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Engine performance, emission and combustion characteristics of a common-rail diesel engine fuelled with bioethanol as a fuel additive in coconut oil biodiesel blends

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Abstract

In the present work, an experimental investigation was conducted to investigate the effect of using bioethanol as additive to biodiesel-diesel blends on the engine performance, emissions and combustion characteristics of a four-cylinder, high-pressure common-rail direct injection diesel engine. Two different mixes fuels: B20 (20% coconut biodiesel + 80% diesel) and B20E5 (20% coconut biodiesel + 5% ethanol + 75% diesel) were tested and compared with baseline diesel. The tests were performed under steady state conditions at constant speed of 2000 rpm with three different engine load (0.17 MPa, 0.69 MPa and 1.20 MPa). The results indicated that higher brake thermal efficiency and brake specific fuel consumption were observed when operating with biodiesel and ethanol-biodiesel fuel blends. The ethanol-biodiesel blends showed lower NOx, smoke and CO emissions compared to baseline diesel fuel. In terms of combustion characteristics, B20E5 shows slightly lower in peak pressure and peak HRR at an operating load of 0.17MPa.

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Keywords: Ethanol; Biodiesel; Engine performance; Emissions; Combustion; Diesel engine

1. Introduction

The energy crisis of fossil fuel depletion, rising concern of the volatile crude oil price and environmental degradation have triggered interests in the search for alternative fuels for internal combustion engine. As one of most promising renewable and clean alternative fuel, biodiesel has been widely studied in recent years for compression ignition engines. Biodiesel is biodegradable, non-toxic and can be substituted for diesel fuel with little or no engine modification. However, biodiesel has some limitations in fuel properties such as low volatility, high viscosity and pour point which may lead to some

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problems in long-period engine performance tests. The higher viscosity in biodiesel affects the fuel droplet size, poor atomization qualities and fuel penetration in the cylinder. Alcohol based co-solvent has been reported as additive for diesel and biodiesel-diesel fuel to improve exhaust emission and engine combustion [1, 2]. The application of alcohol as a supplement fuel in CI engine can decrease reliance on fossil fuel, reduce hazardous pollution and strengthen agricultural economy. Bioethanol is a renewable bio-based resource and it can be produced from raw materials such as corn, sugarcane, barley, wheat and etc. Ethanol is an oxygenate alcohol fuel with high oxygen content of 34% by weight, thereby it can yield significant reduction of particulate emissions in CI engines [3, 4].

Sayin [5] studied the effects of methanol-diesel (M5 and M10) and ethanol-diesel (E5 and E10) fuel blends in a single cylinder, four-stroke, direct injection (DI) diesel engine. The results showed that the brake thermal efficiency (BTE), CO, HC and smoke emissions decreased, while brake specific fuel consumption (BSFC) and NOx emissions increased with methanol-diesel and ethanol-diesel fuel blends. Guido et al. [6] investigated the effect of bioethanol with rapeseed methyl ester and diesel blends in a four-cylinder light duty diesel engine with closed loop combustion control. The results showed a strong smoke and NOx emissions reduction, while higher BSFC, CO and HC emissions were observed with bioethanol blends. Zhu et al. [7] studied the effects of ethanol blends in four-cylinder direct injection (DI) diesel engine. The results indicated that ethanol-biodiesel blends showed higher brake thermal efficiency (BTE) and lower NOx and PM emissions compared to diesel fuel. Increasing the ethanol amount in the fuel blends resulted in higher brake BSFC, HC and CO emissions.

In this research study, the effect of a small amount of bioethanol as a fuel additive in coconut oil biodiesel on engine performance, emission and combustion characteristics was investigated in a common-rail DI diesel engine.

2. Methodology

The experimental work was carried out with a four cylinder, high-pressure common-rail DI diesel engine without catalytic converter. The specifications of the test engine are as follows: bore=76.0 mm, stroke=80.5 mm, compression ratio=18.25:1, and maximum output of 48kW at 4000 rpm. A 150 kW eddy current engine dynamometer was used to maintain the variation of loads and speeds. The intake airflow was measured using a Bosch air mass sensor. In addition, a fuel flow meter was employed to measure the fuel consumption of the engine. Temperature values of ambient air, exhaust gas, lubricant oil and cooling water were measured by using K-type thermocouples. The schematic diagram of the experiment setup is shown in Fig. 1.

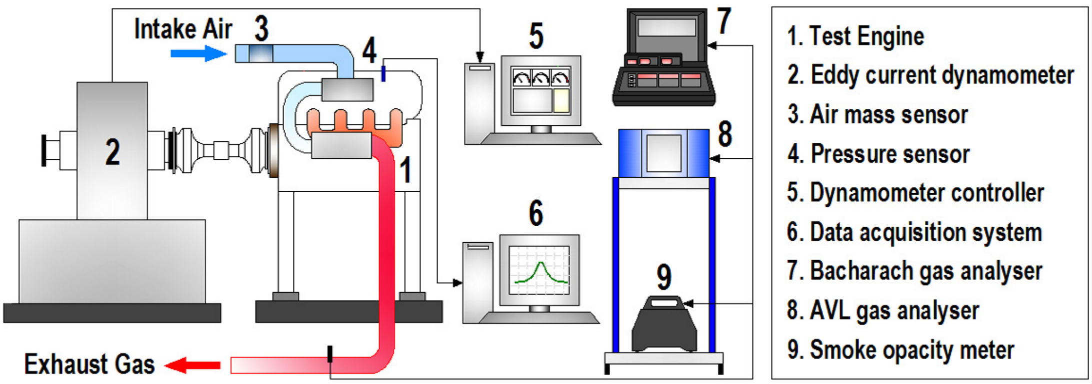


Fig. 1. Schematic diagram of the experiment setup

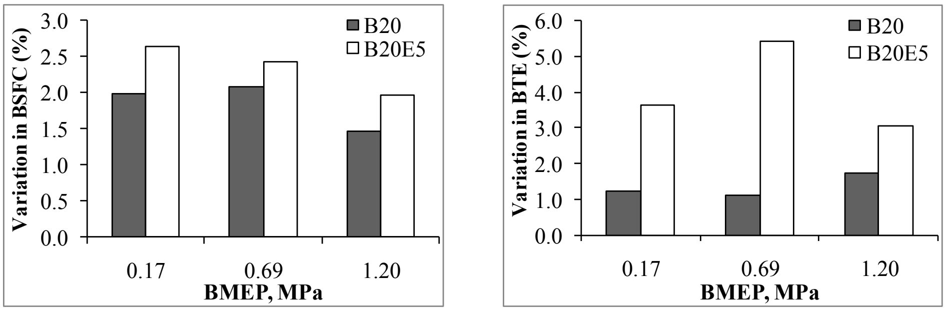
In this study, the tests were performed under steady state conditions at constant speed of 2000 rpm with three different engine loads (0.17 MPa, 0.69 MPa and 1.20 MPa) with three different fuels: baseline diesel, B20 (20% coconut biodiesel + 80% diesel) and B20E5 (20% coconut biodiesel + 5% ethanol + 75% diesel). The bioethanol fuel used in this study is produced from sugarcane with the purity of 99.8%. Table 1 shows the details of the fuel properties of the diesel, B20, and B20E5. The fuel properties testing were conducted according to the ASTM standard.

Table 1: The fuel properties of biodiesel blends

Property	Units	Diesel	B20	B20E5	Test Method
Heating value	MJ/kg	45.31	43.89	43.12	ASTM D4809
Density at 40°C	kg/m^3	840.0	843.1	839.0	ASTM D7042
Kinematic viscosity at 40°C	mm^2/s	3.51	3.74	3.33	ASTM D7042

3. Results and Discussions

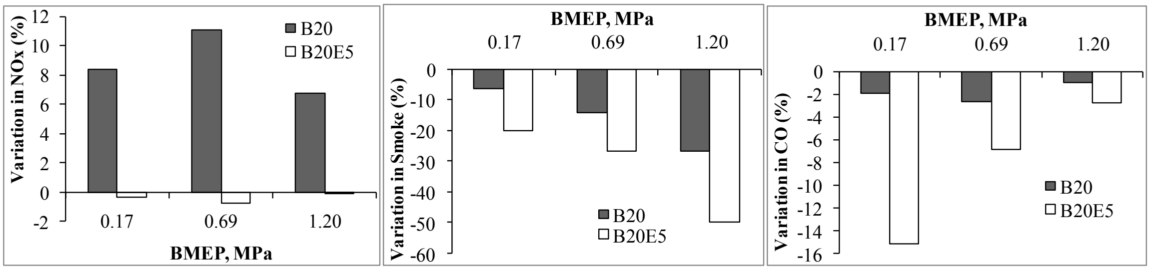
Fig. 2(a) and (b) show the variation in BSFC and BTE for B20 and B20E5 at different engine load conditions. The results show that the BSFC for B20 and B20E5 are 1.5-2.1% and 2.0-2.7% respectively, higher compared to baseline diesel fuel at all engine loads. The increase of BSFC is mainly due to the lower heating value of biodiesel and ethanol blends compared with that of baseline diesel as shown in Table 1. As a result, a larger amount of fuel is required to obtain the same engine power output to that of baseline diesel fuel. As shown in Fig. 2(b), the BTE of biodiesel and blended ethanol fuel is higher than those of baseline diesel under all engine load operations. This can be attributed to the increased availability of fuel bound oxygen content in the oxygenated fuels (B20 and B20E5), thereby enhancing the combustion efficiency and resulting in higher BTE. The addition of ethanol in the fuel blend has improved the BTE by 3.0-5.4% compared to baseline diesel fuel.



(a) (b)

Fig. 2. The variation in (a) BSFC and (b) BTE for B20 and B20E5 at different engine loads

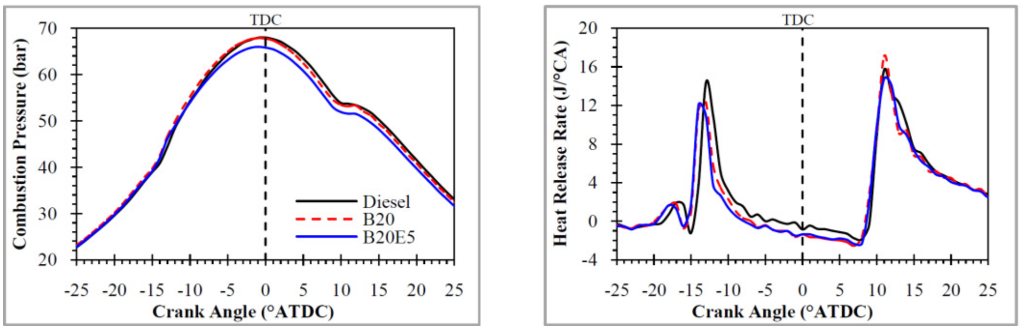
The variation in NOx, smoke and CO emissions for various test fuels is depicted in Fig. 3(a), (b) and (c) respectively. The NOx emission for coconut biodiesel blends is higher compared to baseline diesel at all load conditions. This is mainly due to the oxygen content of biodiesel fuel, which resulted in higher combustion temperature and hence promotes a thermal NOx formation pathway. The addition of ethanol in the blends has resulted in slightly reduction of NOx emission (0.1-0.8%), at all engine load operations. This can be associated with the lower heating value and higher latent heat of vaporization of ethanol, hence produced lower in-cylinder bulk-gas-average temperature [8]. The variation of smoke emissions for B20 and B20E5 is shown in Fig. 3(b). The results show that the smoke emissions reduce when using biodiesel and ethanol-biodiesel blends for all engine load operations due to the presence of high fuel-borne oxygen content in biodiesel and ethanol blends. At the engine load BMEP = 1.20 MPa, the B20 and B20E5 reduced the smoke by 27% and 50%, respectively, compared to baseline diesel fuel. In overall, the results showed that adding ethanol to biodiesel-blend had more significant effect on the reduction of smoke emission by 20-50% compared to baseline diesel fuel. Furthermore, the CO emission for B20 and B20E5 is lower than baseline diesel in all test modes as shown in Fig. 3(c). The results show that the CO emissions for B20 and B20E5 are 0.9-2.6% and 2.7-15.1% respectively, lower compared to baseline diesel fuel at all engine loads. This is due to the fuel-borne oxygen content in coconut biodiesel and ethanol-biodiesel blend promotes more complete combustion in the engine [9, 10].



(a) (b) (c)

Fig. 3. The variation in (a) NOx, (b) Smoke and (c) CO emissions for B20 and B20E5 at different engine load

The plot of in-cylinder combustion pressure and heat release rate (HRR) profiles, averaged over 100 consecutive cycles, in comparison with the baseline diesel for B20 and B20E5 at an operating load of 0.17MPa and 2000 rpm is shown in Fig. 4. Generally, it can be seen that the pressure profiles for both of the fuel blends are comparable to that of baseline diesel and only slightly peak pressure variations are observed. Also, the HRRs for all the tested fuels have similar shape, having a pilot combustion phase during the compression stroke, followed by a main combustion phase during the expansion stroke. The pilot combustion phase is formed due to the combustion of pilot injected fuel, while the main combustion phase is for the combustion of main injected fuel. Compared with the baseline diesel, B20 develops almost the same level of peak pressure. Besides, the peak HRR for B20 at the main combustion phase is slightly higher than that of baseline diesel. The higher peak HRR with the addition of biodiesel in blend can be attributed to the oxygen content in the methyl ester fuel, leading to better combustion and higher in peak HRR. While for B20E5, the resulted peak pressure is decreases compared to the B20 and baseline diesel. From the HRR analysis, the peak HRR for B20E5 at the main combustion phase is lower than that of B20. This is due to the cooling effect of ethanol associated with its lower calorific value and higher latent heat of evaporation, hence reduce the peak HRR at premixed combustion stage. The cooling effect of ethanol can be related to the decreases in NOx emission, as discussed previously.



(a) (b)

Fig. 4. The variation in (a) combustion pressure and (b) heat release rate for diesel, B20 and B20E5 at engine load of 0.17 MPa

4. Conclusions

An experiment was carried out on a common rail DI diesel engine with diesel, biodiesel and bioethanol fuel blends on engine performance, emissions and combustion characteristics at different engine load operations. The following main conclusions can be drawn from this study.

1. The BSFC of B20E5 and B20 is higher than baseline diesel. In overall, B20E5 shows 2.0-2.7% higher BSFC compared to baseline diesel fuel at all engine loads.
2. The B20 and B20E5 show better BTE than baseline diesel. For B20E5, the highest improvement is around 5.4% at medium load (BMEP = 0.69 MPa) with respect to diesel fuel.
3. The B20 and B20E5 fuel blends show a positive effect on reducing in smoke and CO emissions regardless of load setting. The addition of ethanol in the blends has resulted in the reduction of NOx emission under all loading condition.
4. The B20E5 show slightly lower in peak pressure and peak HRR at an operating load of 0.17 MPa. The cooling effect of ethanol can be related to the decreases in peak HRR during the premixed combustion stage, hence lower the NOx emission.

In conclusion, the addition of higher oxygen content of ethanol as additive for biodiesel-diesel blend can be applied in CI engine without any engine modifications.

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