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# Emission and performance improvement analysis of biodiesel-diesel blends with additives

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**Abstract**

This experimental investigation evaluates the comparative improvement of palm biodiesel-diesel blend (20% palm biodiesel-80% diesel) with the help of ethanol, *n*-butanol and diethyl ether as additives regarding emission and performance characteristics. The improved blends consisted 80% diesel, 15% palm biodiesel and 5% additive. Use of additives prominently improved brake power, decreased BSFC (brake specific fuel consumption) and increased BTE (brake thermal efficiency). Diethyl ether showed highest 6.25% increment of brake power, 3.28% decrement of BSFC and about 4% increment of BTE than 20% palm biodiesel-diesel blend when used as additive. Other two additives also showed interesting improvement regarding performance. All the blends with additives showed decreased NO and CO emission but HC emission showeda slight increment. However, this experiment reveals comparative suitability of these three additives on improving biodiesel-diesel blend.

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*Keywords*: Diesel-biodiesel blends ; Additives ; Ethanol ; *n*-butanol ; Diethyl ether

## 1. Introduction

The ever increasing energy demands in the power generation and transport sectors together with the limited availability of fossil fuels and the negative environmental effects resulting from their use have attracted researchers towards finding alternative fuels to progressively substitute conventional ones. Among the alternative fuels, biodieselhas received increasing attention due to their attractive characteristics of being renewable in nature and decreasing effect on HC and CO emissions. On the contrary, major problems associated with the use of biodiesel are lower engine power, higher BSFC due to their lower calorific values, higher densities and viscosities. NOx emission also increases with the use of biodiesel for higher fuel bound oxygen. To overcome some of these difficulties use of ethanol, *n*-butanol or diethyl ether in small proportion as additive has come out with great potential recently. Investigations have been carried out on different proportions of ethanol in the biodiesel - diesel blend to improve the performance and emission characteristics [1, 2]. *n*-butanol is a strong alcohol competitor of ethanol as additive to be used in diesel engine which is also a biomass-based renewable fuel. *n*-butanol has higher heating value, higher cetane number, less hydrophilic tendencyand higher miscibility than ethanol. Hence, *n*-butanol has got superior characteristics than ethanol to be used as additive. Diethyl ether, another potential additive, can be produced from ethanol. It has got a very high cetane number,

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high oxygen content, low autoignition temperature, high miscibility in diesel and broad flammability limits. A literature search revealed a few such works with limited information, where these potential three additives are compared regarding performance and emission while used in a biodiesel-diesel blend. To fill up this gap, the idea of this study was concentrated to improve a 20% blend of palm biodiesel with diesel fuel (DP20) with the help of these additives. For improvement, each of the additives was used in 5%, replacing biodiesel. The final ratio of the improved blends consisted 80% diesel, 15% palm biodiesel and 5% additive. The idea was to maintain 20% of biofuel into the blends. For the sake of ease, blends containing ethanol, *n*-butanol and diethyl ether was named D80P15E5, D80P15B5 and D80P15DE5 respectively. The comparison revealed some interesting features which are interpreted by the following experimental procedure.

## 2. Equipment and experiments

### *2.1. Fuel properties*

Palm biodiesel was collected from Forest Research Institute Malaysia (FRIM) and the additives were purchased from Nacalai Tesque, Inc. Kyoto, Japan certified to a purity of 99.5%. Diesel fuel was collected from the local market. Physiochemical properties of the fuels like density, viscosity, flash point, cetane number, calorific value are very much influential to the engine performance and emission characteristics. These are the properties which indicate the quality of the fuel. Most of the researchers have concentrated their attention to the density, kinematic viscosity, flash point, and calorific value to define the quality of fuel [3-6]. Among them density and viscosity are the most important parameters of fuel because the fuel has to flow through various pipelines, nozzles and orifices. Furthermore, they have great influence on the atomization of fuel which governs the quality of combustion as well as the performance and emission characteristics. As the density and viscosity of biodiesel are higher than diesel, use of ethanol, *n*-butanol and diethyl ether as additives helped to decrease both density and viscosity. These additives have got decreased calorific values than biodiesel, so the blends showed the less calorific value than DP20. Flash point also showed decreased manner. Regarding cetane number, with an exception of D80P15DE5, D80P15B5 and D80P15E5 showed lower values than DP20.Apparatus for testing fuel properties and the properties of the fuels are given in Table 1 and Table 2.

### *2.2. Experimental setup and procedure*

This study was conducted on a YANMAR TF 120-M diesel engine mounted on a test bed, manufactured by Yanmar Co. Ltd of Indonesia. There were two fuel tanks, one for diesel fuel and the other one was for blended fuels. The engine was coupled to an eddy current dynamometer which can be operated at a maximum power of 20 kW at 2450 to 10000 rpm. BOSCH BEA-350 exhaust gas analyzer was used for engine emission analysis of NO, HC and CO. The engine was first ran fuelled with diesel to define the baseline parameters as well as for the warm up purpose. Engine performance parameters those have been measured are brake power, brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE). The engine performance test was carried out at 100% load. Engine speeds were varied in between 1200 to 2400 rpm, at an interval of 200 rpm. For data acquisition, DYNOMAX 2000 data control system was used which is monitored with the help of DYNOMAX 2000 software. Emission analysis was also conducted at full load with engine speeds in between 1200 to 2400 rpm. Specifications of the gas analyzer and the engine are given in Table 3 and 4 respectively.

Table 1. Apparatus for fuel property testing.

| Properties | Apparatus |
|---|---|
| Density<br>Kinematic Viscosity | Stabinger Viscometer SVM 3000<br>Manufacturer: Anton Paar |
| Flash point | Pensky-Martens flashpointautomatic NPM 440<br>Manufacturer: Normalab, France |
| Calorific Value | Semi auto bomb calorimeter<br>Model: 6100EF<br>Manufacturer: Paar, USA |

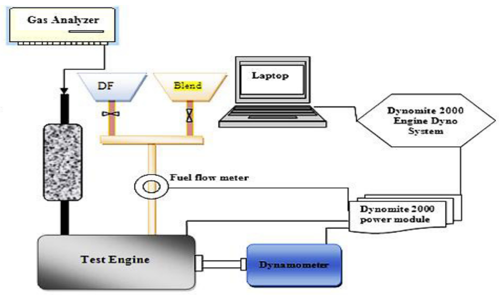


Fig. 1. Schematic of experimental setup

Table 2. Characteristics of the investigated fuels

| | Diesel | Palm biodiesel | Ethanol | *n*-butanol | Diethyl ether | DP20 | D80P15E5 | D80P15B5 | D80P15DE5 |
|---|---|---|---|---|---|---|---|---|---|
| Kinematic viscosity @ 40°C ($mm^2$/sec) | 3.46 | 4.69 | 1.14* | 3.00* | 0.22* | 3.62 | 3.23 | 3.29 | 3.27 |
| Density Kg/$m^3$ | 833 | 859 | 791* | 812* | 712* | 837 | 833 | 833 | 832 |
| Calorific Value (kJ/g) | 44.66 | 39.90 | 27.33 | 34.33 | 33.89 | 43.71 | 43.08 | 43.43 | 43.41 |
| Cetane number | 47 | 55 | 5~8 | ~25 | ~125 | 48 | 46 | 47 | 52 |
| Flash point °C | 69.5 | 188.5 | - | 35 | - | 93.5 | 84.5 | 85.5 | 81.5 |

* Measured at 20°C

Table 3. Exhaust gas analyser specification

| | Method | Measurement | Upper limit | Accuracy | Uncertainties (%) |
|---|---|---|---|---|---|
| BOSCH Exhaust Gas Analyser | Non-dispersive infrared | CO | 10.00 vol.% | ±0.02 vol.% | ±0.2 |
| | Flame ionization detector (FID) | HC | 9999 ppm | ±1 ppm | ±0.5 |
| | Heated vacuum type chemical luminescence detector (CLD) | NO | 5000 ppm | ±1 ppm | ±0.5 |

Table 4. Engine Specification

| Engine type | 4 Stroke DI diesel engine |
|---|---|
| Number of cylinders | One |
| Aspiration | Natural aspiration |
| Cylinder bore * stroke (mm) | 92*96 |
| Displacement (L) | 0.638 |
| Compression ratio | 17.7 |
| Maximum engine speed (rpm) | 2400 |
| Maximum power (kW) | 7.7 |
| Injection timing (deg.) | 17° bTDC |
| Injection pressure (kg/$cm^2$) | 200 |
| Power take off position | Flywheel side |
| Cooling system | Radiator cooling |

## 3. Results and discussion

### *3.1. Engine performance results*

#### *3.1.1. Engine brake power*

Variation in the brake power as the function of speed for diesel fuel and the blends are given in the Fig. 2. It can be seen that, the general trend of brake power was increasing as the speed was increased up to 2000 rpm. After that brake power decreased which can be attributed to the higher frictional force due to higher speed. D80P15DE5 gave the highest brake power while the DP20 gave the lowest. The lowest power for DP20 can be attributed to its lower calorific value and lower combustion efficiency due to higher density and viscosity. D80P15E5, D80P15B5 and D80P15DE5 gave about 3.38%, 6% and 6.25% increment of brake power than DP20 respectively at 2000 rpm. However, in spite of lower calorific value, these blends showed higher brake power than DP20 which ensures higher combustion efficiency. This higher combustion efficiency is the result of their decreased density and viscosity which improved atomization.

### *3.1.2. Brake specific fuel consumption*

Brake specific fuel consumption (BSFC) is shown in the Fig.3.The fuel mass flow rate was calculated from the respective

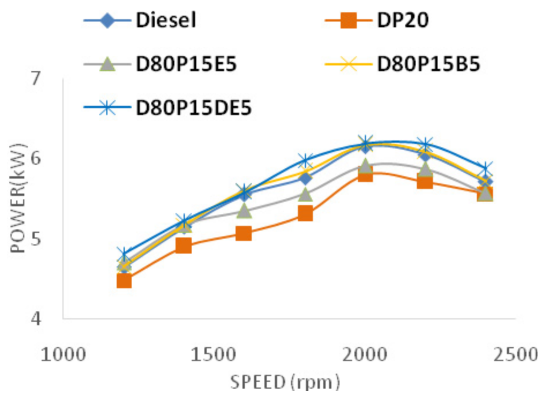


Fig. 2. Comparison of engine power vs. speed

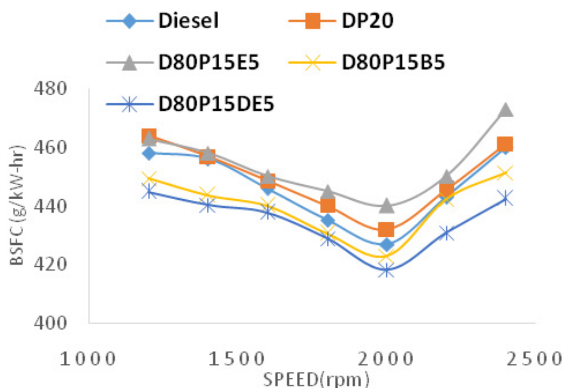


Fig. 3. Brake specific fuel consumption vs. speed

measured volume flow rates and densities. As the comparison of BSFC is effected at the same speed and constant full load, which means at a certain engine power, the values of BSFC are then obviously directly proportional to the fuel mass flow rate [7, 8]. It can be seen from Fig. 3 that D80P15B5 and D80P15DE5 has shown lower BSFC corresponding to DP20 as well as diesel. Though they have got lower calorific values, this kind of result can be attributed to good atomization and combustion quality. Combining the facts, lower BSFC with lower calorific value, Fig.4 can be easily explained where it shows the brake thermal efficiency (BTE) of D80P15DE5 and D80P15B5 are higher than DP20 and diesel fuel. As BTE is simply the inverse of the multiplication of BSFC and calorific value, consequently they showed this kind of higher BTE. For D80P15E5, though its calorific value was the lowest among the blends, it showed lower BTE for its higher BSFC which depicts its lower combustion efficiency than D80P15DE5 and D80P15B5.

## *3.2. Exhaust emission characteristics*

### *3.2.1. Hydrocarbon (HC) Emission*

The effect of addition of additives on HC emission is shown in the Fig.5. Unburned hydrocarbon originates from various sources in the cylinder during combustion. It can be observed that, oxygenated compounds available in the biodiesel made the HC emission lower in the case of DP20. In spite of higher oxygen content of ethanol, *n*-butanol and diethyl ether (34%. 21.6% and 21.6% respectively), blends showed higher amounts of HC emission. This behavior can be the effect of addition of additives like ethanol, *n*-butanol and diethyl ether which make it easier to evaporate the fuel and slipped into the cylinder especially at low speed during expansion stroke [9]. Another reason can be mentioned here is the increase of 'lean outer flame zone'. This actually means the envelope of the spray boundary where the fuel is already beyond the flammability limit because of over mixing [10]. However, the comparative emission of HC among the blends with additives can be explained easily with the oxygen content of the additives mentioned earlier.

### *3.2.2. Carbon monoxide (CO) emission*

Fig. 6 shows the emission of CO of the blends. CO emission of DP20 is much lower than diesel fuel which can be attributed to the higher fuel bound oxygen. D80P15E5, D80P15B5 and D80P15DE5 showed even lower CO emission than DP20 because of their superior level of oxygen content as stated in the previous section. Extra fuel bound oxygen in the blends ensures the oxidation of CO even on locally fuel rich zones which helps to reduce CO emission [11]. However, different level of CO emission among the blends with additives can be explained by the physical and chemical properties of the additives.

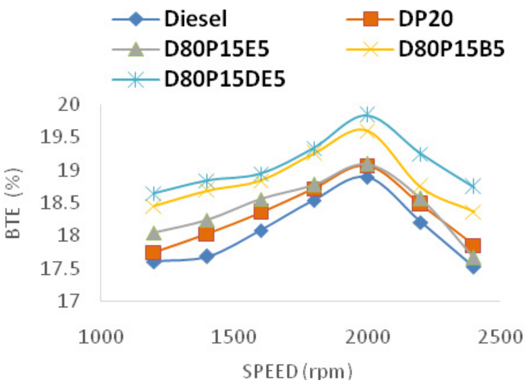


Fig. 4. Brake thermal efficiency vs speed

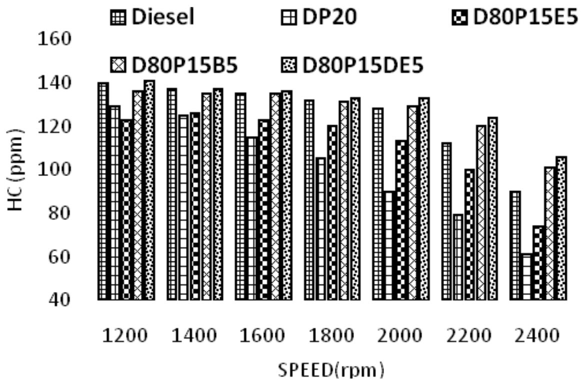


Fig. 5. Comparative HC emission vs speed

### *3.2.3. Nitrogen Oxide (NO) Emission*

Fig.7 shows the comparative NO emission of the diesel and fuel blends. As the speed decreased, NO emission of all the blends increased. It can be attributed to the higher available time span of combustion as the speed becomes lower. DP20 showed higher NO all through the engine test as because it contains higher level of oxygen [12-14]. However, though ethanol and *n*-butanol have got higher oxygen content, D80P15E5 and D80P15B5 showed lower NO which can be explained by their lower calorific value and higher heat of evaporation which resulted in lower in-cylinder temperature. In the case of D80P15DE5, lower NO can be attributed to reduced part of premixed combustion where NO is mainly formed. Nonetheless, among the blends with additives, D80P15E5 showed the highest amount of NO which is for nothing but the comparatively higher oxygen content of ethanol.

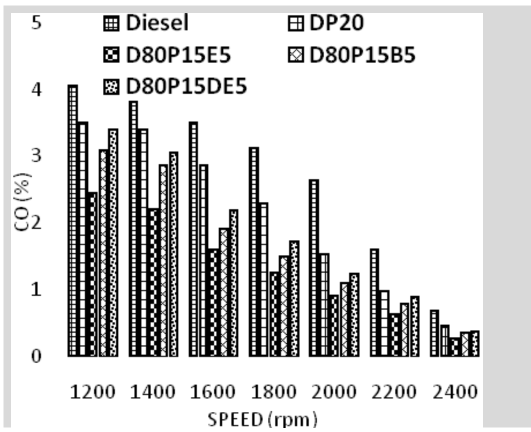


Fig. 6. Comparative CO emission vs speed

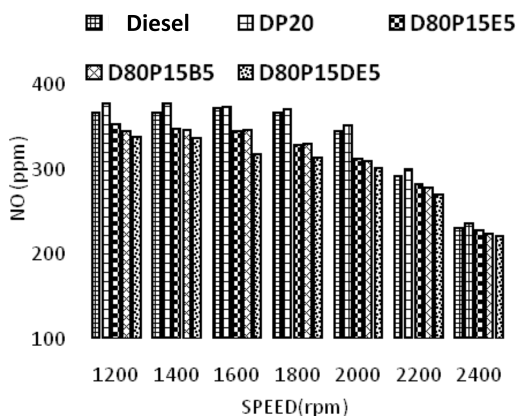


Fig. 7. Comparative NO emission vs speed

## 4. Conclusion

In this study comparative evaluation of the improvement of DP20 was done while blended with additives. These additives improved the fuel blend regarding density and viscosity which in turn improved atomization and showed better combustion characteristics through higher engine brake power, lower BSFC and higher BTE than DP20. Among the additives diethyl ether showed highest improvement through its less density and viscosity profile with quite a high calorific value. *n*-butanol showed quite similar development to diethyl ether but ethanol showed less development because of its lower calorific value. Regarding emission characteristics additives showed quite a good development of CO and NO emission. CO emission decreased for higher oxygen content and NO decreased for lower calorific value and higher latent heat of evaporation of the additives. However, it is revealed from this experiment that, ethanol, *n*-butanol and diethyl ether are quite effective regarding emission and performance even when they are used only about 5% as additive.


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