An Initial Study on the Effects of Philippine CME-Diesel Blends on Drive Cycle Fuel Economy of an In-Use Light Duty Asian Utility Vehicle

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Abstract: The shift to 5% (B5) CME-diesel blend from the current B2 blend in the Philippines is under deliberations with stakeholders. As input to said deliberations, an initial fuel economy study of 1, 2, 3, 5, 10, 20, 50, & 100 percent CME-diesel blends relative to neat diesel was conducted using an in-use Asian utility vehicle on the Japanese 10-15 Mode drive cycle. Specific fuel consumption (SFC, gm/km) was roughly similar for B1-B10, and 2%, 3% & 11% higher for B20, B50 & B100 respectively. Mileage (km/l) was about similar for B1-B20, and 3%-8.4% less for B50-B100. The blends gave less than 2% improvement in “energy mileage” (kJ/km). Maximum power was roughly similar for B1-B50 and 6% less for B100. The higher SFC and lower mileage beyond B20 was attributed to lower heating value at higher blends. The vehicle had comparable fuel economy and maximum power for blends up to B10.

Keywords: biodiesel, biofuels, CME, fuel economy, drive cycle

1. INTRODUCTION

As part of efforts to reduce dependence on imported fossil fuels, develop and utilize indigenous renewable and sustainably-sourced clean energy sources, mitigate toxic and greenhouse gas emissions, the Philippines enacted the Biofuels Act of 2006 (Congress of the Philippines, 2006) which required blending of fatty acid methyl ester (FAME) or biodiesel with diesel fuel sold commercially. The Philippines opted to use coconut oil as a major feedstock to produce coconut methyl ester (CME) as its biodiesel for blending as a parallel effort to support its coconut industry. Fuel properties specifications for CME are indicated in Philippine standards PNS 2020:2003/DOE 002:2003. Present commercial diesel fuel sold in gas stations is a 2% blend (B2) of CME by volume. The shift to 5% blend (B5) is under evaluation by concerned government agencies in consultation with stakeholders.

Although many studies have been performed worldwide on different biodiesel fuels, there are relatively few conducted using Philippine CME-diesel blends tested under local conditions. This initial study aims to support the Philippine biofuels program by providing fuel economy data of different CME-diesel blends from drive cycle tests on a chassis dynamometer of a local in-use Asian utility vehicle. Fuel economy data obtained under local test conditions is sought by local stakeholders and enables effective implementation of the Biofuels Act by concerned government agencies.

Research and development studies initiated by both government and private institutions on the use of coconut oil for automotive fuel application started in the 1970’s. The coconut oil’s high viscosity and low volatility caused operational problems such as clogging of fuel lines, gum formation, and thickening of lubricating oil. These results initiated continuous efforts in the 1980's and 1990's by various government agencies to develop production of coconut methyl ester (CME) and its subsequent use for fuel applications (Bulan, 2003), (Ables, 2004). The Philippine Coconut Authority (PCA) in cooperation with other government agencies, universities, and private entities started an initiative in 2001 to test, demonstrate, and promote the use of CME as a diesel fuel additive or "enhancer" to help comply with the emission requirements for diesel vehicles of the Philippine Clean Air Act (Ables, 2004). Free acceleration tests on in-use vehicles with 1% CME-diesel blend showed about a 50% reduction in smoke opacity versus diesel. An Isuzu C190 engine dynamometer test using 1%, 2%, & 5% CME-diesel blends yielded a 1%-3% power increase over diesel fuel. Yoshida, K. *et al.* (2004) tested CME-diesel blends of 1, 5, 10, 20, and 100 percent by volume using a single-cylinder diesel engine and found a 50-60% reduction in smoke emissions, average NOx reduction of 20%, and average 20% power reduction of 20% relative to diesel fuel. It was also observed that the emission performance characteristics of the 1%, 5%, 10%, and 20% blends showed no significant differences from each other.

Ozawa, Y. *et al.* (2011) used CME-diesel blends of 0, 5, 10, 25, 50, 75, & 100 percent by weight in a single-cylinder engine at 3000 rpm and full load fuel injection pump setting for performance and cold start tests. The bmep decreased with increasing blend ratios while brake thermal efficiency was hardly affected. Smoke, carbon monoxide, and hydrocarbon emissions decreased with increasing blend ratios which was attributed to the CME being an oxygenated fuel. It was also observed that the CME blends had very good ignition characteristics from the cold start tests.

The effects of CME-diesel blends on mileage of public utility jeepneys (PUJ), a popular public transport vehicle in the Philippines, have been also investigated. Thaweesak, S. (2009) compared the drive cycle fuel economy of CME-diesel blends at 1, 3, 5, & 10 percent by volume on selected in-use jeepneys. It was found that the drive cycle fuel economy improvement of the various blends relative to neat diesel fuel were not statistically significant. Quiros *et al.* (2015) conducted a limited study on the fuel economy of 2% and 5% CME-diesel blends using in-use jeepneys plying five urban routes. Drive cycle tests showed that the 5% blend gave an estimated 3% mileage improvement over the 2% blend.

2. METHODOLOGY

The CME-diesel blends used in the study were prepared from single batches of neat diesel and pure CME provided by major local petroleum and chemical companies. The appropriate volumetric quantities of neat diesel and pure CME were mixed in a stirred tank to produce 1%, 2%, 3%, 5%, 10%, 20%, & 50% CME-diesel blends respectively designated as B1, B2, B3, B5, B10, B20, & B50 with B100 as pure CME.

For a given CME-diesel blend, the fuel economy measurement consisted of driving the test vehicle, a common local in-use Asian utility vehicle with a Euro II 2.5-liter naturally aspirated direct-injection diesel engine, distributor-type injection pump, and 5-speed manual transmission, on a chassis dynamometer following the Japanese 10-15 Mode drive cycle. This drive cycle was arbitrarily selected due to the absence of a standard local drive cycle for light duty vehicles. Three drive cycle runs were conducted and the results averaged. The maximum power test followed consisting of the test vehicle being driven at wide-open throttle in 3rd gear until the indicated redline of the engine at 4200 rpm was reached. The peak power during the test was recorded. Three trials were conducted and the results averaged.

The above test procedure was followed for each CME-diesel blend B0 (neat diesel), B1, B2, B3, B5, B10, B20, B50, & B100 (CME). A single drive cycle run and three maximum power tests using neat diesel were performed in between different fuel blends for flushing purposes. Ambient air temperature during the test period ranged from 26-29°C and relative humidity 70-80%.

3. EXPERIMENTAL SET UP

Fuel properties taken from the quality certificates of the neat diesel and pure CME supplied for the study by local companies are shown in Tables 1 and 2 respectively.

Table 1 – Fuel properties of neat diesel

DIESEL Property	Value
Appearance	Clear
Cetane Number	55
Cloud Point, °C	0
Density @ 15 °C, kg/m3	834.4
Flash Point, PM, °C	72
Pour Point, °C	-9
Auto Ignition Temp, °C	220
Viscosity @ 40 °C, mm2/c	3.071
Sulfur, % mass	0.045
Ash, % mass	0.001
Lower Heating Value, kJ/kg	45,624

Table 2 – Fuel properties of pure CME

CME Property	Value
Appearance	Clear
Cetane Number	70
Cloud Point, °C	-2
Density @ 15 °C, kg/m^3	873.5
Flash Point, °C	106
Pour Point, °C	-6
Viscosity @ 40 °C, mm^2/c	2.76
Sulfur, % mass	0
Sulfated Ash, % mass	0.01
Lower Heating Value, kJ/kg	39,545

This initial study was conducted at the Vehicle Research and Testing Laboratory (VRTL), Department of Mechanical Engineering, University of the Philippines. Figure 1 shows a schematic diagram of the chassis dynamometer test set up. An AVL 48” compact chassis AC dynamometer rated at 150 kW was used for the tests. Power generated during dynamometer runs was sent to the electrical grid. Engine intake air flow was measured with an ABB Sensyflow air mass flow meter while an AVL Di-speed engine speed sensor monitored engine rpm. Fuel consumption and density were measured with an AVL 735 Fuel

Mass Flow Meter together with the AVL 753 Fuel Temperature Control unit. An external fuel tank containing the test blend supplied fuel to the engine via the fuel meter and fuel temperature control unit. Chassis dynamometer operation, control, and data acquisition were performed using the Man Machine Interface personal computer in the control room. Figure 2 shows the test vehicle mounted on the chassis dynamometer with the drive cycle display panel and driver's aid computer near the vehicle's driver-side window.

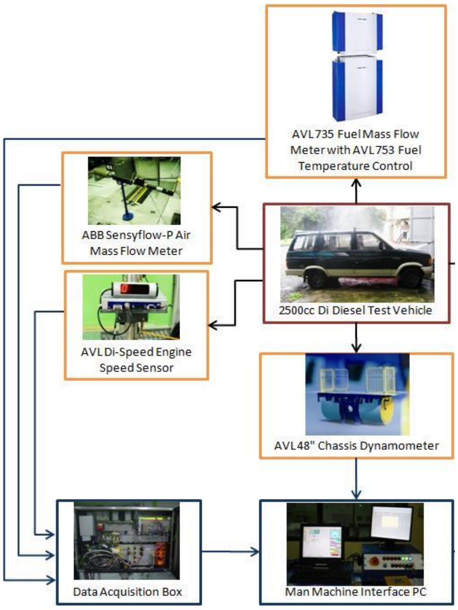

Fig. 1 – Chassis dynamometer test set up

Fig. 2 – Driver's aid display beside test vehicle

4. RESULTS AND DISCUSSION

Figures 3(a) & 3(b) show the measured actual fuel density and relative to neat diesel density respectively as a function of CME percentage in the fuel blend. CME-diesel blend density was practically the same for neat diesel up to B20. B100 density was about 3.8% higher than neat diesel. Variations in the fuel blend density affect the final mileage figure eventually paid for in fuel costs (Quiros *et al.* 2015). The calculated lower heating values of the various CME-diesel blends are shown in Figure 3(c) and corresponding relative values in

Figure 3(d). The heating value began to be significantly lower than neat diesel beyond B20.

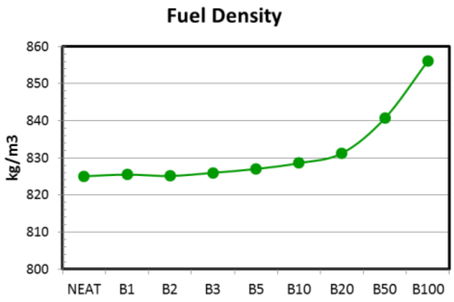

Fig. 3(a) – Measured actual fuel blend density

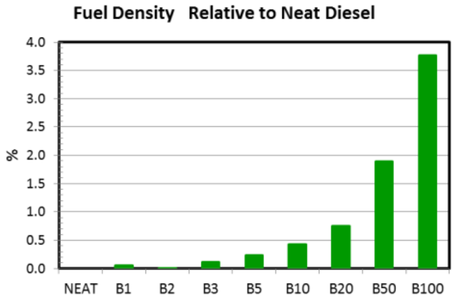

Fig. 3(b) – Relative fuel blend density

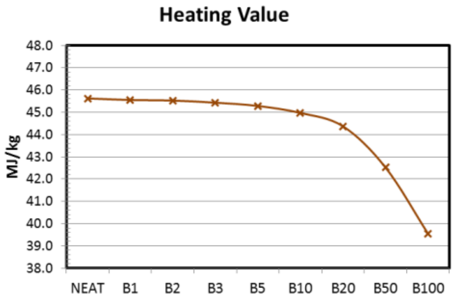

Fig. 3(c) – Heating values of fuel blends

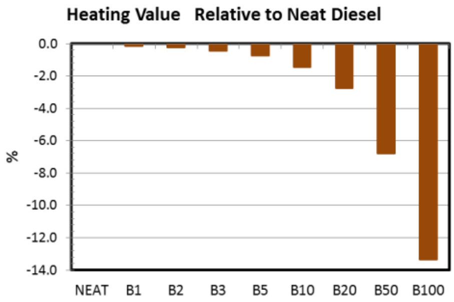

Fig. 3(d) – Relative heating values vs. fuel blend

The drive cycle specific fuel consumption (SFC) and the SFC relative to neat diesel for the various CME-diesel blends are shown in Figures 4(a) and 4(b) respectively. The SFC was about the same for blends up to B10 after which, the SFC began to increase significantly

(2%, 3% & 11% more for B20, B50 & B100 respectively). This is attributed to decreasing heating value of the fuel blend as the CME component increased.

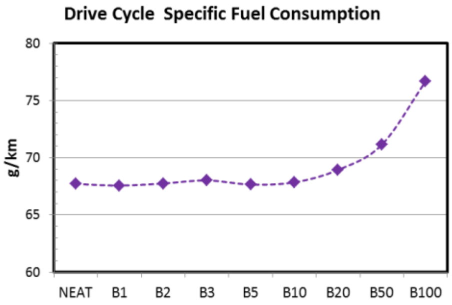

Fig. 4(a) – Drive cycle SFC vs. fuel blend

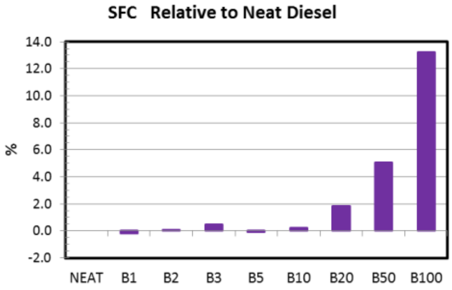

Fig. 4(b) – Drive cycle Relative SFC vs. fuel blend

Figures 5(a) and 5(b) show the drive cycle mileage obtained from the tests. Mileage is considered to reflect the combined effects of fuel blend heating value and density. The graphs indicate that mileage was practically similar for blends up to B20. The decrease in mileage (3% - 8.4%) beyond B20 is attributed to decreasing fuel heating value tempered by a slightly increasing fuel density as the amount of CME in the blend increased.

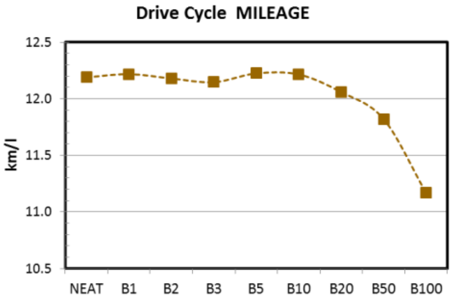

Fig. 5(a) – Drive cycle Mileage vs. fuel blend

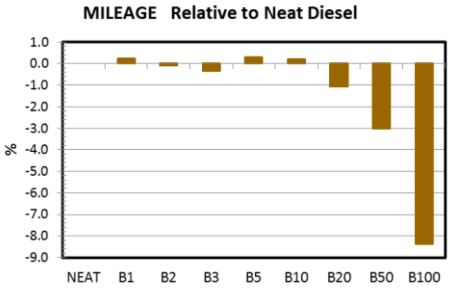

Fig. 5(b) – Relative Mileage vs. fuel blend

While mileage is a useful parameter in directly estimating operational fuel costs as fuel is sold by the liter, the energy used per unit distance, here called "energy mileage", gives an indication of the efficiency of the fuel energy conversion process. Figure 6(a) indicates an overall decreasing energy mileage trend as CME content increases. However, the relative energy mileage presented in Figure 6(b) shows that blends up to B20 were only up to 1% better than neat diesel. B50 and B100 were only about 2% less than neat diesel. The lower relative energy mileage with higher CME-diesel blends seemed marginal for the vehicle tested in this study.

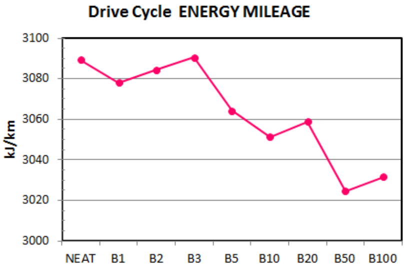

Fig. 6(a) – Energy Mileage vs. fuel blend

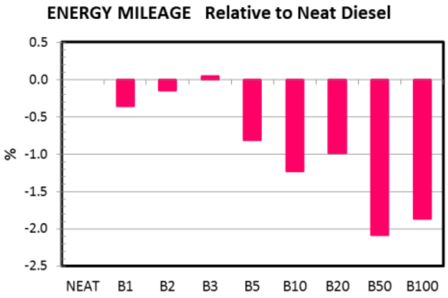

Fig. 6(b) – Relative Energy Mileage vs. fuel blend

Figures 7(a) and 7(b) show wheel power from the maximum power tests. Blends B1 to B10 have a marginally higher, B20 similar, and B50 marginally lower power than neat diesel. If a power difference of 1-2% is considered negligible, then blends up to B50 had roughly the same maximum power output. The effect of lower heating value for blends beyond B50 results to a decrease in maximum power of up to about 6%.

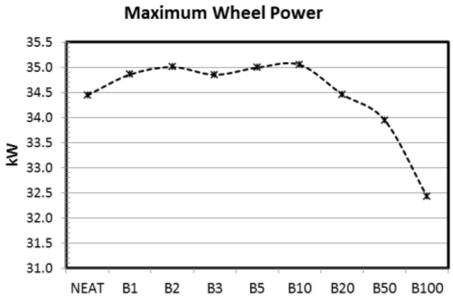

Fig. 7(a) – Maximum wheel power vs. fuel blend

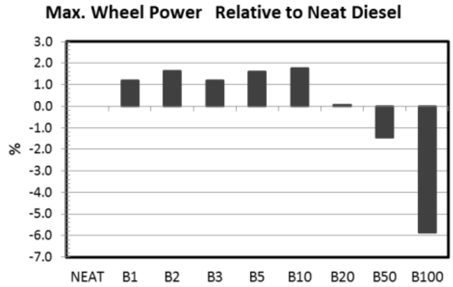

Fig. 7(b) – Relative max. wheel power vs. fuel blend

5. CONCLUSION

An initial local comparative study was conducted on the fuel economy of an in-use Euro 2 Asian utility vehicle, with a normally aspirated direct-injection engine, fueled with different Philippine CME-diesel blends of 1, 2, 3, 5, 10, 20, 50, & 100 percent by volume CME. Fuel economy measurements via chassis dynamometer tests were performed using the Japanese 10-15 Mode drive cycle. The findings of the study were as follows:

1) SFC (in gm/km) relative to neat diesel was roughly similar for B1-B10, 2%, 3% & 11% more for B20, B50 & B100 respectively. The increasing SFC at B20 up to B100 was ascribed to the decreasing fuel blend heating value.
2) Mileage (in km/l), was about similar for neat diesel up to B20, and 3%-8.4% less than diesel for B50-B100.
3) The “energy mileage” (in kJ/km), relative to neat diesel was only up to 1% less for B1-B20, and around 2% less for B50 & B100. Fuel energy conversion improvement with the use of CME-diesel blends was considered marginal for the vehicle tested.
4) Maximum wheel power tests showed that compared to neat diesel, B1-B50 blends had roughly similar power while B100 about 6% less.

The authors recommend additional similar studies on representative samples of the local vehicle population for a better appreciation of the impact of CME-diesel blends on the transport sector.

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