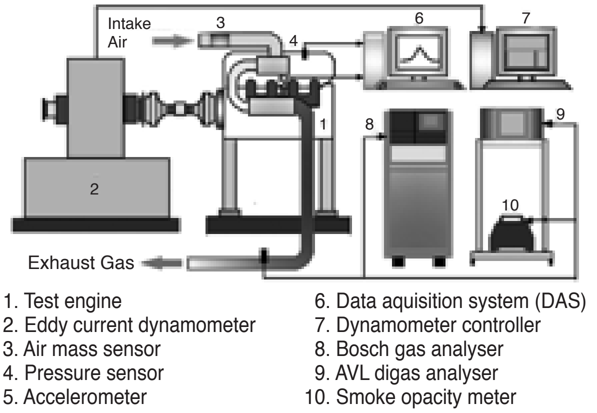

Figure 1. Layout of engine set-up.

TABLE 4. TECHNICAL SPECIFICATIONS OF GAS ANALYSER AND SMOKE METER

Model of gas analyser	QROTECH type 402	
Pollutant	Range	Accuracy
CO	0%-9.99 %	0.01%
HC	0-1 500 ppm	1%
NO_x	0-5 000 ppm	0.01%
Smoke meter (AVL 437 smoke meter)	0%-100%	± 1%

RESULTS AND DISCUSSION

Carbon Monoxide Emission (CO)

Variation in brake specific carbon monoxide emissions with load for POBD100, POBD90P10, POBD80P20 and diesel is shown in *Figure 2*. CO emissions from palm oil biodiesel are less than diesel at all loads. This is because of the abundant availability of oxygen in palm oil biodiesel and pentanol blends (Li *et al*., 2015). CO emission reduces significantly with increase in pentanol percentage. By appending 10% and 20% of pentanol (volume basis) to neat palm oil biodiesel, 8.1% and 9.3% of CO emissions is reduced. Pentanol release additional oxygen during combustion and enhance the rate of combustion Yuvarajan *et al*. (2017). Further, appending pentanol reduces the viscosity of neat palm oil biodiesel. The POBD100 with lesser viscosity assists improved evaporation of fuel with air in the cylinder and results in lower CO emissions. This result is in line with the experimental study

TABLE 5. PROPERTIES OF PALM OIL BIODIESEL AND ALCOHOL BLENDS

PROPERTIES	POBD100	POBD90P10	POBD80P20	Diesel	Method
Water content (%)	0.12	0.11	0.11	Nil	ASTM D2709
Density @ 15°C (g m^{-3})	0.855	0.841	0.836	0.8200	ASTM D4052
Kinematic viscosity @40°C (mm^2 s^{-1})	4.50	4.17	3.96	2.5	ASTM D445
Calorific value (kJ kg^{-1})	41 312	40 967	40 512	42 957	ASTM D240
Cetane index (CI)	60	61	62	47	ASTM D976
Flash point in (°C)	172	173	172	50	ASTM D93

conducted by Atmanli (2016a) and Yuvarajan and Masuswamy (2017). The CO emissions for POBD100, POBD90P10, POBD80P20 and Diesel are 3.518 g $kWhr^{-1}$, 2.083 g $kWhr^{-1}$, 1.801 g $kWhr^{-1}$ and 3.754 g $kWhr^{-1}$ respectively at 100% load conditions.

Hydrocarbons Emission (HC)

Variation in brake specific hydro carbon emissions with load for POBD100, POBD90P10, POBD80P20 and diesel is shown in *Figure 3*. HC emissions from palm oil biodiesel are less than diesel at all loads. This is because of the rich availability of oxygen during combustion and higher cetane number in palm oil biodiesel and pentanol blends when compared to diesel (Dogan, 2011). HC emission reduces with the increase in pentanol percentage. By appending 10% and 20% of pentanol (volume basis) to neat palm oil biodiesel, 2.4% and 3.8% of HC emissions are reduced. This is due to the combined effect of higher oxygen content and reduced viscosity of POBD100. Lower viscosity of POBD90P10 and POBD80P20 improves the atomisation of fuel and enhances the combustion rate (Atmanli *et al*., 2014). Further, the rapid vaporisation of pentanol during combustion reduces the ignition delay and increases the rate of mixing between fuel and air in the cylinder. This in turn increases the burning rate of fuel and lowers unburned HC emissions (Rajesh *et al*., 2015). This result is in line with the experimental work done by Atmanli (2016b) and Yuvarajan and Manuswamy (2017). HC emissions for POBD100, POBD90P10, POBD80P20 and diesel are 0.36 g $kWhr^{-1}$, 0.29 g $kWhr^{-1}$, 0.28 g $kWhr^{-1}$ and 0.39 g $kWhr^{-1}$ respectively at 100% load conditions.

Oxides of Nitrogen Emission (NO_x)

Variation in brake specific NO_X emissions with load for POBD100, POBD90P10, POBD80P20 and diesel is shown in *Figure 4*. It is observed that the NO_X emission from palm oil biodiesel is higher than diesel at all loads. Higher inbuilt oxygen in the palm oil biodiesel and pentanol blends promotes combustion and raises the temperature during combustion (Koc *et al*., 2013; Choi *et al*., 2015). NO_X emission reduces with increase in pentanol

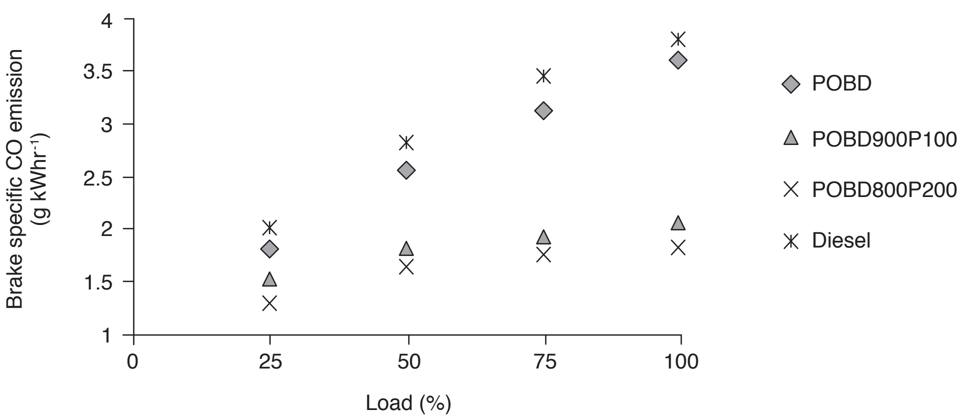

Figure 2. Variation of carbon monoxide (CO) with load.

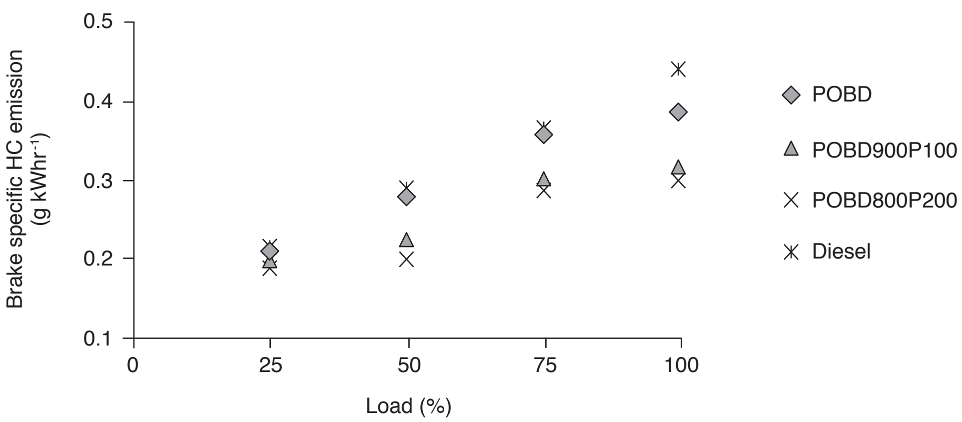

Figure 3. Variation of hydrocarbon emission (HC) with load.

percentage. By appending 10% and 20% of pentanol (volume basis) to neat palm oil biodiesel, 4.2% and 6.6% of NO_X emissions are reduced.

Appending pentanol to palm oil biodiesel reduces its calorific value which in turn reduces the cylinder combustion temperature (Rajesh and Saravanan, 2015). In addition, appending pentanol to palm oil biodiesel reduces its kinematic viscosity. Fuel with lower kinematic viscosity (POBD90P10 and POBD80P20) enhances the contact between air and fuel in the cylinder during combustion and aids the improved combustion and lower NO_X emissions. This result is in line with similar earlier work carried out by Atmanli (2016b) and Yuvarajan and Manuswamy (2017). The NO_X emissions for POBD100, POBD90P10, POBD80P20 and diesel are 11.9 g $kWhr^{-1}$, 11.6 g $kWhr^{-1}$, 11.4 g $kWhr^{-1}$ and 10.9 g $kWhr^{-1}$ respectively at 100% load conditions.

Smoke Concentration

Variation in smoke concentration with load for POBD100, POBD90P10, POBD80P20 and diesel is shown in *Figure 5*. Smoke concentration for palm oil biodiesel and pentanol blends is lesser than diesel. This is as a result of inherent oxygen content present in palm oil biodiesel (Gonca *et al*., 2016; Venkata Ramanan and Yuvarajan, 2015). Smoke concentration reduces with increase in pentanol percentage. By appending 10% and 20% of pentanol on volume basis to neat palm oil biodiesel, 1.9% and 2.7% of smoke concentration is reduced. Higher oxygen content in pentanol and palm oil biodiesel improves the rate of combustion. In addition, oxygen atoms in palm oil biodiesel and pentanol get bonded to hydroxyl group and reduce smoke concentration (Rajesh and Savaranan, 2015). Smoke emissions for POBD100, POBD90P10, POBD80P20 and diesel are 1.1, 0.9, 0.7 and 1.3 BSU respectively at 100% load conditions. The result is in line with the similar work by Choi and Jiang (2015) and Yuvarajan and Manuswamy (2017).

CONCLUSION

An experimental investigation is performed to evaluate the emissions characteristics of palm oil biodiesel and pentanol blends in 1300 rpm constant speed diesel engine. Emissions such as CO, HC,

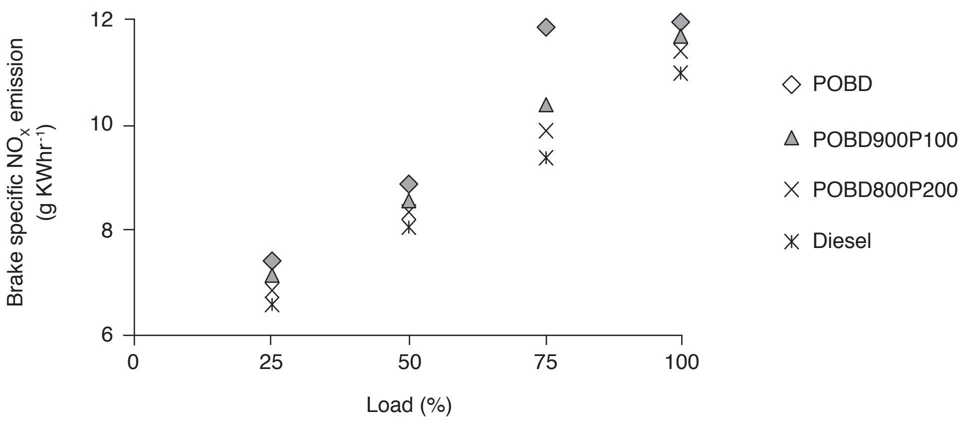

Figure 4.Variation of nitrogen emissions (NO_X) with load.

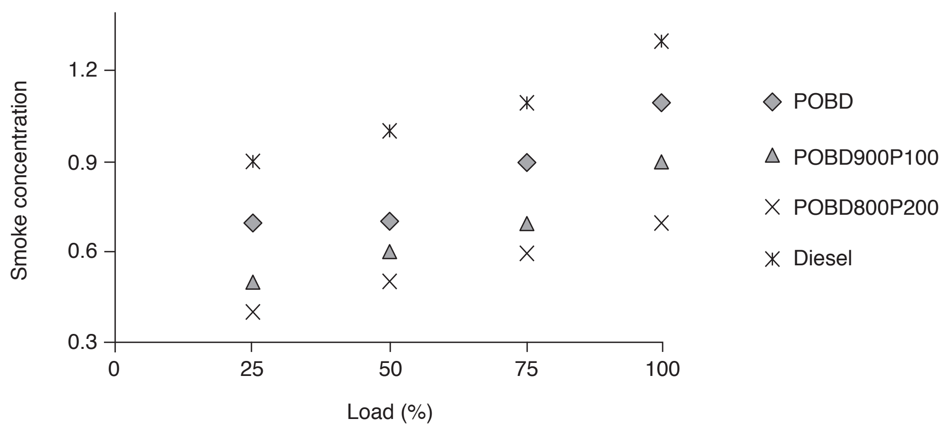

Figure 5.Variation of smoke with load.

NO_X, and smoke concentration are measured for each test fuel. The following are the major findings from this study:

- palm oil biodiesel can be used as a fuel without any major modification in diesel engine;
- no surfactants were employed for blending of palm oil biodiesel with higher alcohols;
- overall CO emissions for palm oil biodiesel are reduced by 8.1% and 9.3% by blending it with 100 and 200 ml of pentanol;
- HC emissions palm oil biodiesel are reduced by 2.4% and 3.8% by blending it with 100 and 200 ml of pentanol;
- appending 100 and 200 ml of pentanol to palm oil biodiesel reduced overall NO_X emissions by 4.2% and 6.6% at all loads; and
- blending 100 and 200 ml of pentanol to palm oil biodiesel reduced overall smoke concentration by 1.9% and 2.7% at all loads.

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