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Effect of DEE as an Oxygenated Additive on Palm Biodiesel-Diesel Blend in the Context of Combustion and Emission Characteristics on a Medium Duty Diesel Engine

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Abstract. An investigational effort was conducted for the improvement of Palm biodiesel-diesel blend (P20) with the help of diethyl ether (DEE) which is commonly used as oxygenated cold starting fuel. The selected improved fuels were P15D5 (80% Diesel + 15% Palm biodiesel + 5% DEE) and P10D10 (80% Diesel + 10% Palm biodiesel + 10% DEE). Comparative improvement of the DEE blends than P20 was evaluated in the context of combustion and emission characteristics. Oxygenated nature of DEE reduced the CO and Smoke emissions on average 25% and 35.5% than P20. NO emission reduced for P10D10 on average 20% than P20. However, HC emission was higher for the DEE blends. Combustion parameters like in-cylinder pressure profiles and the heat release rates of the modified blends were also unlike the P20 blend due to number of dissimilarities of chemical properties.

Keywords: diesel-biodiesel blend, diethyl ether, combustion, emission

1. Introduction

Now-a-days this is unanimous that, conventional diesel can be replaced by biodiesels up to a certain extent to solve both of the concerns; energy crisis and legislative emission standards. Therefore, in the automotive fuel market, the share of biodiesel is going to be increased though it has some inherent disadvantages and complications. Higher density and viscosity, poor atomization and evaporation quality, advanced combustion and higher NO emissions and poor cold flow properties etc. are the main problems regarding the use of biodiesels on diesels engines. A convenient way to modify biodiesels is to use various kinds of cold starting fuels to improve the characteristics of the properties [1, 2]. Recently, DEE has emerged as a potential oxygenated fuel to improve the fuel properties of both diesel and biodiesels [3]. It has very high cetane number, reasonable energy density and low autoignition temperature with high oxygen content [4]. In a word, quite suitable to be used in diesel engine either with diesel or biodiesel. Rakopoulos et al. [5] worked with a Ricardo Hydra engine to evaluate the performance and emission of 8%, 16% and 24% blend of DEE with diesel. They reported, except HC, all the regulated emissions like smoke, CO and NO_x decreased with the higher percentage of DEE. However, a gap on the literature was found regarding the improvement of Palm biodiesel-diesel blend with the addition of DEE. An attempt was taken previously by the authors for the improvement with the addition of DEE [4]. On that investigation with an unmodified single cylinder engine, it was observed that 5% DEE improved the performance and emission characteristics of P20 blend in a good manner. Therefore, in the present investigation the authors have attempted to increase the percentage of DEE to observe the effect of increment on combustion and emission characteristics.

2. Materials and Methodology

2.1. Feedstock and additive

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Palm biodiesel was collected from the FRIM (Forest Research Institute Malaysia) and DEE was purchased from Nacalai Tesque, Inc., Kyoto, Japan; certified as 99.5% pure. Petroleum diesel was supplied from the local market supplier.

2.2. Test fuels

In total four test fuels were finalized for this investigation. The test fuels were (a) 100% petroleum diesel, (b) 20% Palm biodiesel + 80% diesel (P20), (c) 15% Palm biodiesel + 5% DEE + 80% diesel (P15D5), (d) 10% Palm biodiesel + 10% DEE + 80% diesel (P10D10). These all fuels were blended on volume basis. Diesel and biodiesel blending was completed by a blending machine at 4000 rpm for 15-20 min. As DEE is volatile in nature, after addition of DEE, the blend was taken to a closed container and shaked with a shaker machine for about 30 min.

2.3. Experimental setup

This experiment was conducted using an inline four-cylinder, water-cooled, turbocharged diesel engine without any emission treatment system. The engine specifications are listed in Table 1. A Bosch BEA-350 exhaust gas analyzer was used for engine emissions analysis of HC, NO and CO. Bosch RTM 430 smoke opacimeter was used to measure the smoke opacity. Engine tests were carried out at constant 80 Nm torque with variable speed ranging from 1000 rpm to 3000 rpm at a 500 rpm interval. For combustion analysis, in-cylinder pressure was measured by using a Kistler 6058A type pressure sensor. Kistler 2614B4 type charge amplifier was used to amplify the charge signal outputs from the pressure sensor. A high precision Leine & Linde incremental encoder was used to acquire the top dead center (TDC) position and crank angle signal for every engine rotation.

Table 1: Test engine specification

Description	Specification
No. and arrangement of cylinders	4 in-line, longitudinal
Rated Power	65 kW at 4200 rpm
Combustion chamber	Swirl chamber
Total displacement	2477 cc
Cylinder bore x stroke	91.1 x 95 mm
Valve mechanism	SOHC
Compression ratio	21:1
Lubrication system	Pressure feed, full flow filtration
Fuel system	Distributor type injection pump
Air flow	Turbocharged
Fuel Injection Pressure	157 bar
Fuel Flow meter	Positive displacement flow meter

3. Results and Discussion

3.1. Fuel properties

Table 2 shows the physicochemical properties of the base fuels and the blends. Each property was tested several times and then mean value was taken.

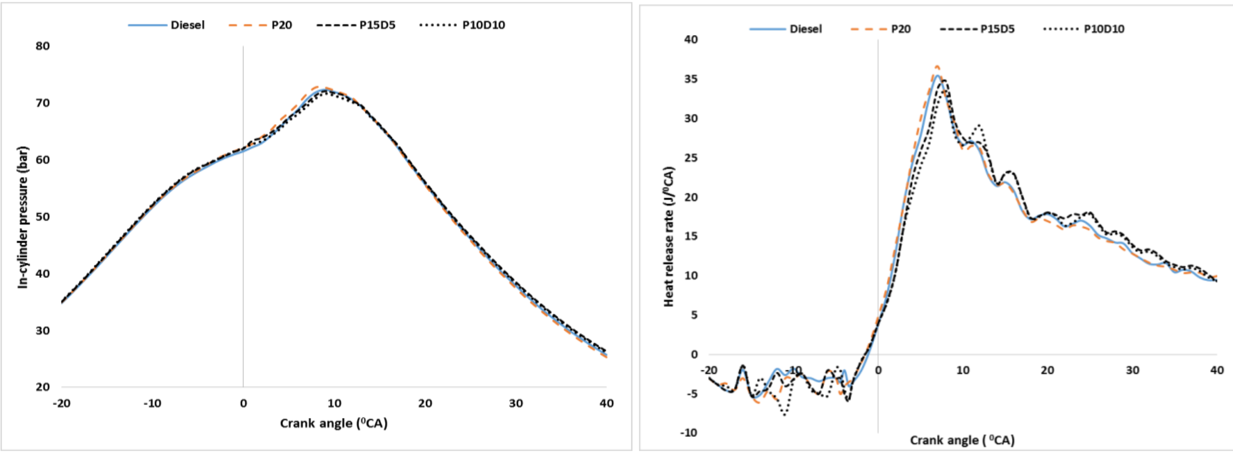
It can be seen from the table that, addition of DEE into the palm biodiesel-diesel blend, reduced the viscosity and density on average 13% and 1.1% compared to P20. Flash points of the modified blends were also lower compared to P20. However, though calorific values decreased for the modified blends, it was only 1% lower on average than P20.

3.2. In-cylinder pressure and heat release rate

Focusing the ‘hot’ part around TDC (top dead centre), cylinder pressure and heat release rate (HRR) against crank angle diagram for palm biodiesel blend and its modified blends with DEE are illustrated in Fig. 1 (a) and (b) respectively at 2000 rpm keeping the toque constant at 80 Nm.

Table 2: Base fuel properties

Property	Unit	Diesel	Palm biodiesel	Diethyl ether	P20	P15D5	P10D10	ASTM D6751	EN 14214
Kinematic Viscosity at 40^{0}C	mm^2/s	3.46	4.62	0.22	3.67	3.26	3.10	1.9-6.0	3.5-5.0
Density at 40^{0}C	kg/m^3	833	870	712	838	831	826	n.s.	n.s.
Lower heating value	MJ/kg	44.66	39.90	33.89	43.70	43.40	43.12	n.s.	n.s.
Flash Point	^{0}C	69.50	188.50	-40	93.50	79.50	70.50	130 (min)	120 (min)
Cetane number (CN)		48	61	~125	-	-	-	47 (min)	51 (min)



(a) (b)

Fig. 1: (a) In-cylinder pressure and (b) heat release rate (HRR) against crank angle diagram for palm biodiesel blend and its modified blends with DEE at 2000 rpm keeping the toque constant at 80 Nm.

Maximum in-cylinder pressure for P20 was 72.78 bar at 8^0 ATDC. Diesel produced 72.38 bar at 9^0 ATDC. Slight early and higher maximum pressure for the P20 blend can be attributed to the higher cetane number of the palm biodiesel compared to diesel [6]. Maximum pressures were reduced and somewhat delayed for the DEE blends. P15D5 and P10D10 showed maximum pressure of 71.71 bar and 71.20 bar respectively at 9.6^0 ATDC and 10.1^0 ATDC. Despite higher cetane number of DEE, combustion pressure reduced which can be explained more clearly by combining it to the HRR analysis of the corresponding fuels. Heat release rate of the Palm biodiesel blends with the addition of DEE at 80 Nm torque and 2000 rpm are given in the Fig. 1 (b). SOCs of P15D5 and P10D10 occurred at -4.1^0 ATDC and -3.1^0 ATDC. More delayed SOCs of DEE (despite its higher cetane number) blends were may be due to the vaporization of DEE, which caused injection into a lower gas temperature environment because of higher latent heat of evaporation and this is verified by the work of Rakopoulos [1]. It can also be observed that the peak heat release rate was also decreased with the incremental addition of DEE and it was actually translated into lower in-cylinder pressures for the DEE blends.

3.3. NO emission characteristics

Fig. 2 illustrates the NO emission for the test fuels. P20 produced 13% higher NO emission on average than diesel. However, 5% blend of DEE gave higher emission of NO. Further addition of DEE reduced the NO emission about 20% compared to P20. It is evident that, on the case of 5% blend, the effect of higher oxygen content was dominant while for 10% blend amount of DEE was good enough to create lower in-cylinder temperature due to higher latent heat of evaporation which has been shown by other researcher for other fuels [7].

3.4. CO emission characteristics

Fig. 3 illustrates the CO emission of the blends. P20 produced on average 25.2% reduced CO emission compared to diesel. P15D5 and P10D10 showed even lower CO emission than P20. They showed 22% and 27% decrement of CO emission respectively compared to P20. Lower density and viscosity of the modified blends increased the atomization efficiency and on top of that higher oxygen content really assisted complete oxidation of the fuel, hence reduced CO emission.

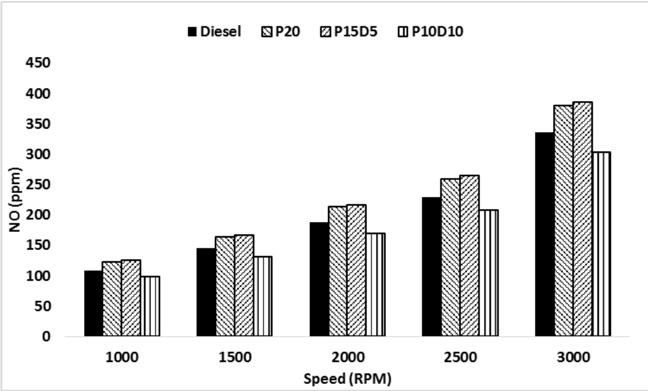


Fig. 2 NO emission of the test fuels

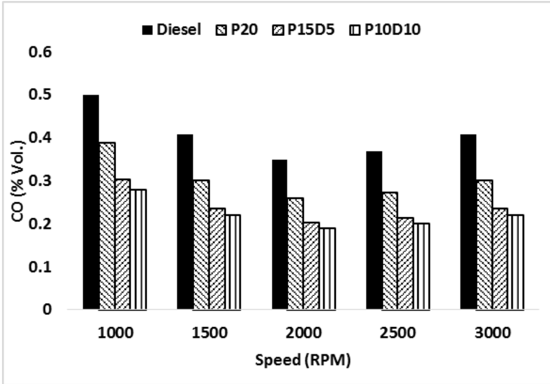


Fig. 3 CO emission of the test fuels

3.5. HC emission characteristics

Comparative HC emission from the test fuels at constant 80 Nm torque with different engine speeds are shown Fig. 4. P20 gave about 20% decreased emission than diesel on average. However, P15D5 and P10D10 showed 47% and 65% increment of HC emission than P20 on average. HC emission was supposed to be reduced due to even higher oxygen content of DEE. However, slip of fuel out of the cylinder especially at low speed during expansion stroke might be the reason for such higher emission as additive like DEE made fuel evaporation easier.

3.6. Smoke emission characteristics

Fig. 5 illustrates the exhaust smoke opacity of the test fuels. P20 gave about 9.2% decreased smoke opacity than diesel fuel. It can be attributed to advanced start of combustion of P20 for higher cetane number. Hence, the combustion started early, it allowed more time for the oxidation of soot [8]. P15D5 and P10D10 showed 32% and 39% decrement of smoke opacity compared to P20. Therefore, it is obvious that such oxygenated blends reduced the probability rich fuel zone formation and assisted to decrease the soot emission.

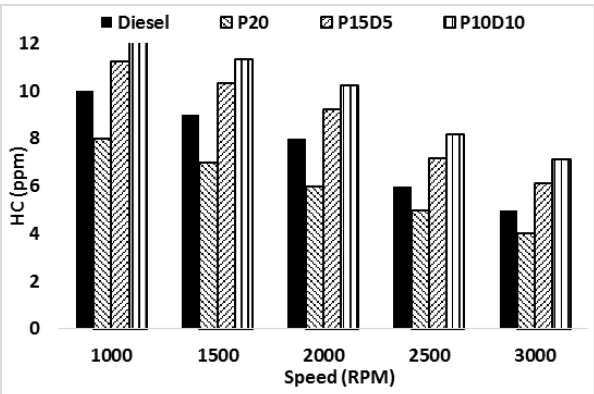


Fig. 4 HC emission of the test fuels

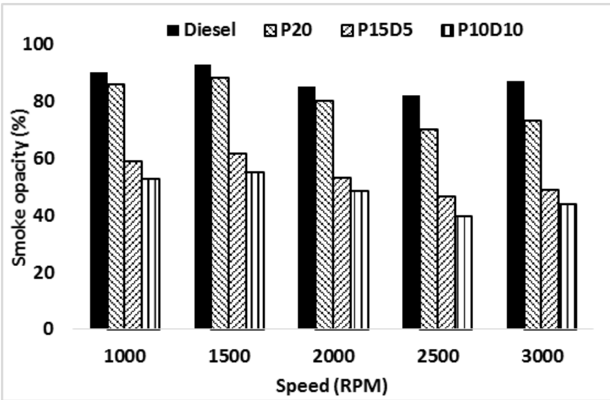


Fig. 5 Smoke opacity of the test fuels

4. Conclusions

From the investigation it is evident that, addition of DEE on the palm biodiesel-diesel blend shows significant improvement regarding the combustion and emission characteristics. DEE reduces effect of advanced combustion of biodiesel increasing the ignition delay. Most importantly, it reduces the in-cylinder temperature and pressure due to higher latent heat of evaporation. Consequently, NO emission reduces compared to biodiesel blends. In addition, due to its higher oxygen content, it reduces CO and smoke opacity. Therefore, addition of DEE is obviously a good technique to improve the combustion qualities and emission characteristics hand in hand.

5. Acknowledgements

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