EXPLORING THE EFFECTS OF ALTERNATIVE BIODIESEL FEEDSTOCKS ON GOVERNMENT-MANDATED EMISSION LEVELS FOR COMPRESSION-IGNITION ENGINES

Carlos E. Zapanta

Technological University of the Philippines
Integrated Research and Training Center

Abstract

The use of biofuels, specifically biodiesel, is becoming popular for a couple of reasons: because the resource is renewable and in view of implementing fully the Philippine Biofuels Law signed in 2006. However, a clamor persists to further increase the biodiesel content in the diesel blend, most especially for public transport to improve air quality. Unfortunately, the increase of biodiesel in the blend will require more feedstocks; hence, this study intends to assist policymakers in identifying alternative biodiesel feedstocks. Biodiesel from such feedstocks as Moringa, Jatropha and waste cooking oil had been blended with unadditized diesel fuel. Each fuel blend was tested at different speeds in a four-stroke, single-cylinder compression-ignition engine integrated with an exhaust gas analyzer to determine the levels of emissions, compared to using unadditized diesel fuel. Results showed that using the fuel blends lowers the exhaust emission in compression-ignition engines. In sum, using the alternative biodiesel feedstocks (Moringa, Jatropha, and waste cooking oil) will promote cleaner ambient air.

Keywords: *Biodiesel, feedstock, compression-ignition engine, emission, unadditized diesel, Moringa, Jathropa, waste cooking oil*

Introduction

The primary source of energy in the Philippines is dominated by fossil fuels such as coal, petroleum and natural gas. About forty-five percent (45%) of the country's energy consumption comes from petroleum oil, mostly consumed by road vehicles (EIA-DOE, 2011). According to the United Nation Environment Programme-TNT (2009), road vehicles are the main source of air pollution in the Philippines. To this effect, a study done in Metro Manila showed that seventy percent (70%) of air pollution comes from vehicle emissions due to incomplete combustion from petroleum fuels, specifically by diesel powered engine like jeepneys, trucks and buses (Energy and Environment-USAID, 2013)

The passage of the Philippine Clean Air Act (RA 8749) in 1999 implements emission standards for motor vehicles to improve air quality. Biodiesel became an immediate solution to reduce emissions from diesel powered vehicles. Biodiesel, a renewable and biodegradable alternative fuel, can be used either as a substitute or as an extender for diesel fuel without engine modification. Feedstock used to produce biodiesel can be sourced from different varieties of oil, such as plant oils, animal fats or recycled restaurant grease.

The Philippines is the first country to use biodiesel from Coco-diesel or Coconut Methyl Ester (CME) produced from transesterification of coconut oil (Philippine Department of Energy, 2006). The enactment into law of RA 9367, otherwise known as the Biofuels Act of 2006 on January 12, 2007, mandated the use of two-percent (2%) blend in all diesel products in the country. The aim of the law is to develop and utilize indigenous renewable sources of energy to reduce dependence on imported oil and provide cheaper and environment-friendly alternatives to fossil fuels.

At present, the Philippine government is studying other sources of biodiesel, such as Moringa, Jatropha Curcas, waste oil, Hanga, and other potential indigenous feedstocks for biodiesel to ensure the sustainability of biodiesel production in the country.

Statement of Purpose

Purposely, this study attempts to determine the effect/s on emissions of different feedstocks of biodiesel in compression-ignition engines. Specifically, it aims to determine the reduction of exhaust gas emission levels and the smoke density of motor vehicle engines using different biodiesel feedstocks.

Methodology

Republic Act 8749, otherwise known as the “Philippine Clean Air Act of 1999,” sets an emission standard for Type-approval and In-use motor vehicles equipped with compression-ignition engine. New vehicles introduced in the market shall comply with the EURO 2 standard and the emission limit for the Type Approval.

Table 1. Type Approval Emission Limits for Passenger Vehicle (M) and Light Duty Vehicles (N1), Euro 2

Category/Class of Vehicle		Reference Mass RW (kg)	Mass of Carbon Monoxide L_1 (g/km)	Combined Mass of Hydrocarbons and Oxide of Nitrogen L_2 (g/km)	Mass of Particulates L_3 (g/km)
Category	Class				
M(2)	-	all	1.0	0.7	0.08
N_1(3)	I	RW≤1,250	1.0	0.7	0.08
	II	1,250<RW≤1,700	1.25	1.0	0.12
	III	1,700<RW	1.5	1.2	0.17

Table 2. Emission Limits for Heavy Duty Vehicle Type Approval (Euro II)

Type of Engine	Class of Vehicle	CO (g/kWh)	HC (g/kWh)	NOx (g/kWh)	PM (g/kWh)
Compression-ignition	Heavy Duty	4.0	1.10	7.0	0.15

All in-use motor vehicles with compression-ignition engine shall comply with the emission standard as a requirement for renewal of registration. Only light absorption coefficient or smoke density will be tested, depending on the date of registration.

Table 3. Emission Standard for In-use Vehicle with Compression- Ignition Engines.

Vehicle Registration	Light absorption coefficient, m^{-1}, k
Registered for the first time after December 31, 2007	2.0
Registered for the first time on or after January1, 2003 but before January 1, 2008	2.5
Registered for the first time on or before December 31, 2002	2.5 3.5 (turbocharged) 4.5 (1,000m increase in elevation)

Three potential biodiesel feedstocks such as Jatropha, Moringa, and waste cooking oil were used in this study. The biodiesel from feedstock was added in unadditized diesel in three percent blend (B3) and tested in a single-cylinder, four-stroke compression-ignition engine at 10 different speeds to validate the performance of the various blends in terms of emission. Emission results from fuel blends of Jatropha Methyl Ester (JME) extracted at TUP-IRTC, Moringa Methyl Ester (MME), and Waste Cooking Oil Methyl Ester (WCOME), obtained from biodiesel manufacturers, were compared with those of unadditized diesel fuel (UD) from Petron Corporation.

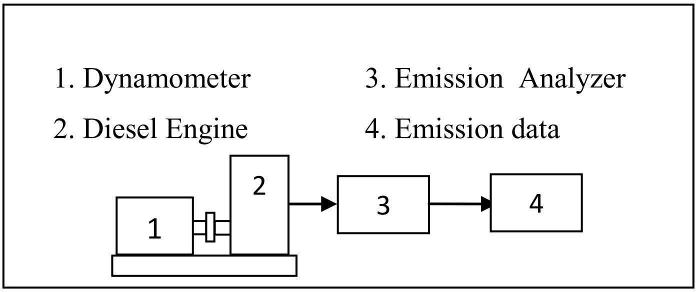


Figure 1. Engine emission testing experimental set-up

Table 4. Engine Specification

TD 212 Diesel Engine	
ITEM	**SPECIFICATION**
Dimension (W x H x D)	400 mm x 450 mm X 350 mm
Net Weight	35 kg
Fuel Type	Diesel
Absolute Maximum Power	3.5 kW (4.8 hp) at 3600 rpm
Continuous Rated Power	3.1 kW at 3000 rpm
Bore	69 mm
Stroke/Crank Radius	62 mm/31 mm
Connecting Rod Length	104 mm
Engine Capacity	232 cm^3 (0.232 L) or 232 cc
Compression Ratio	22:1
Oil Type	Multigrade SAE 5 W – 40
Oil Capacity	2.6 Liters

AVL Dicom 4000 gas emission analyzer was used to measure the amount of exhaust gases from compression-ignition engine such as Carbon Monoxide (CO), Hydrocarbon (HC), Nitrogen Oxide (NOx) and smoke density (K value).

Table 5. AVL Dicom 4000 Exhaust Gas Analyzer Measurement Parame**ters**

	MEASUREMENT RANGE	**RESOLUTION**
CO	0…10% by vol.	0.01% by vol.
CO_2	0…20% by vol.	0.1% by vol.
HC	0…20000 ppm vol.	1 ppm vol.
O_2	0…4% by vol. 0…22% by vol.	0.01% by vol. 0.1% by vol.
NO	0…4000 ppm vol.	1 ppm vol.
λ- calculation	0.9.999	0.001
λ- sensor voltage	0…5.0 V	0.04 V
Opacity	0…100%	0.1%
Absorption (k-value)	0.99.99 $^1/_m$	0.01 $^1/_m$
Acceleration time	0…5 s	0.1 s
Engine Speed	250…9999 rpm	10 rpm
Oil temperature	0…120°C	1°C
Angle measurement TDC sensor strobe	-10…100°CA 0…60°CA	0.1°CA 0.1°CA
Dwell angle	0…100%	0.1%

Results and discussion

Fuel Property Test

The physical and chemical properties of MME, JME, and WCOME samples are shown in Table 3 with reference to the Philippine National Standard for Biodiesel (PNS/DOE QS 002:2007).

The aforesaid biodiesel standard uses different test methods, such as ASTM and AOCS, in determining the properties of the methyl esters. Result shows that MME and JME met the PNS for Biodiesel requirements; however, WCOME failed in terms of total glycerin, where the standard only requires a maximum of 0.2 percent mass.

Table 6. Physico-Chemical Analysis of Different Methyl Esters

Test /Analysis	Moringa Methyl Ester	Jatropha Methyl Ester	Waste Cooking Oil Methyl Ester	PNS for Biodiesel (PNS/DOE QS 002:2007)
Kinematic Viscosity @ 40°C, mm^2/sec.	2.78	4.44	3.4	2.0 – 4.5
Flash Point (PMC), °C	115	165	121	100, min
Copper Strip Corrosion, 3 hrs.@ 50°C	1a	1a	1a	No. 1, max
Cloud Point, °C	-1	4	2	5, max.
Sulfur, % mass	0.0013		0.0004	0.050
Sulfur, ppm		2ppm		50 max
Sulfated Ash, % mass	0.003	0.002	0.0004	0.02, max.
Distillation AET 90% recovered, °C	340	328	ND	360, max.
Water and Sediments, % volume	nil	0	0	0.050
Acid Number, mgKOH/g	0.21	0.12	0.18	0.50 max.
Free Glycerin, % mass	<0.01	<0.01	0.001	0.02, max.
Total Glycerin, % mass	0.19	0.11	0.61	0.2 max

Emission Test

The test was intended for in-use vehicles (vehicles previously registered to LTO) powered by compression-ignition engine for emission standard compliance. Emission test was conducted to determine the effects of blending biodiesel feedstocks such as Moringa, Jatropha, and waste cooking oil on the engine as to smoke density at varying speeds and loads that represent real driving pattern for the engines.

Exhaust gases such as CO, HC and NOx were also measured to validate the effects of biodiesel feedstocks in the exhaust gas emission compared to unadditized diesel fuel.

The smoke density was gauged using the absorption test for unadditized diesel and for the three biodiesel blends. The graph shows that high smoke density occurs at low speed, high load in three biodiesel blends and in unadditized diesel, as shown in Figure 2. In average, biodiesel blends emit less smoke with a reduction of 14% for JME, 8% for MME and WCOME, as compared to unadditized diesel.

Table 7. Smoke Density Concentration of Unadditized Diesel and Fuel Blends at Different Speed

RPM	Smoke Density, (K)			
	Unadditized Diesel	**JME**	**MME**	**WCOME**
1400	0.62	0.51	0.52	0.51
1600	0.45	0.51	0.43	0.53
1800	0.51	0.49	0.55	0.53
2000	0.41	0.39	0.54	0.45
2200	0.49	0.45	0.48	0.42
2400	0.50	0.41	0.41	0.41

2600	0.48	0.36	0.43	0.40
2800	0.44	0.34	0.36	0.36
3000	0.24	0.14	0.12	0.18
3300	0.11	0.08	0.09	0.12
AVE.	**0.425**	**0.368**	**0.393**	**0.391**

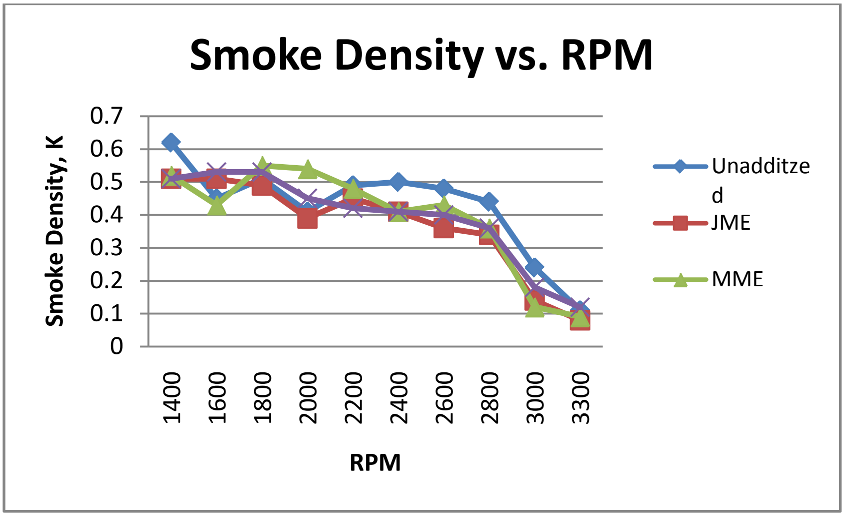


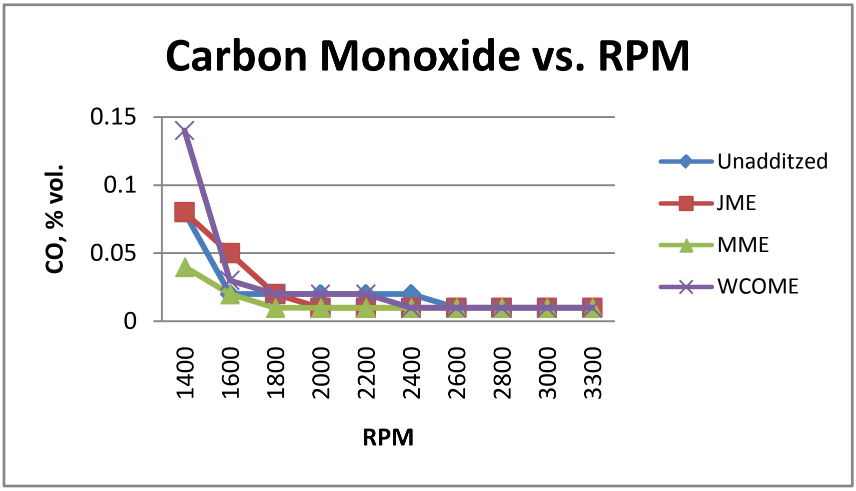
Figure 2. Smoke Density vs. Engine Speed

Carbon monoxide (CO) is a poisonous gas formed by incomplete combustion and measured using the gas emission analyzer. The graph shows that high concentration of CO occurs at low speed, high load for three biodiesel blends and unadditized diesel and decreases at high speed, less load as shown in Figure 3. On the average, as shown in Table 8, JME yields similar result as unadditized diesel. A decrease of 37% in using MME and an increase of 27% in a CO concentration in blending WCOME, as compared to unadditized diesel.

Table 8. Carbon Monoxide Concentration of Unadditized Diesel and Fuel Blend

RPM	Carbon Monoxide, (% volume)			
	Unadditized Diesel	**JME**	**MME**	**WCOME**
1400	0.08	0.08	0.04	0.14
1600	0.02	0.05	0.02	0.03
1800	0.02	0.02	0.01	0.02
2000	0.02	0.01	0.01	0.02
2200	0.02	0.01	0.01	0.02
2400	0.02	0.01	0.01	0.01
2600	0.01	0.01	0.01	0.01
2800	0.01	0.01	0.01	0.01
3000	0.01	0.01	0.01	0.01
3300	0.01	0.01	0.01	0.01
AVE.	**0.022**	**0.022**	**0.014**	**0.028**

Figure 3. Concentration of Carbon Monoxide vs. Speed



Hydrocarbon (HC) is also a product of incomplete combustion in the engine. Unadditized diesel and the three biodiesel blends have a small amount of HC concentration from low speed/high load to high speed/less load, as shown in Table 9. In average concentration, the three biodiesel blends emit fewer HC, as compared to unadditized diesel with a reduction of 39% in blending MME, 13% in blending JME and 11% with WCOME.

Table 9. Hydrocarbon Concentration of Unadditized Diesel and Fuel Blends at Different Speed

RPM	**Hydrocarbon, (ppm HEX)**			
	Unadditized Diesel	**JME**	**MME**	**WCOME**
1400	17	22	3	2
1600	4	4	6	12
1800	6	7	7	14
2000	9	8	6	15
2200	12	1	5	17
2400	12	7	5	1
2600	5	8	6	2
2800	9	8	8	4
3000	12	5	5	6
3300	1	6	2	4
AVE.	**8.7**	**7.6**	**5.3**	**7.7**

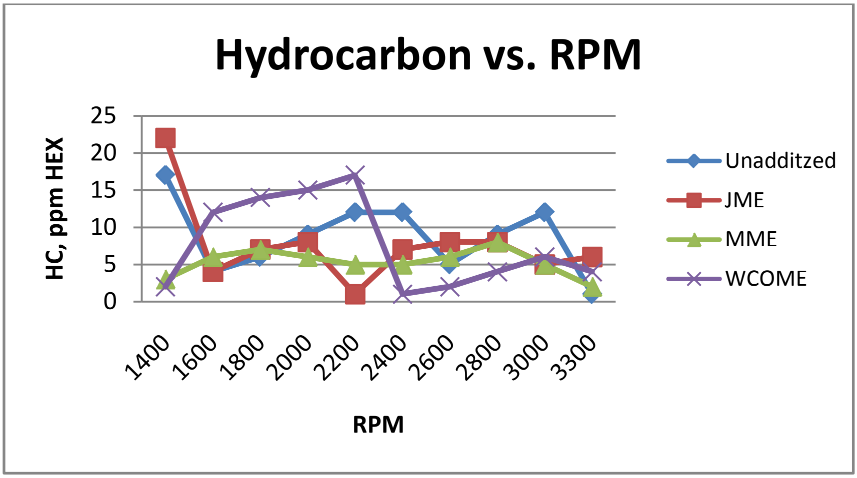


Figure 4. Concentration of Hydrocarbon vs. Speed

The nitrogen oxide (NOx) formed during combustion is a by-product of high temperature in the engine. As shown in Figure 5, high concentrations of NOx for the unadditized diesel and for the three blends were registered at 1,600 rpm to 2,000 rpm and decreases as the speed increases or the load decreases. In average concentration, as shown in Table 10, JME decreases by 3% followed by MME with 2% reduction. The WCOME biodiesel blend has almost the same concentration of NOx as unadditized diesel.

Table 10. Nitrogen Oxide Concentration of Unadditized Diesel and Fuel Blends at Different Speed

RPM	**Nitrogen Oxide, (ppm vol.)**			
	Unadditized Diesel	**JME**	**MME**	**WCOME**
1400	262	251	275	251
1600	335	281	319	308

1800	302	290	303	303
2000	283	295	278	285
2200	267	257	253	261
2400	230	230	221	228
2600	205	207	202	215
2800	183	181	168	179
3000	122	122	123	134
3300	38	39	45	51
AVE.	**222.7**	**215.3**	**218.7**	**221.5**

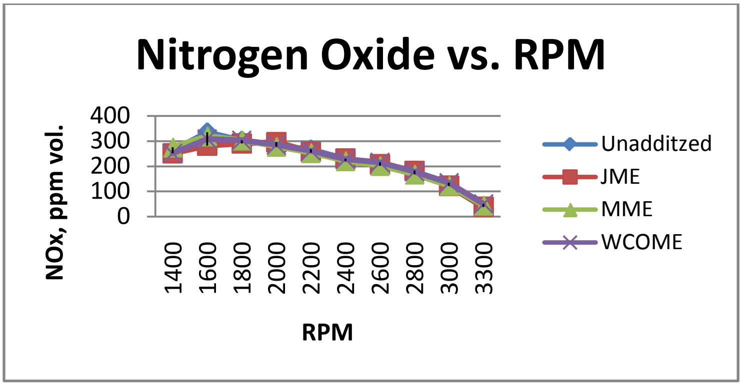


Figure 5. Concentration of Nitrogen oxide vs. Speed

Conclusion and Recomendation

1. Smoke densities of unadditized diesel and of the three biodiesel blends such as JME, MME, and WCOME conform to the in-use vehicle emission standards for compression-ignition engine from low speed/high load to high speed/less load.
2. CO concentration from MME decreased by 37% on average, compared to unadditized diesel. JME registered the same concentration as unadditized diesel. An increase of 27% in the

average concentration of WCOME was registered due to incomplete combustion attributed to the chemical properties of the oil.

3. HC concentrations of unadditized diesel and of JME, MME and WCOME registered lower at different speeds. On average, JME, MME and WCOME showed lesser hydrocarbon concentration, as compared to unadditized diesel.
4. NOx concentration of the three blends slightly decreased compared to unadditized diesel

The results of this study show that other feedstocks for biodiesel, including Moringa and Jatropha, can be used as an alternative to coconut oil to lower smoke density and exhaust gas emissions from compression ignition engines. Methyl ester from waste cooking oil did not pass the biodiesel standard, likely due to insufficient combustion.

It is recommended that further testing on these possible biodiesel feedstocks be done using an engine dynamometer test bed to validate the performance of the engine in terms of power and efficiencies.

REFERENCES

Ristinen, R.A. and Kraushaar, J.J (1999). Energy and the Environment. John Wiley & Sons , Inc.

Kinast, J. (2003). Production of Biodiesels from Multiple Feedstocks and Properties of Biodiesels and/Blends. National Renewable Energy Laboratory.

McCormick R.L., et al (2006). Effect of Biodiesel Blends on Vehicle Emissions. National Renewable Energy Laboratory.

UNEP_TNT .(April 2009). Toolkit for Clean Fleat Strategy Development Philippine Pilot Case Study Report. Retrived from http://cleanairinitiative.org/portal/sites/default/files/presentations/pres45.pdf

USAID- Philippines, (2013). Reducing Emissions to Increase Profits of Jeepney and Bus Drivers in Metro Manila. Retrieved from http.//www. Philippineusaid.gov/programs/energy-environment.