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The Use of Dihydroxy Fatty Acid and Palm-Based Polyol as Selected Components of Envo-Diesel Fuel Blends to Reduce C.I. Engine Gaseous Emissions and Carbon Deposits

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ABSTRACT

Nowadays, engine problems such as higher NOx, increase in smoke content and low brake power output due to biofuel fueled engine have been reduced by several improvements by using additives or modifications on engine itself. This paper presents a type of compositions and proper combination of selected chemical components which may be used in palm olein-diesel blends namely “Envo-Diesel”. The blended component was designed as an additive package which was blended with diesel-biofuel at 99:1 up to 95:5 percent ratios. Blended fuels with additive have been used in the single cylinder engine which operated under 2000 rpm for 100 hours. Engine performance and emissions tests were conducted as well as engine deposit analysis was done after 100 hours engine operation time. The result was found that by using combined additive engine fuel consumption was decreased about 5%, NO_x and SO_x emission also reduced about 10% and carbon deposit was found less compared to other fuels especially for higher percentage of additive. Other results such as engine power and CO emission were found quite similar with 100% diesel fuel. These phenomena was shown that by using selected additive in certain amount found to be suitable to reduce diesel engine consumption and exhaust emissions as well as minimizing carbon deposit.

INTRODUCTION

Recently, the use of diesel engines has increased rapidly because of their low fuel consumption and high efficiencies [**1**]. Nowadays, diesel engines are used in transportation, power plant generation equipment, construction and industrial activities. These wide fields of the usage lead to increase the demand for petroleum fuel due to diesel engine usage is increased with increased in their applications [**2**]. The world is presently confronted with crises of fossil fuel depletion and environmental degradation.

The present energy scenario has stimulated active research interest in non-petroleum, renewable, and non-polluting fuels. The world reserves of primary energy and raw materials are, obviously, limited. According to an estimate, the reserves will last for 218 years for coal, 41 years for oil, and 63 years for natural gas, under a business-as-usual scenario [**3**].

The depletion of world petroleum reserves and increasing of demand also causes rise in fuel prices. The prices of crude oil keep rising and fluctuating on a daily basis which are at near record levels and are stabilizing at about US$140 per barrel now at Malaysia [**4**]. This necessitates developing and commercializing unconventional fuel from natural sources. This may well be the main reason behind the growing interest for unconventional bio-energy sources and fuels around the world especially developing countries, which are striving

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hard to offset the oil monopoly.

This study concentrates on assessing the viability of using alternative fuels in the existing internal combustion engines. In Malaysia, many researches are carried out on palm oil to produce biofuel or biodiesel as an alternative fuel. Malaysia has become the biggest palm oil producer country in the world followed by Indonesia. Recently, Malaysian Palm Oil Board (MPOB) has been produces the palm oil-diesel blended fuel which called "Envo Diesel" for local use.

The objective of this study is to carry out an experimental investigation of the deposits characterization, performance and the exhaust emission characteristics of a diesel engine fueled with Envo Diesel (ED) and Envo-Diesel blended combined additives with percentages 1% and 5% respectively. The additive was used in this study is combination of DiHydroxy Fatty Acid (DHFA) and palm-based polyol in 50:50 percentage.

The used of these additives was selected due to DHFA and Polyol were synthesized and produced from palm oil which is renewable, safe and environmental friendly. The plam-based polyol can be produced from epoxidized palm oil which is reacted with polyhydricalcohol. A polyol istself is an alcohol with more than two reactive hydroxyl groups per molecule. DHFA is also produced from palm oil which is proven improved biofuel pour point and cloud point [**5**]. Since these low-temperature properties of biofuel are important to represents oil quality for wide storage and pipeline distribution. The properties of a typical palm-based polyol are showed in Table 1 [**6**].

Table.1 Typical properties and specifications of polyol from palm oil

Properties	Result	Method
Colour	Brownish yellow	Visual
Odour	Slight/typical	Odiur
Hydroxyl value, mg KPH g^{-1}	170-200	AOCS CD-13-6
Viscosity, mPa.s @ 40ºC	3,500-4,500	ASTM D 4878
pH	6.5-7.5	pH meter
Acid value	3.0 max	AOCS CS-3D-63
Water content, %	0.3 max	AOCS CA2E-84
Specific gravity	0.95-0.98	Gravimetriv

TEST PROCEDURES AND FUEL PROPERTIES

Five samples were prepared for this experiment namely ED100 for 100% Envo-Diesel, ED99 for 99% Envo-Diesel blended 1% additive, ED95 for 95% Envo-Diesel blended 5% additive and D100 for 100% conventional diesel no.2 as baseline. Additive was prepared based on 50%-50% volume base of each additive (DHFA and plam-polyol) which mixed using homogenizer machine under room temperature and 2500 rpm.

The dynamometer instrumentation used in this investigation and experimental procedure was done in accordance with SAE Recommended Practice J1349 JUN 90. All tested fuels were used as a fuel for single cylinder diesel engine which operated under 2000 rpm for 100 hours and 50% load. This study with this condition was designed to according to meet the long period durability test condition. It's also expected has big possibility to characterized the deposit due to proper amount could be obtained. Although, engine deposits, emissions and performance of diesel engine have been influenced with several factors such as engine operation condition, fuel components, engine combustion system, etc, the preliminary investigation of fuel component which involved mostly renewable based components are presented in this paper. The use of 50% load result in reduction of engine power output, since this study was focused only on emissions and deposit, the effect of fuel and engine operation condition was excluded in this paper.

Exhaust emissions were measured using HORIBA MEXA 9200D Compact Cabinet Gas Analyzer. The analyzer was interfaced with engine data acquisition system which possible to collects all of the data's at the same time. Exhaust gases concentration was logged for every 5 sec which was result in average emission finally. The Hartridge smoke meter was used to measure smoke emission. The smoke probe was placed at the end of exhaust pipe during the test and the smoke concentration was collected every 1 min manually from analyzer LED display.

Experimental set-up and fuel composition as well as their properties are showed in Table 1 and Table 2 respectively.

Table.1 Engine specification and test condition

Engine and Dynamometer type	Yanmar L100 AE coupled with digitally controlled SACHS Eddy Current dynamometer
Engine specification	406 cc, Single cylinder, 18 kW max. power output, direct injection, Power @ 3600rpm: 10.0hp Max. Speed: 3600 Compression ratio: 20:1 Engine head material: Aluminium Speed governor: Centrifugal mechanical Lubrication system: Forced Oil sump capacity with filter: 1.7qt. Engine stop system: Fuel solenoid Fuel pump: Electric Fuel pump discharge: 2.3' Fuel consump. @ full load: .660gal/hr Air combustion requirement: 23cfm Starting battery: 45Ah - 12V Starter: 0.8kW - 12V Max. inclination: 30° Water pump flow: 4.4gal/min
Test duration	100 hours
Load	50%
Speed	2000 rpm

Table.2 Fuel composition and properties

Properties	D100	ED100	ED99	ED95
Viscosity (cSt) at 40 °C at 100 °C	 3.97 -	 4.44 1.70	 4.35 1.66	 4.4 1.6
Density (kg/L) at 15 °C	0.8	0.84	0.85	0.86
Flash Point (°C)	98	140	115	100
Calorific Value (MJ/kg)	46.2	45.8	46	46.16
Sulfur Content (%)	0.5	n/a	0.28	0.16
Specific Gravity At 15ºC	0.83	0.87	0.835	0.846

RESULTS AND DISCUSSIONS

3.1 *Carbon deposit characterization*

Fraction concentration based on TG analysis is shown in Figure 1. D100 shows higher fractions of oxidized hydrocarbons and polymeric materials compared to the likes of ED100, ED99 and ED95. Some studies concluded that greater accumulation of hydrocarbon material is associated with the polymeric additives which acts like a binder or adhesive to promote deposit accumulation [**7**].

Carbon black and inorganic ash would probably be the main culprits of the main components in the accumulated deposits on the cylinder head but with less polymeric materials (binder) there would be a less risk or possibility of sticking together as accumulated deposits. This can be also seen in the initial observation of deposits before scrapping it of the cylinder head.

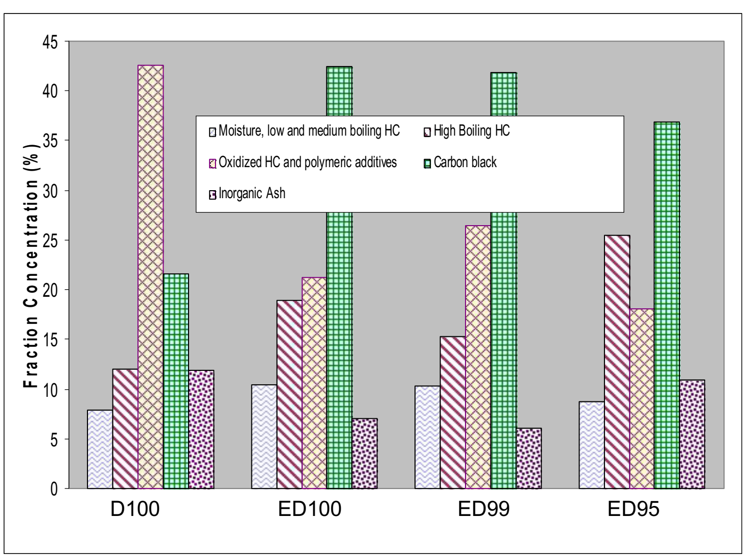

Fig. 1 Fraction concentration for every fuel samples

Figure 2 depicts 20x optical microscopy pictures of fuel samples. These images show most of the deposits consist of fine particles. However, ED95 sample shows large aggregates of carbon deposits and large void volumes which with initial examination from the cylinder head engine would seen as brittle and less sticky compared to other fuel samples like D100, ED100 and ED99. This would form an indication that deposits from ED95 samples are easier to flow out through the exhaust pass ways because there are not accumulated due to the stickiness of the deposits.

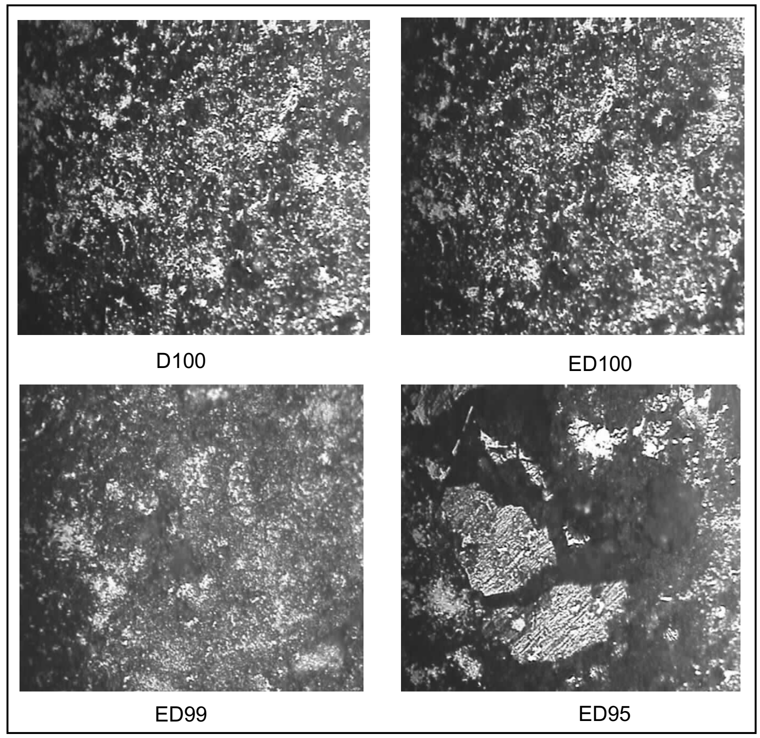

Fig. 2 Microscopy picture (20 x magnifications) of cylinder head deposit for every tested fuels

3.2 *Exhaust Emissions*

3.2.1 Oxide of Nitrogen and Exhaust Temperature

The variation of exhaust gas temperatures of all the fuels are shown in Fig. 3. Exhaust gas temperatures of the blended fuels are lower than those of the diesel fuel due to the lower heating value of envo-diesel and also might be due to the ability of additive to control combustion temperature. Exhaust temperature data was collected during test for every 10 minute and was analyzed in order to get average of exhaust temperature during 100 hours test. The exhaust temperature also strongly related to NOx emission which is confirmed that NOx emission is increased when exhaust temperature higher. This phenomenon has been detected by other workers when engine fueled by oxygenated fuel or vegetable oil [**3**].

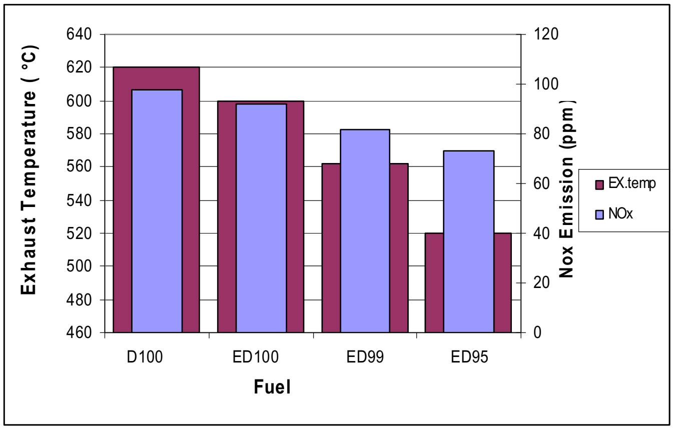

Fig. 3 Exhaust temperature and NOx relationship

NOx emission for every tested fuel is showed in Fig. 3. It can be seen that with presence of 5% combined additive into envo-diesel blended fuel the NOx emission was successfully reduced approximately 15% compared to conventional diesel. This result confirmed that by using fatty acid additive and polyol it's possible to control peak combustion temperature and extreme combustion chamber wall temperature. Other researcher was stated that DHFA and polyol is suitable additive for pour point improver which affects to fuel stability [**5**]. However, in this study other beneficial of these combined additives have been obtained and it's suggested as post-combustion exhaust gas treatment additives.

3.2.2 Smoke Emission

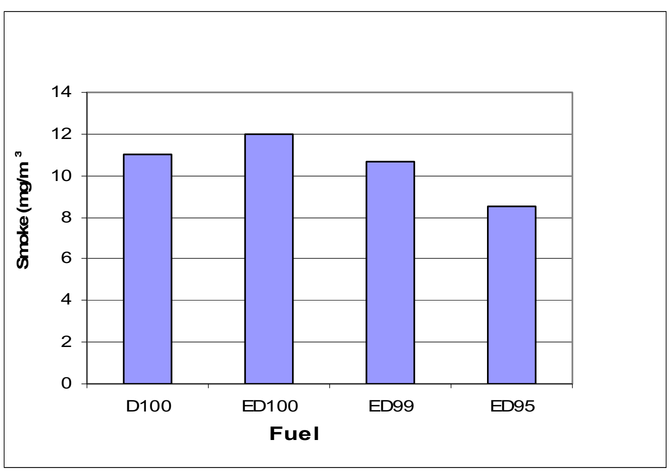

Fig. 4 Smoke content

Smoke is a suspension in air (aerosol) of small particles resulting from incomplete combustion of a fuel. It is commonly an unwanted by-product of fuel combustion. Smoke produces from incomplete combustion of fuel resulting from fuel cooling effect or fuel air mixing problem etc. The average smoke emission is shown in Fig.4. It is found that the lowest smoke produces by 5% additive blended envo-diesel. However, for 1% additive smoke opacity reduction showed less significant compared to conventional diesel fuel.

This proves that by using 5% additive could produces more complete combustion as compared to 1% additive and 100% envo-diesel. From the figure also could be noted that with presence of combined additive about 1.75% up to 5% reduction of smoke opacity could be achieved.

3.2.3 CO, CO_2 and HC Emissions

As diesel engine operates with an overall lean mixture, their CO emissions are normally lower than gasoline engines. Carbon monoxide (CO) is a toxic gas formed by the results from incomplete combustion. Emissions of CO are greatly dependent on the air-fuel ratio relative to the stoichiometric proportions. The CO emission depends on many parameters such as air–fuel ratio and fuel combustion performance into the engine cylinder. Unburned hydrocarbons (HC) are the results of fuel incomplete combustion.

Moreover, HC emission also as a result from flames quenching in crevice regions and at cylinder walls. Other causes of unburned hydrocarbons are running engine on too rich fuel air ratio with insufficient oxygen and the incomplete combustion of lube oil. Another cause is the oil film around the cylinder absorbs hydrocarbons, preventing them from burning, and then releases them into the exhaust gas. Also misfire admits hydrocarbons into the exhaust.

The result of this study shows that the reduction of HC emission when palm based polyol and DHFA were added into envo-diesel fuel. The increase in Polyol-DHFA percentage on envo diesel fuel reduces HC emission. The simply explanation can be made from this result is by using these components could reduces fuel oxidation rate inside the cylinder due to lower fuel evaporation just after its injected. In other word, higher percentages of DHFA-Polyol added into envo-diesel may be affecting to the fuel boiling point which is affect combustion quality finally.

Another thing to be noted is diesel engine HC emission is very low at all engine conditions, less than 200 ppm at most, far below the requirement of the current emission standard. Therefore, very limited researchers were reported results on this particular emission especially for stationary test [**8-10**].

The CO, CO_2 and HC emissions for every fuel showed in Fig.5. From Fig. 5 it's clearly shown that envo-diesel blended additive could reduce CO and HC emissions significantly compared to conventional diesel and envo-diesel without additive. Since CO_2 emission was also noted as one of combustion efficiency parameters, envo-diesel with additive was produced almost similar CO_2 compared to others.

It's confirmed that by using envo-diesel blended additive resulting similar combustion efficiency which is successfully reduced HC, NO_x and CO emissions finally.

This phenomenon also worth to be noted that by using envo-diesel with additive does not have significant negative effects to engine performance but clearly shown positive effects in terms of reducing noxious gases emissions.

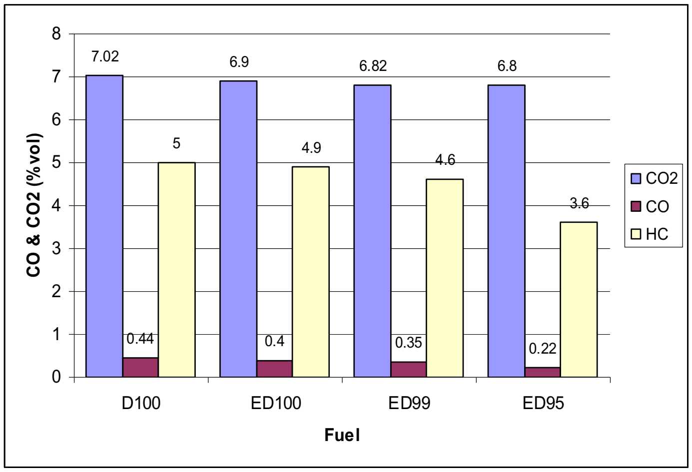

Fig. 5 CO, CO_2 and THC emissions

CONCLUSION

The conclusions can be drawn from this investigation as follows:

1. A single cylinder diesel engine emissions and deposits characteristic when fueled with envo-diesel with selected components such as DHFA and Polyol is presented in this paper.

2. The use of selected components added into envo-diesel is due to they are renewable based and also could improves fuel stability. The components also help to reduce the polymeric fraction which functions as binder to promote deposit accumulation.

3. 1% combined DHFA-Polyol (ED99) was found successfully reduces inorganic ash of deposit compared to other fuel samples. Although, the use of these components were found not significantly reduces carbon deposit of engine cylinder head, the ability of DHFA-Polyol blends on deposit reduction still worth to be noted.

4. Based on microscopy photograph ED95 sample shows large aggregates of carbon deposits and ED95 deposit would seen as brittle and less sticky compared to other fuel samples which are easier to flow out through the exhaust pass ways because there are not accumulated due to the stickiness of the deposits.

5. In terms of exhaust emissions, the use of DHFA and Polyol were found successfully reduces exhaust emissions. The significant amount of emission reduction was found for CO, NOx and HC for envo-diesel blended 1% and 5% DHFA-Polyol compared to 100% envo-diesel and 100% conventional diesel fuel.

6. Smoke content was found lesser for envo-diesel blended DHFA-Polyol fueled engine. However, 100% envo-diesel produce higher smoke emission which shown this particular fuel should be mixed with other components such as DHFA and Polyol in order to compete conventional diesel fuel in terms of smoke emission.

Therefore, DHFA-Polyol was found suitable as additional fuel component especially for biofuel-diesel blends, since they are renewable, can be produced from any vegetable oils and was found successfully reduces exhaust emissions. Although, detail of combustion analysis and the effect of chemical structure of DHFA-Polyol on fuel stability and engine performance are not presented in this paper, based on emissions reduction the simply assumption can be made that by adding these components could improves engine combustion.

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