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Emissions From Refined Coconut Oil Ethyl Ester-Diesel Blends – a Preliminary Study

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Abstract – The study describes the production of ethyl ester biodiesel from refined coconut oil. It aimed to replace the toxic methanol by a renewable and relatively safe ethanol and to determine whether the product properties conform to Philippine National Standard (PNS) specifications for B100 fatty acid methyl ester biodiesel. Emission characteristics of the biodiesel were also studied using a single-cylinder engine generator set fueled with neat diesel, B1, B2, and B5 biodiesel blends, at 61%, 77%, and 93% electrical loads, which are low, medium, and high load respectively. Successful conversion via base-catalyzed transesterification was carried at process conditions of 1% (weight to oil) KOH catalyst, 59% excess ethanol, 1.5 hours reaction time and ambient temperature at mixer setting of about 4500 rpm with a yield of 93.64% ester. Several properties of the produced coconut ethyl ester conformed to PNS specifications with the exception of cetane index, acid value, water content, and total glycerine content. The calculated cetane index was 46.327 which is close to US and Brazil standards for cetane number. Emission tests revealed that the B1 blend had the optimal emission characteristics with most of the parameters while B2 blend had the most significant decrease in CO emission. B1 reduced CO2 emission by 8%, NOx at 7% and THC by 2.5% at high load when compared to base petro diesel. B2 blend reduced CO emission significantly by 46% at low load and 22% at medium load when compared to base petro diesel. The remaining B2 and B5 blends had an average increase of about 10% and 16% NOx emissions respectively, a typical characteristic for most biodiesels.

Keywords—biodiesel, ethanol, ethyl ester, coconut oil, biodiesel emissions

I. INTRODUCTION

Climate change and greenhouse effect in recent years have become global issues that spurred nations to develop eco-friendly solutions. Many attributed these global problems to the world's increasing demand for energy by using fossil fuels. The problems caused by ups and downs of oil supply in previous decades have shown even more the instability of fossil fuels and a proof that global crude oil reserve is finite and will be depleted in a much faster rate if demands continue to soar. With these concerns, the world now has regained interest in renewable and alternative fuels such as biodiesel. Many countries have now adapted this biofuel technology to actively participate in the alleviation of climate change problems and promotion of sustainable energy. Today, materials for biodiesel production are sourced domestically to improve its renewability and availability.

Biodiesel is made conventionally through transesterification of oils and fats from plant and animal sources where triglycerides are converted to mono alkyl esters. Although there are other methods for producing biodiesel such as emulsion, enzymatic techniques, microwave irradiation and recently thru ozonation, the widely used production process for most countries is still thru transesterification of refined oil by methanolysis or breakdown of triglycerides using methanol [2, 5, 24]. Biodiesel is used as an additive for diesel engine mainly to improve emission characteristics and lessen the use of petro diesel. Increasing the amount of biodiesel as an additive to petro diesel will give greater reduction in air pollutants such as CO2, particulate matter, carbon monoxide, hydrocarbons, sulfur oxides and other toxic and greenhouse gases with the exception of nitrogen oxides [7].

This study was inspired by the goal in attaining a true zero CO2 net emission for diesel-powered engines. The commercial Philippine biodiesel or CME is made from transesterification of refined coconut oil using methanol. Most of biodiesel-producing countries today with the exception of Brazil use methanol, a toxic and fossil fuel-derived alcohol, for converting triglycerides of oil and fat feedstocks to methyl ester biodiesel. Methanol is currently produced inexpensively from petroleum sources including coal and natural gas, but with rapidly increasing oil prices, methanol costs are expected to increase [12]. Replacement of methanol by biomass-derived ethanol could further reduce greenhouse gas emissions from fossil fuel products. Production of ethanol from non-food biomass resources specifically from lignocellulosic materials could also help in the reduction of abandoned or unused biomass in any country. As the world today seeks actively in eliminating causes of climate change, biodiesel production from totally renewable materials can be a significant step in attaining that goal. The eventual use of pure biodiesel without engine modification not only reduces greenhouse gas emissions but will also alleviate dependence from fossil fuels.

Studies have been made to replace methanol using safe and renewable alcohol alternative in the form of ethanol [4, 12, 15, 16, 29, 31, 32]. However, Philippines which exports about 80% of its copra production and one of the largest producer of coconut oil in the world has yet to conduct detailed research on coconut ethyl ester biodiesel [8, 21]. The current major drawback from using ethanol as replacement for methanol is its expensive cost. Feedstock costs account for a large percent of the direct biodiesel production costs, including capital cost and return [3]. But with government support and an effective program for production of biomass derived ethanol, cost can become even cheaper than methanol in the future. Furthermore, vegetable oils as well as use of food crops wastes as biofuel feedstocks hold great potential for stimulating rural economic development because farmers would benefit from the increased demand for these materials [1].

This study dealt with the production of biodiesel from refined coconut oil by ethanolysis and determined the emission characteristics at different biodiesel blends using a 3.3 kW single cylinder diesel engine electric generator. Conversion process was performed under ambient temperature and pressure conditions to eliminate additional operation cost made by heating the feedstock materials as done by industries and other studies. The feasibility of producing coconut ethyl ester biodiesel within the acceptable properties as specified by local and international standards for fatty acid methyl ester was also assessed.

II. MATERIALS AND METHODS

2.1 Properties of Refined Coconut Oil

Oil feedstock used in the production of ethyl esters was from the popular local brand Minola cooking oil. The coconut oil feedstock was bleached, deodorized and contained less than 1.0% by weight saturated and unsaturated free fatty acids. Properties of the coconut oil feedstock are shown in Table 1.

Table 1 Properties of Refined, Bleached, and Deodorized Coconut Oil

% Free Fatty Acid (as oleic acid)	0.015 – 0.35
% Free Fatty Acid (as lauric acid)	0.03 (max)
Color (5 – 1/4" Lovibond cell)	1.5 red (max.); 6.0 yellow (max.)
Specific Gravity at 25 °C	0.917 – 0.923
Peroxide Value	0.5 (max)
Iodine Value	7.5 – 10.5
Saponification Value	250 – 264
Moisture and Volatile Matters	Nil
Titer	20 – 25 °C
Shelf life	1 year if hermetically sealed

Source: http://www.ciif.ph

2.2 Laboratory Scale Base-Catalyzed Transesterification Using Ethanol

Previous trial experiments determined the process conditions enough to provide significant yield of ethyl esters at ambient conditions of temperature and pressure. Ethanolysis can be performed under ambient condition which was validated by previous studies made on different vegetable oils [4, 12, 22, 32]. In this study, the choice of catalyst and its amount including that of the percentage excess of ethanol were influenced by the experiments conducted by Petersen [22]. However, the oil feedstocks used by Petersen was highly unsaturated as opposed to coconut oil which consists mostly of saturated fatty acids. It was also necessary to use absolute ethanol or at least 99.5% by volume purity of ethanol in the conversion process to minimize reverse reaction and other troublesome effects caused by the presence of water or moisture during the reaction. Production of coconut ethyl ester biodiesel was performed at the Chemical Engineering Laboratory, University of the Philippines – Diliman.

Table 2 shows the conditions applied in the conversion process for producing coconut ethyl ester biodiesel in 500mL batches after trial experiments were performed. Base catalyst used was KOH at 1% by weight to oil which was dissolved in about 59% excess ethanol by volume (200mL) to oil or only about 3.435:1.0 ethanol to oil molar ratio. This was a significant decrease from the ethanol quantity used by previous studies and very close to the theoretical molar ratio of 3:1 alcohol to oil. The prepared potassium ethoxide solution was mixed with the refined coconut oil in a glass beaker so that ambient conditions were observed. Another significant change made was the use of high shear Silverson mixer operating at about 4500 rpm. The suggested mixing speed ranges from 600 to 1200 rpm only [4, 12, 16, 24]. Mixing duration was 1.5 hours before the conversion process was stopped. Successful conversion will give 2 layers of product after several minutes of settling but preferably overnight. The biodiesel will separate as the top layer while glycerin settles at the bottom. Separation of biodiesel from glycerin was made prior to washing.

Table 2 Properties of Refined, Bleached, and Deodorized Coconut Oil

Amt. KOH Catalyst	Temperature	Vol. Ethanol (199 Proof)	Mixing Speed	Reaction Time
1%	Room (27 – 32 °C)	200 mL (59% excess)	4300 to 4500 rpm	1.5 hours

Washing was performed using distilled water in order to remove excess catalyst and unreacted oils. Water was chosen as the washing fluid instead of dilute acid because it is readily available, no preparation has to be made and use of acids might contaminate groundwater. The volume used was half the volume of the biodiesel produced. Washing was performed several times until pH falls around 7 to 8. Each washing forms 2 layers of liquid where the biodiesel sits on top and water and other impurities settle at the bottom. Milky or cloudy wash water forms during initial washings but will clarify on succeeding washes as impurities were removed. Gentle washing was very necessary to prevent soap formation and consequent losses in the biodiesel product. The washed ethyl ester was heated at 105°C to 110°C for about 30 minutes to remove excess water. The final biodiesel product was then analyzed for relevant properties prior to emission testing.

2.3 Chemical and Physical Analysis of Coconut Ethyl Ester

Some relevant properties of the coconut ethyl ester biodiesel were analyzed in private and government laboratories. Since raw materials used were either refined or analytical grade plus the fact that the biodiesel product has slight difference in the chemical structure, not all property specifications provided by local and international standards for B100 fatty acid methyl esters were evaluated. The properties included in the analyses were appearance, acid number, cetane index, cloud point, pour point, density, distillation AET at 50% and 90% volume recovery, ethyl ester content, flash point PM, free glycerin, total glycerin, kinematic viscosity, water content, calorific value and pH. Due to lack of available equipment, cetane index was estimated using EPA's mathematical calculation method as documented in National Vehicle and Fuel Emissions Laboratory Reference Number 121. Ester content analysis was performed in Chempro Analytical Services Laboratory. Analyses on free glycerin, total glycerin, kinematic viscosity and calorific value were made at the Department of Energy, Energy Research and Testing Laboratory while the other property analyses were conducted at Petron Laboratory.

2.4 Emissions Test Equipment

2.4.1 Test Engine

A single cylinder, 3.7 kW vertical 4-cycle air-cooled direct-injection Sumo diesel engine coupled with 3.3 kW 15A 60Hz single phase electric generator was used for the experimental study. The detailed technical specifications are given in Table 3.

Table 3 Technical Specifications of Sumo Diesel SDE3000x Generator Set

Engine	Model	SD70	Diesel Generator	Maximum Output (kW)	3.6
	Total Displacement (cc)	296			
	No. of Cylinders	1		Rated Power (kW)	3.3
	Bore x Stroke (mm)	78 x 62		Rated Voltage AC/DC (V)	220V /12V
	Engine Speed (rpm)	4.0			
	Maximum Output (kW)	3.7		Current (A)	15
	Continuous Output (kW)	3.5		No. of Phases	single
	Fuel Tank Capacity (L)	3.5		Frequency (Hz)	60

2.4.2 Gas Analyzer Specifications

The exhaust emissions of CO, CO2, THC, NOx and O2 at different electric loads from various fuel blends were measured by SEMTECH-DS on-vehicle diesel emission analyzer (see Table 4 for specifications). Particulate matter (PM) was not measured as the analyzer used did not have such capability. The test procedure was patterned in the spirit of EPA test methods in 40 CFR 60, appendix A for the use of portable analyzer which is also adopted by North Dakota Department of Health [30]. Emission tests were performed on 1%, 2% and 5% blends of coconut ethyl ester biodiesel with neat automotive diesel oil (ADO) from Petron Corporation as the base fuel. Electrical loads were about 61%, 77% and 93% of the design capacity of the electric generator which correspond to low, medium and high loads, respectively. Electric appliances were used as loads on the generator and actual current reading using a clamp ammeter was performed to determine the exact electric load. The test was conducted at University of the Philippines Vehicle Research and Testing Laboratory (UP VRTL) in the Mechanical Engineering Department, College of Engineering, University of the Philippines – Diliman. Figure 1 shows the actual experimental set-up.

Table 4 Technical Specifications of SEMTECH-DS On-Vehicle Diesel Emission Analyzer

Parameter / Principle	Range / Resolution	Accuracy
CO2 / non-dispersive infrared	0 – 20% volume / 0.01%	E3% of reading or E0.1%, whichever is greater
CO / non-dispersive infrared	0 – 8% volume / 10 ppm	E3% of reading or E50 ppm, whichever is greater
THC / heated flame ionization detector (FID)	0 – 1000 ppmC* / 1 ppmC	E2% of reading or E5 ppmC whichever is greater
NOx / non-dispersive ultraviolet	0 – 500 ppm / 1 ppm	E3% of reading or 10 ppm, whichever is greater
O2 / electrochemical sensor	0 – 25% / 0.1%	E1% oxygen

*ppmC = parts per million expressed as methane

Fig. 1 Emissions Test Experimental Setup

III. RESULTS AND DISCUSSION

3.1 Preparation of Coconut Ethyl Ester via Base-Catalyzed Ethanolysis

Molar ratio of ethanol to oil at 3.435:1.0 or about 59% excess by volume of ethanol to oil proved to be sufficient in providing significant conversion of refined coconut oil to ethyl ester even at ambient conditions. The ethanol used was only about 15% excess from the theoretical molar ratio of 3:1 which is beneficial for small batch processes that do not have ethanol recovery. This could also signify better conversion at slightly higher molar excess of ethanol but the price of absolute ethanol can draw significant consideration in the commercialization of the process. The base catalyzed transesterification achieved 93.64% conversion of coconut oil to ethyl ester using gas chromatography and modified EN14103 method. Figure 2 shows the chromatograph of the ethyl ester biodiesel. Currently, there is no ester content standard specification for fatty acid ethyl ester biodiesel in the Philippines but the minimum 96.5% methyl ester content standard for FAME is achievable at optimal process conditions.

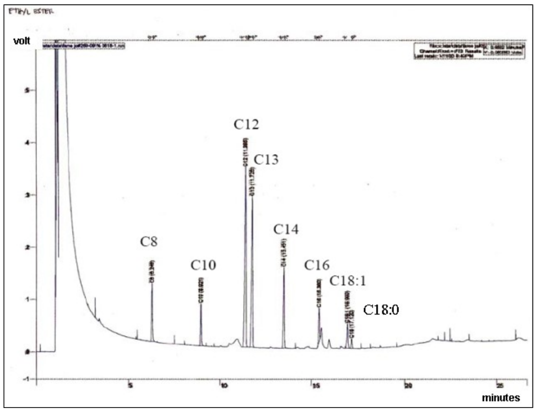

Fig. 2 Chromatograph of Coconut Ethyl Ester

The experiment also showed that heating was not necessary to achieve significant conversion provided that there is enough agitation to improve mass transfer during the conversion reaction. Shear mixing at about 4500 rpm compared to usual mixing at 600 to 1200 rpm gave significant yield at a much lower excess alcohol and without heating. It is assumed that the over-all operation cost will be improved due to elimination of heating process done by biodiesel industries although it operates under increased mixing speed.

3.2 Properties of Coconut Ethyl Ester Biodiesel

Table 5 summarizes the results of the analyzed properties of coconut ethyl ester. Some properties were within limits while others have to be improved but nevertheless achievable when production process is optimized. The properties were compared to B100 standard fatty acid methyl ester local specifications since there are no standards yet for ethyl esters.

Table 5 Physical and Chemical Property Analyses of Coconut Ethyl Ester

Property	Results	PNS Limit	Test Method
Appearance	Clear	Clear	Visual
Acid Number (mg KOH/g)	1.0	0.5 max	PNS ASTM D664
Cetane Index	46.327	51 min	EPA NVFEL ref. # 121
Cloud Point, ^{o}C	+3	Report	PNS ASTM D2500
Pour Point, ^{o}C	0	Report	PNS ASTM D97
Density @ 15 ^{o}C, kg/L	0.8685	0.86 – 0.90	PNS ASTM D1298
Distillation AET, ^{o}C		360 max	PNS ASTM D86
90% recovered	321		
50% recovered	283		
FAME content, %mass	93.64% ethyl ester	96.5 min	PNS EN 14103 modified
Flash Point, Pensky-Marten, ^{o}C	122	100 min	PNS ASTM D93
Free Glycerin (% mass)	Non-detectable	0.02 max	PNS AOCS Ea 6-51
Total Glycerin (% mass)	1.04	0.24 max	PNS AOCS Ca 14-56 (1997)
Kinematic viscosity @ 40 ^{o}C, mm^2/s	3.18	2.0 – 4.5	PNS ASTM D445
Water, % volume	0.2278	0.05 max	PNS ASTM D6304
Calorific Value (MJ/kg)	37.97	–	Iso-peribol method
pH	6.57	7-8	

As discussed earlier, higher yield can be achieved by additional excess ethanol to meet the minimum specification of 96.5% ester content. Other options include longer reaction time and an increase in the amount of KOH catalyst used. Total glycerin of 1.04 % mass compared to the maximum limit of 0.24 % mass indicated incomplete breakdown and conversion of triglycerides to mono alkyl esters. Ester content can be associated to total glycerin since formation of esters depends on the release and conversion of fatty acids from their triglyceride structure. Therefore, improving ester yield could also reduce total glycerin content of the biodiesel. The coconut ethyl ester moisture content of 0.2278 % volume from a maximum limit of 0.05 % volume showed insufficient dehydration. It is important to completely dehydrate the final biodiesel product since presence of water can hydrolyze the ester resulting to formation of free fatty acids and lower yield. Free fatty acid decreases the pH of biodiesel as well as increases its acid number beyond biodiesel specifications which resulted to an acid number of 1 and pH of 6.57 of the ethyl ester product. Better drying techniques, such as longer drying time at slightly higher temperature and use of drying agents, can help eliminate the effects of moisture on biodiesel. The calculated cetane index of 46.327 was very close to US and Brazil minimum standards for cetane number at 47 and 46, respectively but not of the local standard which is 51.

Other properties such as density, kinematic viscosity, free glycerin, flash point and atmospheric equivalent distillation temperature were within local specifications. Cloud point and pour point of the biodiesel at 3 oC and 0 oC respectively were suitable for tropical countries where coconut trees grow abundantly in the region. Calorific value of 37.97426 MJ/kg showed typical energy content for biodiesel as provided in the biomass energy handbook.

3.3 Emissions of Coconut Ethyl Ester-Diesel Blends

One of the objectives of this work is to develop emission characteristics of different blends of coconut ethyl ester and compare the results to unblended automotive diesel oil. It is important for biofuels to achieve similar if not better results with their petroleum counterparts to assure that they can have direct impact in the reduction of air pollutants when used.

3.3.1 CO emission

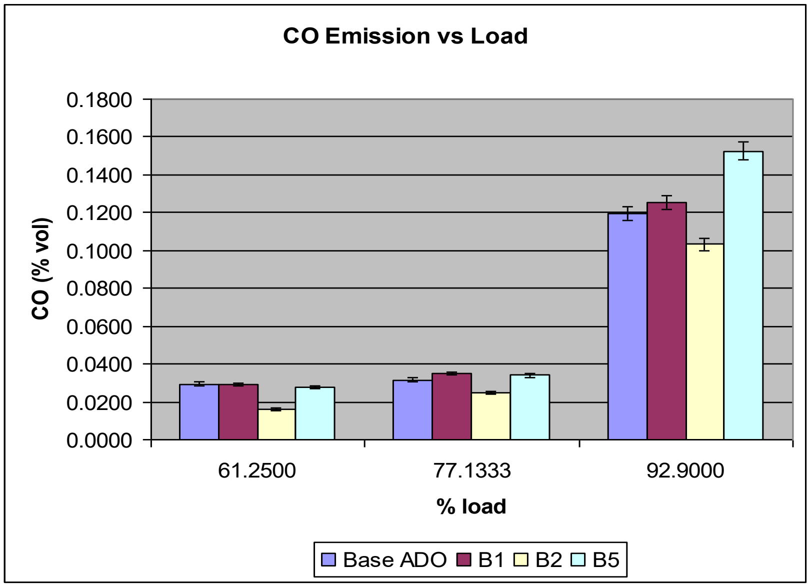

Fig. 3 Carbon Monoxide Emission of Blends at Varying Electrical Loads

Figure 3 shows the CO emissions of the neat diesel fuel and the biodiesel mixtures including the electrical load applied for each fuel and blends. CO, a colorless poisonous gas, is an intermediate product of combustion and is formed mainly from incomplete combustion of hydrocarbon fuels. Complete combustion of the fuel essentially produces CO2 as product with the CO intermediate converted to CO2. Incomplete combustion occurs when there is shortage of air or due to low gas temperature consequently producing CO. Usually, high diesel CO emission forms with fuel-rich mixtures, but as diesel combustion occurs with lean mixtures and has an abundant amount of air, CO from diesel combustion is low. CO emission has a slight increase or almost similar results in the 1% blend compared to neat diesel fuel. However, significant decrease in CO emission was recorded in the 2% blend and projected to increase as biodiesel blends increase beyond 2% despite the fact that the fuel blend becomes more oxygenated. A reduction in CO emission indicates that combustion was improved when using B2 blend. Error bars made according to the instrument's accuracy indicated that the measured values for the B2 blend had significant difference from the neat petro diesel and other biodiesel blends for all load conditions. A maximum CO reduction of about 48% was calculated for the 2% blend at 61.25% electrical load (low load) capacity when compared to neat diesel. The figure shows that as load increases, CO emission also increases. This can be explained by the engine's increased demand for fuel when the load increases while the amount of air remains constant. The change in gas temperature did not also have an effect in the effective conversion of CO to CO2 unlike in the study made by Li et al [18]. The data also suggest the effect of increased difficulty of mixing the fuel and air at higher loads for this type of engine.

3.3.2 CO2 Emission

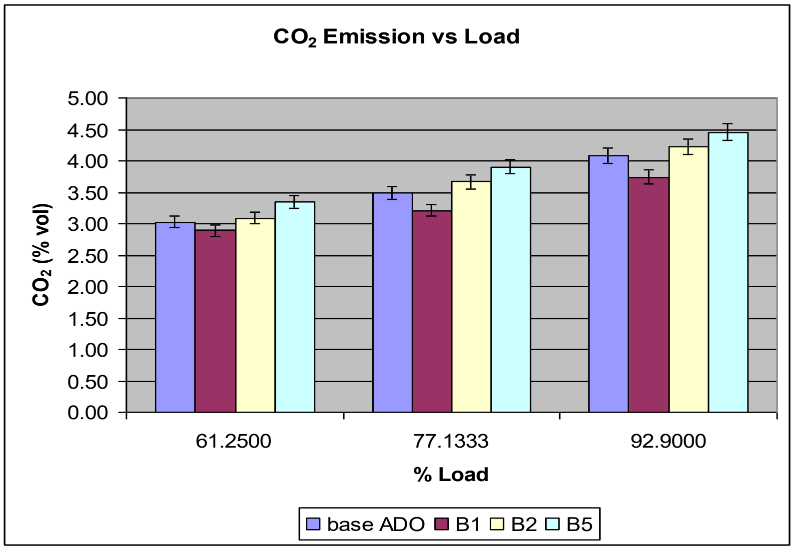

Fig. 4 Carbon Dioxide Emission of Blends at Varying Electrical Loads

Figure 4 shows the effects of biodiesel percentage on the CO2 emission. Coconut ethyl ester biodiesel at B1 blend showed decrease in CO2 emission with respect to base diesel for all electrical loads with a maximum decrease of about 8.5% at high load. The figure also shows that CO2 emission increases beyond 1% by volume of biodiesel. Carbon dioxide emission increased with increase in load conditions for base petro diesel and for biodiesel blended fuels mainly due to increase in fuel consumption. B2 and B5 blends showed increase in CO2 emission compared to the base fuel for all electrical loads with the highest increase of about 9% on B5 blend at high load. The increase in CO2 emission with increasing biodiesel blend was observed as well in the study of Liaquat et al [33]. The increase can be due to significant amount of extra oxygen present in the biodiesel fuel blend which can react with stray unburned carbon atoms. [34] Accumulation of CO2 in the atmosphere accelerates greenhouse effect and global warming. However, if emission of this greenhouse gas comes from a renewable source, the natural carbon cycle will be promoted.

3.3.3 THC emission

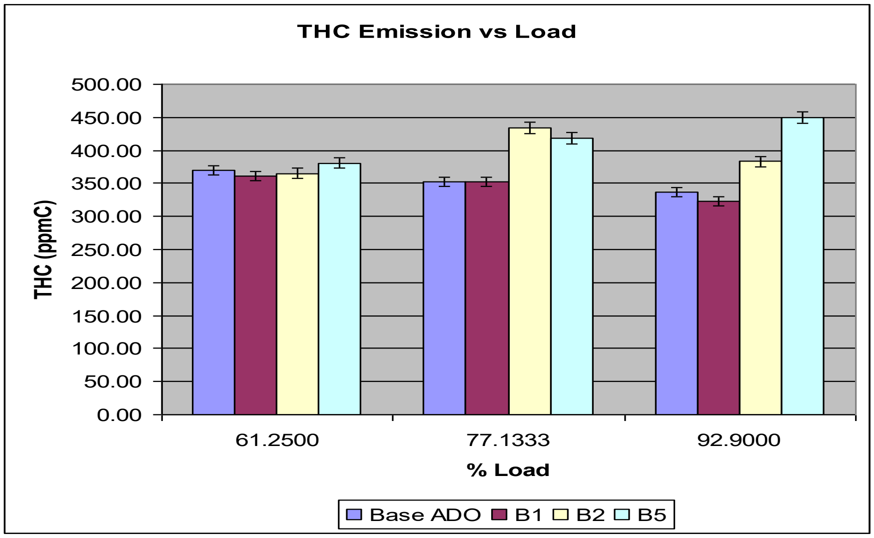

Fig. 5 THC Emission of Blends at Varying Electrical Loads

The total hydrocarbon (THC) emissions, expressed as parts per million methane (ppmC), of the base diesel fuel and biodiesel blended fuels are shown in Figure 5. THC emissions consist of fuel that is completely unburned or only partially burned. The amount of THC in the exhaust depends on the engine's operating conditions, fuel properties, fuel-spray characteristics, and the interaction between fuel spray and air in the combustion chamber [6]. Comparison of biodiesel blends revealed that the B1 blend exhibited the best emission characteristic for THC level on all electrical load conditions. B1 blend also had similar or slightly lower THC emission when compared to neat petro diesel on all loads. The B1 blend had 4% as its highest THC reduction at high load condition. B2 was able to reduce THC emission by 1.3% at low load. The figure also shows that total hydrocarbon (THC) emission increases as biodiesel blends increase beyond 1%. Neat diesel and B1 blend had decreasing THC emission as load increases while B2 and B5 registered their lowest THC emission only at low loading condition. Neat petro diesel, B1, B2 and B5 blends have similar THC emission at low load condition. The results suggest that THC emission formation mechanism is a complex process and is mainly caused by the engine's operation and design geometry such that the biodiesel's properties cannot directly influence the formation of hydrocarbon in the exhaust gas [10, 11].

3.3.4 NOx Emission

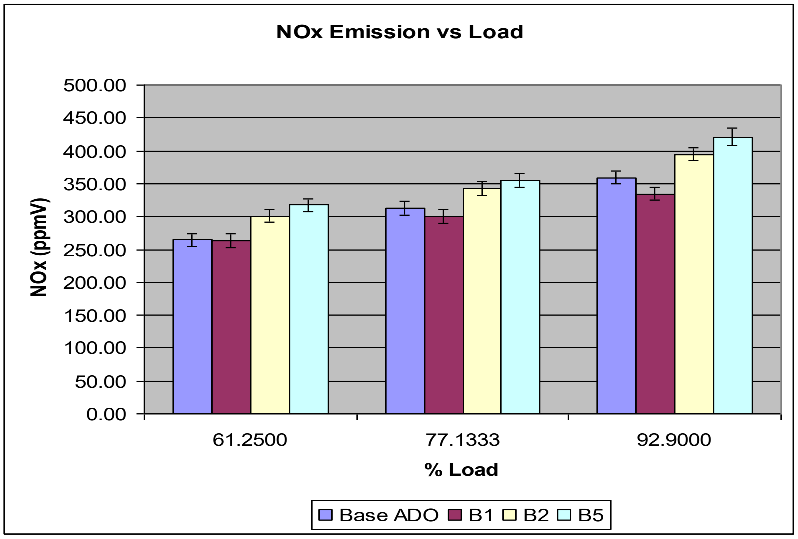

Fig. 6 NOx Emission of Blends at Varying Electrical Loads

Figure 6 shows the effect of different biodiesel percentages and electrical load conditions on the NOx emission of the single-cylinder diesel engine. NOx and volatile organic carbons are key components for the formation of ground level ozone which can cause skin and respiratory problems. NOx is formed when the inert gas nitrogen from air becomes reactive to oxygen when the combustion gas pressure and temperature become high or reaches 1100°C or greater [67]. Since the formation of nitrogen oxides do not attain chemical equilibrium reaction; then after the end of expansion stroke when the burned gases cool and the formation of NOx freeze, the concentration of the formed NOx in the exhaust gas remains unchanged [67]. Surprisingly, the B1 blend was able to reduce NOx emission on all electrical load conditions when compared to neat diesel but emission increases beyond 1% blend. The decreases were about 0.6%, 4% and 7% at low, medium and high electrical loads respectively with significant difference at high load as indicated by error bar. This can be due to the lowered premixed burning rate following the delay period where there is lower air entrainment and fuel-air mixing rates resulting to lower combustion temperature [17].

As expected, B2 and B5 blends have higher NOx emission than neat petro diesel and increased as load increases. B2 and B5 blends had an average increase in NOx emission of about 10% and 16% respectively compared to petro diesel. The increase can be due to significant amount of extra oxygen present in the biodiesel fuel blend which might contribute to additional formation of NOx. The figures also show that NOx emission has a direct relationship with engine loads indicating that temperature also increases as load increases.

The increase in NOx concentration, a major concern with biodiesel, can be reduced by making suitable changes in the engine operating parameters [26]. Forgiel and Varde (1981) observed that the NOx concentration depended on the size of orifice. They reported that the NOx increased when the orifice size was reduced. It was also reported that the NOx concentration can be reduced by advancing the beginning of injection time by 0-3° [9]. This change is suitable for biodiesel fuel blends that have lower cetane number than neat petro diesel. A lower cetane number means an increase in ignition delay and more accumulated fuel/air mixture, which causes a rapid heat release at the beginning of the combustion, resulting in high temperature and high NOx formation [24].

IV. CONCLUSION

From the experimental results, the following conclusions were made:

1. Base-catalyzed transesterification of refined coconut oil to make biodiesel using ethanol at ambient conditions is a feasible process for replacing the toxic and fossil fuel-derived methanol. Significant conversion of refined coconut oil to ethyl ester biodiesel was achieved at process conditions of 1% (weight to oil) KOH catalyst, 59% by volume excess ethanol, 1.5 hours reaction time and ambient temperature using Silverson L4R shear mixer at about 4500 rpm. The method possibly can save operational cost because heating the reactants during the conversion process was unnecessary. The yield was 93.64% ethyl ester.

2. Several properties of the coconut ethyl ester conformed to PNS specifications for B100 Fatty Acid Methyl Ester (FAME) with the exception of acid value and water content which can be solved by careful washing and dewatering. Total glycerine was also higher than the local standard but can be resolved by better conversion. The calculated cetane index was 46.327 which is lower than local specification but very close to US and Brazil minimum standards for cetane number set at 47 and 45, respectively. Average pour point and cloud point values were below 10°C which is suitable for tropical countries like the Philippines.

3. Emission tests for coconut ethyl ester revealed that the biodiesel blend at 1% volume seems to be optimal due to decrease in NOx and THC emissions and almost similar CO emission when compared to neat petro diesel. B2 blend on the other hand, had the most significant decrease in CO emission. B1 blend reduced CO2 emission by 8%, NOx by 7% and THC by 2.5% all at 93% (high) electrical load when compared to base petro diesel. B2 blend reduced CO emission significantly by 46% at low load and 22% at medium load when compared to base petro diesel. The remaining B2 and B5 blends had an average increase of about 10% and 16% NOx emissions respectively, a typical characteristic for most biodiesels.

4. The results show that the overall trends in emissions of CO, CO2, THC, and NOx were as follows:
    - Increase in CO, NOx and THC emissions at increasing loads for all blends with exception for neat petro diesel and B1 blend. THC emissions decrease as load increases for neat petro diesel and B1 blend.
    - CO emission increases as biodiesel blends increase beyond 2%.
    - CO2 emission increases as biodiesel blends increase beyond 1%.
    - Total Hydrocarbon (THC) emission increases as biodiesel blends increase beyond 1%.
    - NOx emission increases as biodiesel blends increase beyond 1%.

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