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Engine Performance And Smoke Emission Tests Of Transesterified *Swietenia macrophylla King* (Philippine Broad-Leaved Mahogany) Seed Oil

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Biodiesel is the most common alternative fuel that can be used in diesel engines. Commercially 2% of coco methyl ester (CME) as biodiesel is blended with petroleum based diesel and is used as fuel. Exhaust emissions are improved using the biodiesel blends. This study is devoted to the engine performance test of diesel engine as affected by Mahogany Methyl Ester (MhME). The MhME was produced by extracting the oil of the mahogany seeds by solvent extraction using petroleum ether. Sulfuric acid catalyzed esterification and potassium hydroxide- catalyzed transesterification were used for the MhME production. The fuel properties of the B5 and B50 biodiesel blends were determined. The kinematic viscosities of B5 and B50 were reported as 3.21, and 3.63 mm^2/sec, respectively. The engine performance test was done on a Gunt Hamburg CT 110 Four-Stroke Diesel Engine. Results showed that B5 MhME obtained the highest power and highest torque at full fuel load. For the fuel consumption, pure commercial diesel was observed to have the lowest at 2500 and at 2750 rpm. In addition, B50 MhME emits less CO_2, CO, hydrocarbon and O_2.

Keywords : hybrid coal, co–pyrolysis, low rank coal, biomass waste

INTRODUCTION

Fossil fuels like petroleum are nonrenewable resources. The increase in demand of this limited and dwindling natural resource is not enough to meet the world's demand. These crises have motivated researchers to explore and investigate the performance of alternative fuels such as biodiesel in internal combustion engines. Biodiesel is considered a renewable and ecofriendly source of energy making it one of the best options among other renewable fuel sources. It has the capability to reduce exhaust emission and toxicity. It is biodegradable as it is derived from a renewable and domestic feedstock. It has negligible sulfur content, has superior flash point and has higher combustion efficiency [1].

Carbon dioxide, the chief by-product of

fossil fuel combustion, is a strong greenhouse gas that remains in the atmosphere indefinitely. When fossil fuels are burned through the process of combustion, they release their carbon as heat and their impurities as emissions. These brought health risks like respiratory infections, cardiovascular diseases and lung cancer and poses environmental risks like eutrophication, haze and acid rain. To cut down on carbon dioxide emissions, most companies and the government are seriously pursuing potential viabilities of alternative energy sources.

METHODOLOGY

Materials

The mahogany seeds were ordered from Marsse Tropical Timbers and Plantations Inc. in Los Banos, Laguna. The seeds were then authenticated by University of Santo Tomas Research Center for the Natural and Applied Sciences (UST RCNAS) and the other chemicals used were petroleum ether, potassium hydroxide (KOH), sulfuric acid (H2SO4), methanol (MetOH), and anhydrous sodium sulfate (Na_2SO_4) were provided by the UST RCNAS.

Methods

Oil Extraction

The seeds were sun dried until all of the free moisture content was removed. The drying process continued until three consecutive constant weight readings were obtained. The size of the seeds was reduced using an Osterizer and was immersed in 1:1.5 seed to petroleum ether volume ratio and was mixed for 15 minutes in a span of 3 days. Vacuum filtration was used to separate the solids from the liquid and a rotary evaporator was used to separate crude oil from spent petroleum ether.

Biodiesel Conversion

The Mahogany Crude Oil was esterified using H_2SO_4 with methyl hydroxide as catalyst. The reaction time was 1 hour, continuously stirring the oil at 300 rpm. As the temperature of the oil reached 70°C, the 0.8M sulfuric acid – methyl hydroxide solution was introduced at aan acid to methanol ratio of 8:1. Maintaining the temperature at 70°C after 30 mins., 10% excess methanol was added. Gravity settling was carried out on the esterified Mahogany oil for at least 24 hours. The less dense liquid was collected and was subjected to alkali-based transesterification.

KOH pellets in methanol solution (0.6M) was used as a catalyst during transesterification. This catalyst was introduced to the oil in a ratio of 6:1 and then proceeded similarly with the same reaction temperature and agitation speed that were employed during esterification. The transesterified oil was again subjected to gravity settling for at least 24 hours for complete layering of components. The lower portion was removed and the Mahogany Methyl Ester (MnME) was collected and washed with distilled water that was initially heated to 50°C. The mixture was stirred vigorously for 3 minutes using a separatory funnel, and allowed to settle until visible separation occurred. This procedure was repeated until the water in the lower layer was clear and showed no signs of turbidity. Thereafter, the washed MhME was purified using a filter paper with a pinch of Na_2SO_4. The purified Mahogany methyl ester was subjected to a flame test to pre-validate its ignition characteristic as a biodiesel.

Characterization of MhME Blends

Since MhME in its pure form (B100) has been previously characterized, the properties of B5 and B50 MhME in terms of Acid Number, Carbon Residue, Cloud Point, Copper Strip Corrosion, Distillation, Flash Point, Kinematic Viscosity, Total Glycerin and % Water were determined at the Department of Energy in Bonifacio Global City, Taguig, Philippines. The obtained results were then compared with the standards set by the Philippine National Standards in preparation for engine performance tests.

Engine Performance Test of B5 and B50 MhME

The Gunt Hamburg CT 110 with Hatz 1B30 Four-Stroke Diesel Engine was used for the Engine Performance Test. The speed regulator was adjusted to 50% and the torque regulator was adjusted to 100%, in order for the engine to start easily. The power, torque and fuel consumption using the B5 and B50 as fuel had been tested. The speed at which the torque became zero was used as the baseline for the experiments and using an interval of 100 while lowering the speed until it reaches 1500 rpm. The procedure was done on 100% throttle load. The same procedures were followed for 75% load and 50% load.

For the fuel consumption test, the speed knob was set to 50% while torque knob was set to 100%. Torque was continuously increased by 5% in each reading. To maintain the speed at 2500rpm, the speed regulator was adjusted again since addition in torque will decrease the speed. In every adjustment in the speed regulator, fuel consumption against power was recorded and plotted in the curve through the LabView Application Software.

Smoke Emission Test

The Infralyt Smart Exhaust Gas Analyzer was used for the smoke emission test of each sample. The exhaust gases that were measured were Carbon Monoxide, Carbon Dioxide, Hydrocarbons and Oxygen. For every data recorded in each interval for the power and torque tests and for the fuel consumption test, the smoke measurements were measured at the same time.

RESULTS AND DISCUSSION

Oil and Mahogany Methyl Ester Yields

The average yield of the extracted oil in petroleum ether was 48.9%, a significant increase compared with the 38.5% yield obtained by Caguimbal, *et al.* [2]. The density obtained was 0.881a $g{\cdot}cm^{-3}$.The average yield obtained for MhME from the extracted Mahogany oil was 65.1%.

Fuel Characterization of the Mahogany Methyl Ester Blends

The fuel characterization of the blended Mahogany Methyl Ester, as determined at the Energy Research and Testing Laboratory of the Philippine Department

Table 1. Properties of MhME-Diesel Blends compared with CME and PNS

Test	Method [ASTM]	B5	B50	B100 [6]	PNS/ CME
Acid Number, mg KOH/g	ASTM D 664	0.05	0.09	0.88	
Carbon Residue on 10%	ASTM D 4530	0.022	0.41	0.04	0.15, max.
Cloud Point	ASTM D 2500	5	11	15	
Copper Strip Corrosion, 3 hrs at 50°C	ASTM D 130	1a	1a	1a	1a
Distillation AET @ 90% Recovered, °C	ASTM D 86	344	344	ND	370, max.
Flash Point (PM), °C	ASTM D 93	90	82	132	55, min.
Kinematic Viscosity at 40°C, $mm^2 \cdot s^{-}$	ASTM D 445	3.21	3.63	4.4	2.0 – 4.5
Total Glycerin, %mass	Aocs Ca 14-56	ND*	0.08	0.15	
Water, % Vol	ASTM E 203	0.03	0.08	0.13	0.10, max.

of Energy, were compared with the B100 results obtained by Caguimbal, *et al.* [2] and the PNS based on the Coconut Methyl Ester (CME). Refer to **Table 1**.

The acid numbers of both blends were acceptable as a higher number of acid number may cause corrosion, poor cold flow properties, fuel system deposits or filter plugging and may be an indication of the presence of water [3].

The carbon residue on 10% distillation for B5 and B50 are lower than the maximum standard value of 0.15%, indicating minimal tendency of both biodiesel to produce on injector tips and inside the combustion chamber when used as automotive fuel [4].

A cloud or haze of crystals appeared at 5°C in MhME B5 and 11°C in MhME B50, ensuring trouble free operation of engines in cold climates as its impact on cold flow properties must be monitored [4].

The distillation temperature at 90% recovered for B5 and B50 were favourably lower than the set maximum PNS value. On the other hand, the MhME blends has less tendency of being flammable as the flash points were higher indicating their good storage properties.

The kinematic viscosities of the two blends were within the acceptable range set by the PNS. This then indicates that both blends assure power efficiency due to a possible effective fuel injection and minimal injector leakage [5]. Based on the low water% in the blends, contaminants in fuel is low; thus, requiring lesser maintenance.

Engine Performance Tests Analyses

The power of the engine is relatively high at higher engine loads. However, at partial loads, the overall mixture deviated from the exhibited full load trend.

The maximum power of 4.206 kW manifested in B5 at full load at an engine speed of 2700 to 3000 rpm shown in **Fig. 1 (a)**. The minimum power which was regulated at 1.5 kW occurred in the 50% engine load for B5 at 500 rpm shown in **Fig. 1 (c)**. At full load and 75% load **Fig. 1 (b)**, B5 manifested the highest power with

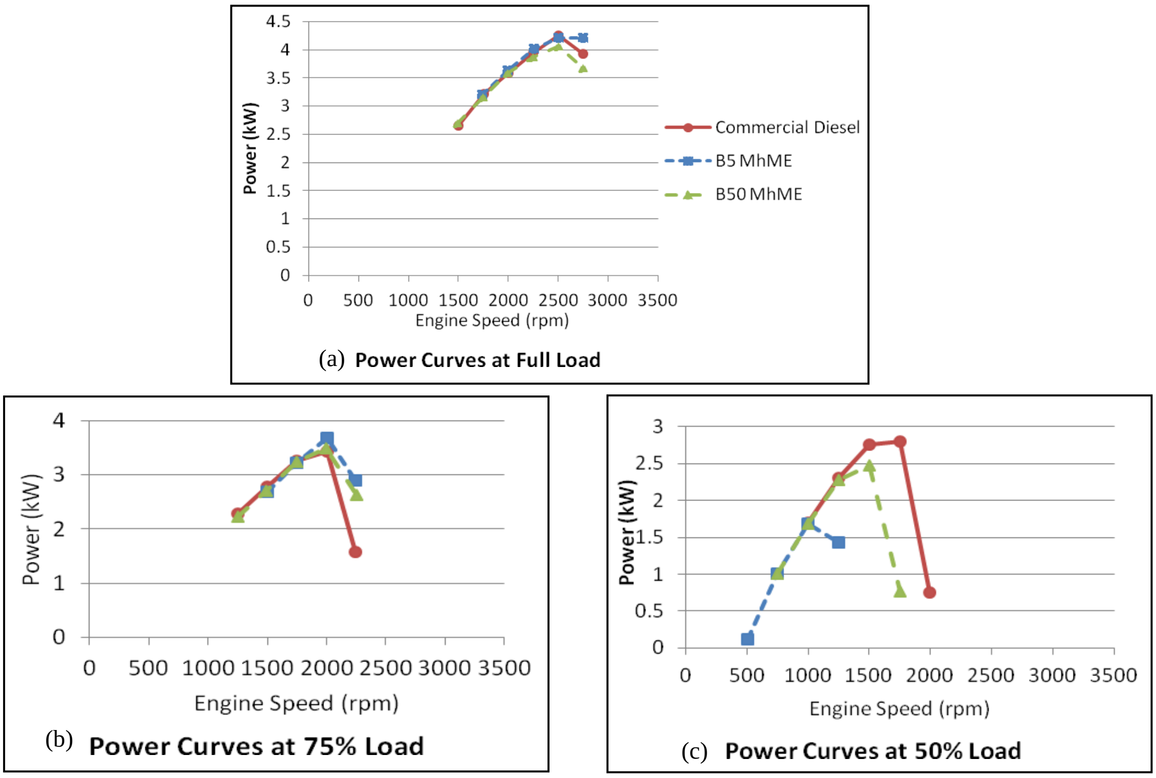

Fig. 1: Engine speed on power at (a) 100%, (b) 75%, and (c) 50% engine loads.

an engine speed of 2400 to 2800 rpm for full load and 2000-2300 rpm for 75% load. In terms of loading, the engine speeds of the three fuel concentrations have constant engine speeds at full load and 75% loading. However, once the maximum power at different loads had been reached, a common decrease in engine speed follows as shown in **Fig. 1**.

At full load, the torques of the commercial diesel and B5 at 2500 rpm exhibited convergence with negligible deviation with the pure diesel demonstrating the averaged value of B5 and B50. The maximum torque among the different loads and different blends was manifested at about 17.8 Nm. This was registered on B5 at full load with an engine speed of 1700 to 1900 rpm. At 75% load, B50 and pure diesel displayed convergence, as well at 2000 rpm (**Fig. 2**). At 50% load, the torques of pure diesel and B50 were the same (17.5 Nm), corresponding with their respective decrease in speed. These results infer that the 75% loading provided better torque on pure diesel and B50 at 2000 rpm.

It is interesting to note that the different MhME concentrations manifested the expected behaviour, matching the commercial diesel at the speed of 2500 rpm, starting at 1.5 to 4.0 kW

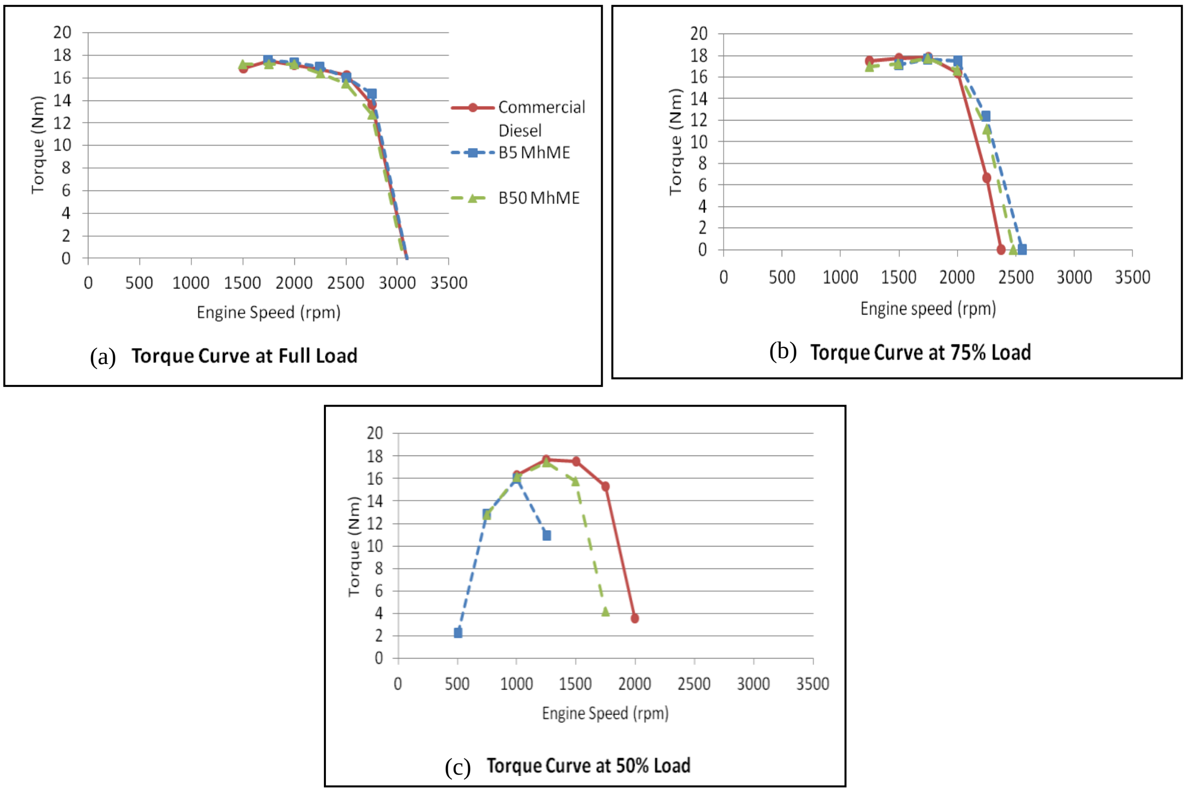

Fig. 2: Engine speed on power at (a) 100%, (b) 75%, and (c) 50% engine loads

corresponding to a specific consumption of about 250 to 300 g·kWh^{-1}. The mechanical power increased as the specific fuel consumption decreased as presented in **Fig. 3**.

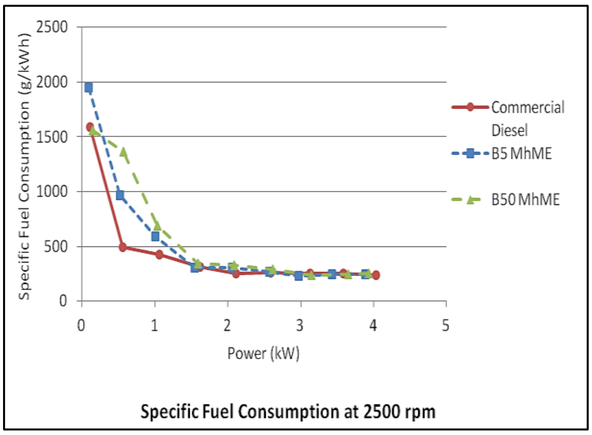

Fig. 3: Power vs. specific fuel consumption at 2500 rpm

At 2750 rpm, a similar behaviour was observed where the diesel blends demonstrated congruency with the commercial diesel as seen in **Fig. 4**. Commercial diesel obtained the lowest fuel consumption at 2500 and 2750 rpm.

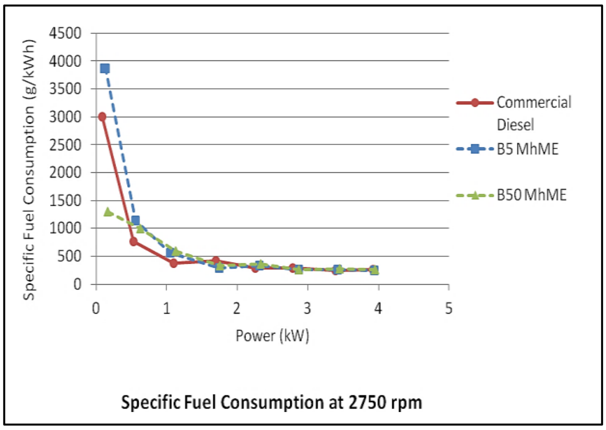

Fig. 4: Power vs. specific fuel consumption at 2750 rpm

For the 100% loading, commercial diesel registered speeds of 1500 to 2500 rpm with increasing efficiency. Similarly, B50 also exhibited an increase in speed with increasing efficiency. With an increase in MhME concentration, it

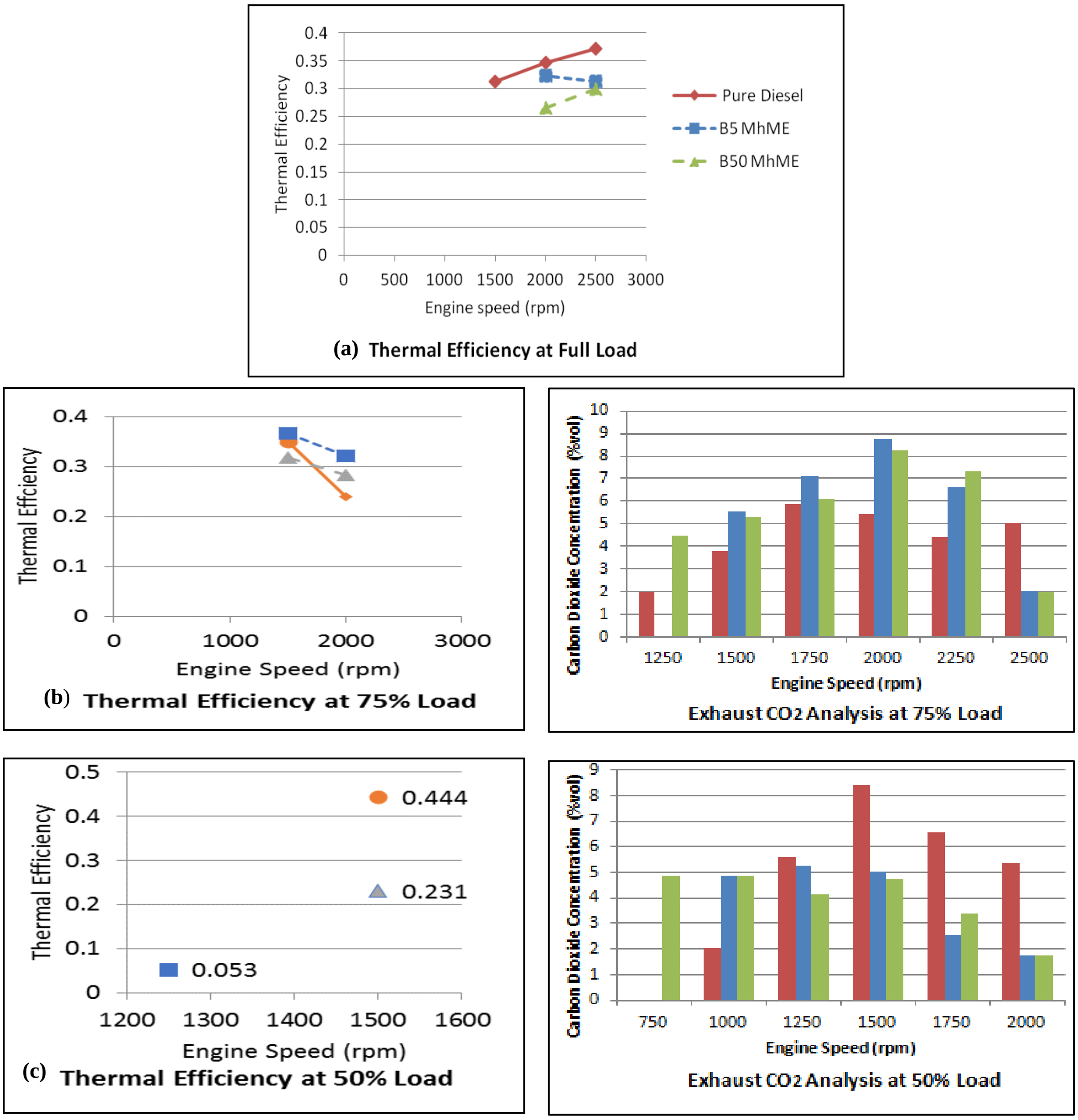

Fig. 5: Thermal efficiency vs. engine speed at (a) full, (b) 75%, and (c) 50% engine loads

followed that an increase in efficiency corresponded to the decrease in engine speeds. The highest efficiency was taken at 0.444 at 1500 rpm for commercial diesel. Refer to **Fig. 5.** This behaviour may be due to the partial introduction of fuel to power the engine, coupling with the probable effect of engine speed to the engine efficiency. Pure commercial diesel provided the highest efficiency at a speed of 1500 rpm and 50% loading.

Emission Tests

At a high rotational speed, the carbon dioxide emitted by the engine using commercial diesel and the two MhME blends increased up to 2500 rpm. Consequently after the 2500 rpm was reached, all the three samples were observed to be decreasing in carbon

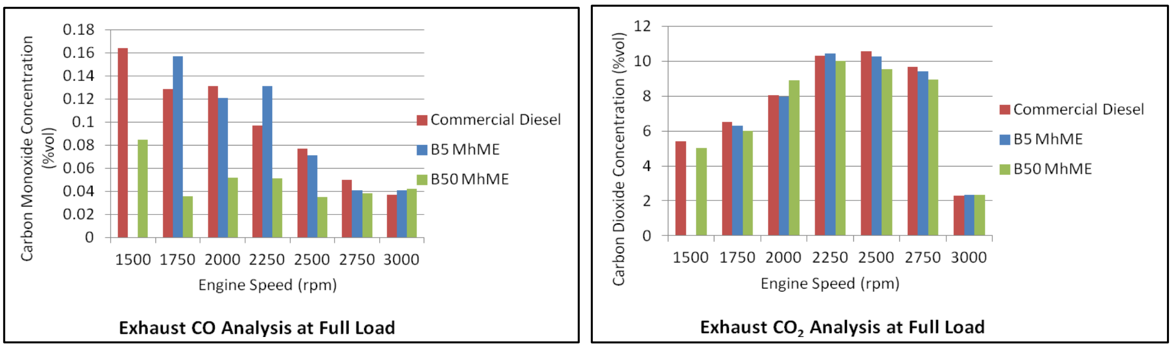

Fig. 6: Engine speed on carbon dioxide concentration at full, 75 %, and 50% engine load

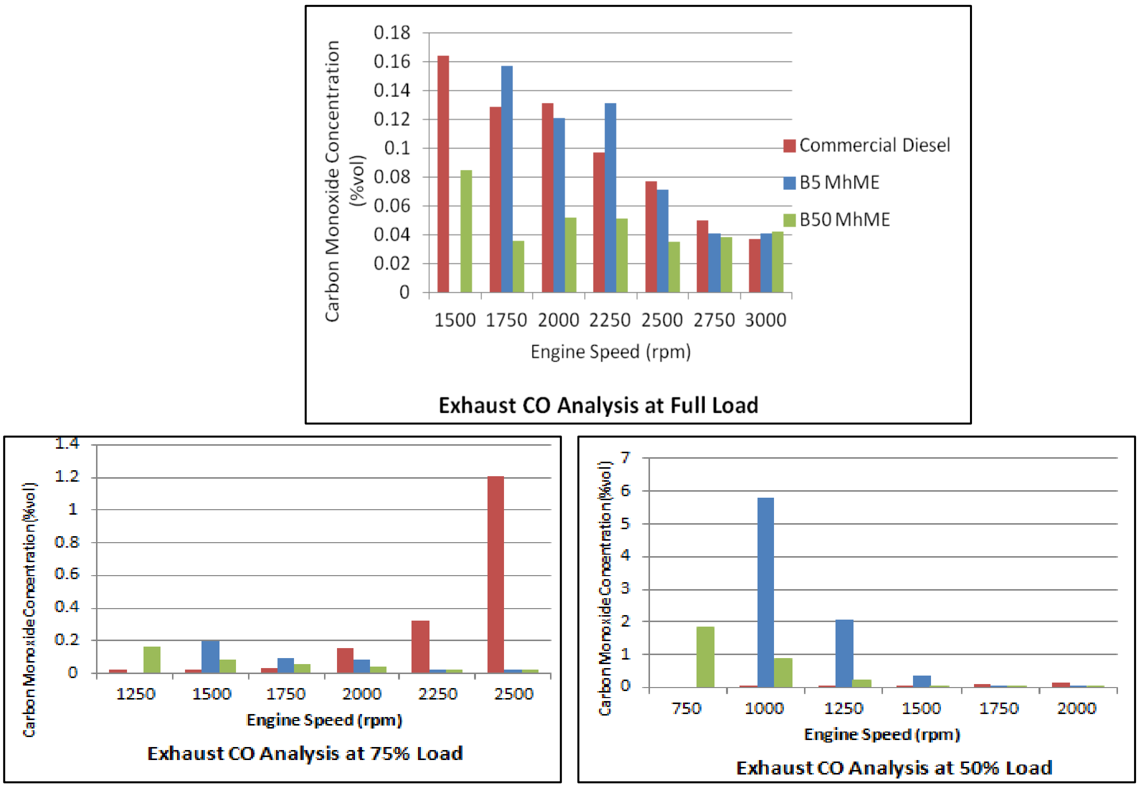

Fig. 7: Carbon monoxide emission at full, 75% and 50% engine loads at different engine speeds

dioxide emission. However, both **B5 a**nd B50 gave the highest carbon dioxide concentrations at about 2000 rpm with 75% load. Refer to **Fig. 6 (b)**. At lower loads, B5 can produce more carbon dioxide compared with pure commercial diesel. At 50% load presented in Fig. 6 (c), pure diesel gave off the most amount of carbon dioxide at 1500 rpm. B50 and B5 has the lowest CO_2 emission of 1.08% at 2000 rpm.

At full load, CO emission with pure diesel decreased as the rotational speed increased (Refer to **Fig. 7.** The minimum amount of CO emission was obtained with B50 at 0.038% at 1750 rpm. CO emission at 75% load in pure commercial diesel increased with increasing rotational speed.

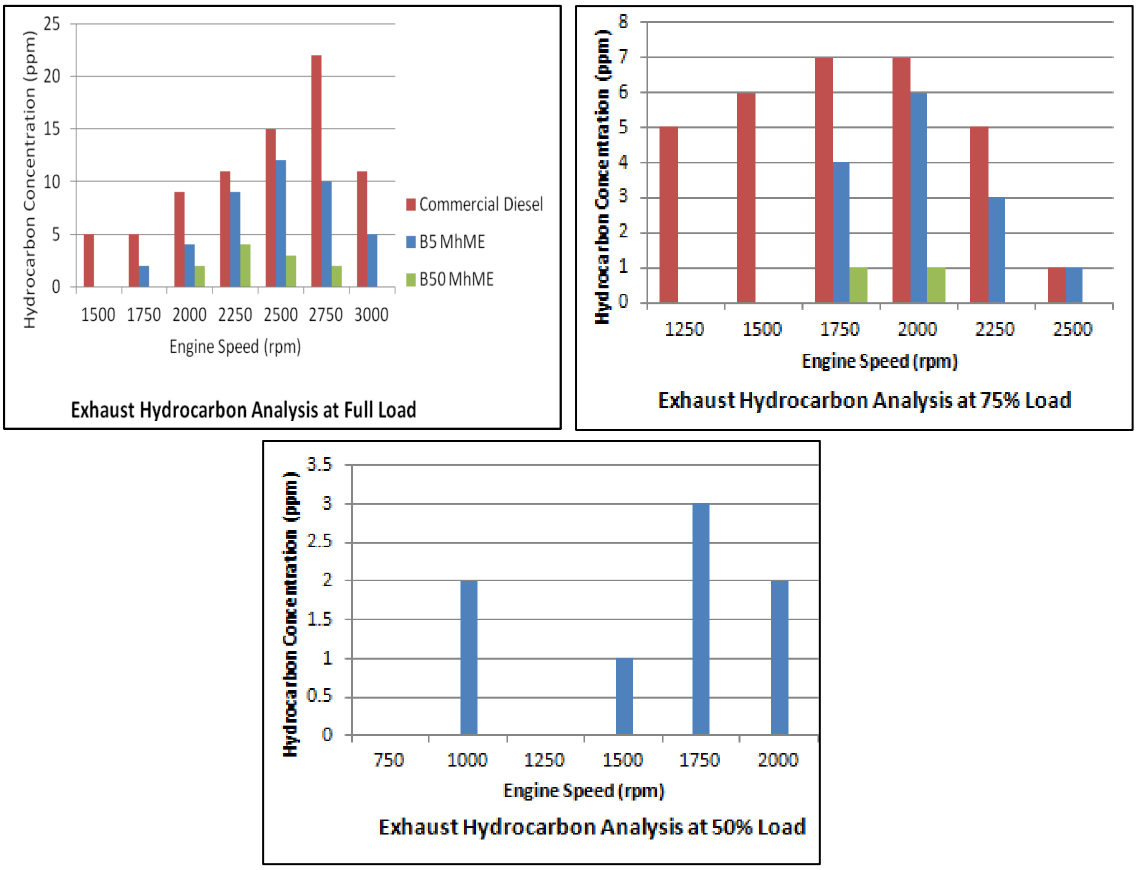

Fig. 8: Hydrocarbon emissions at full, 75%, and 50% engine loads at varying engine speeds

B50 produced a lower amount of CO at different speeds compared to B5 and pure commercial diesel. As shown in the figures, MhME and its blends emit the least CO.

Pure commercial diesel gave off the highest amount of hydrocarbon emission at full load and B50 gave the least as shown in **Fig. 8**. At full load, not all of the hydrocarbons present in the pure commercial diesel had been fully combusted. B5 gave values close to pure diesel and B50 due to dilution. Pure diesel still gave off the highest amounts of hydrocarbons even at a lower load and continued to increase with decrease in rotational speed. This B5 still manifested few amounts of HCs but B50 showed real low amounts from 0-1 ppm. Both pure diesel and B50 showed the absence of hydrocarbons in their exhaust gases at 50% load.

The oxygen concentration from all samples gave the same trend at full load. As the rotational speed increased up to 2500 rpm, the oxygen concentration started to decrease and regained again until 3000 rpm. B5 emitted the lowest oxygen concentration. As shown in all figures in **Fig. 9**, commercial diesel exhibited the highest concentration of oxygen emission.

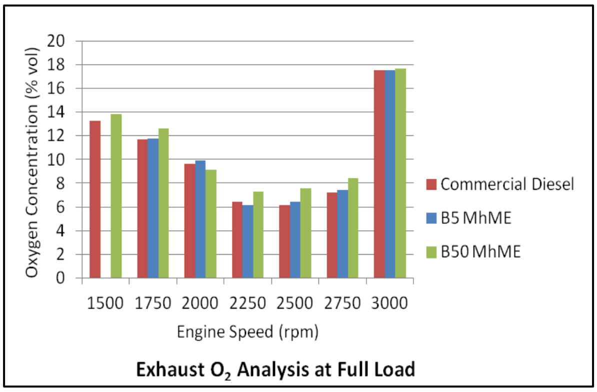

Fig. 9: Exhaust oxygen at full engine load at varying engine speeds

CONCLUSIONS AND RECOMMENDATIONS

The extracted Mahogany oil was extracted from the Philippine Mahogany seeds. The biodiesel conversion yielded an average of 65.1% which was lower than the previously determined MhME by the same research teamCaguimbal}, However the flaming property of the MhME pre-validated the biodiesel properties of the product. The prospectivity of MhME as an alternative biodiesel was validated by the results determined at the Department of Energy. The fuel properties that were analyzed complied with the required characteristics set by the Philippine National Standards based on the Coconut Methyl Ester which is now being used in the Philippines. The potential of MhME was further substantiated by the results obtained from the engine performance tests that were conducted using the MhME blends of B5 and B50 with the pure commercial diesel used as the standard. Of the two blends, B5 exhibited the higher power and torque at full load with 4.26kW and 17.5Nm, respectively. However, at 2500 and 2750 rpm, pure commercial diesel showed the least fuel consumption. Expectedly, the thermal efficiency increased at increasing engine speed due to improved fuel-air mixing. The brake power increased with increasing engine speed up until 2740 rpm and then started to decrease due to its effect of higher mechanical losses and lowered the engine volumetric efficiency. This was because of its maximum air limit that was drawn into the cylinder. The air-fuel ratio requirements were responsible to the shape of the torque curve. With the exhaust gas analyses, the addition of MhME conformed with the environmental thrust of decreasing the emission of unwanted air pollutants. There were significant decreases in CO_2, CO and hydrocarbon emissions.

REFERENCES

1. O.S. Stmenkovic, I.B. Bankovic-llic, V.B. Veljkovic, Renew. Sust. Egy. Revs, 3621-2467 (2012)
2. K.V. Caguimbal, D.M. Lastimoso, C. Navarette, M.N.R. Dimaano, *RSCE 2015 Proceedings*, IN-ENG-033 (2015)
3. J. MacFarlene, JM Science (2008)
4. T.E. Grift, A.C. Hansen, J. Xue, Renew. Sust. Egy. Revs, **15,** 2, 1098-1116 (2011)
5. Y. Bian, H. Chen, L. Geng, J. Liu, D.H. Qi, Ren. Egy., **34**, 12, 2706-2713 (2009).