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ScienceDirect
Energy Procedia 61 (2014) 2145 – 2148
Energy Procedia

The 6th International Conference on Applied Energy – ICAE2014

Effect of diesel fuel blend with biobutanol on the emission of turbocharged CRDI diesel engine

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Abstract

The objectives of this study are to investigate the effect of diesel fuel blend with biobutanol on the emission of turbocharged CRDI(common rail direct injection) diesel engine. The blends considered here were blends of diesel fuels with 10 and 20% (by vol.) n-butanol. Engine performance and emission characteristics were measured by the ESC(European Stationary Cycle) test. Emissions of HCs, CO, NOx, HCHO, HCOOH and NH_3 were measured by the FTIR. Size and number distribution of particulate matter were measured by the SMPS. From the results, for the n-butanol blend, NOx emission increased compared with the neat diesel fuel case. At the case of 20% butanol, both THC and CO emissions increased significantly, and both HCHO and HCOOH increased modestly in the low loading of ESC 7, 9, 11 and 13 mode comapring with the neat diesel fuel case. While n-butanol blending with diesel fuel reduced the mass of PM by 50~73%, it emitted ultrafine particles (Dp<200nm) slightly more.

Peer-review under responsibility of the Organizing Committee of ICAE2014

Keywords: diesel engine, butanol, particulate matter, HCHO, HCOOH, emission

1.Introduction

Many researchers have studied the compression ignition engines to observe engine performance and exhaust emission by using alcohol/diesel blended fuels[1-3]. The previous studies showed that alcohol fuel blends can improve some exhaust emissions of smoke, CO and NOx and decrease the diesel engine performance[2-5], and increase the break specific fuel consumption. However, there have been few detailed studies about the number of PMs which is one of the main problems in recent diesel engine development, especially about the emission characteristics of aldehydes which has not been regulated yet. Butanol has a lower auto-ignition temperature than that of methanol and ethanol.

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Peer-review under responsibility of the Organizing Committee of ICAE2014
doi:10.1016/j.egypro.2014.12.096

Therefore, butanol can be ignited more easily when burned in diesel engines. Butanol is much less evaporative and releases more energy per unit mass than ethanol and methanol. Butanol has also a higher cetane number, thus makes it more suitable additive than ethanol and methanol for diesel fuel. Butanol is less corrosive and energy content of butanol is higher than ethanol and methanol[3-5]. Since transportation of the bio-ethanol through pipe line is difficult because of its strong affinity for moisture and corrosion inside fuel pipe line of the engine, biobutanol is expected to solve these problems of the ethanol as an alternative fuel [6]. The objectives of this study are to investigate the effect of diesel fuel blend with biobutanol on the emission(NOx, HC, CO, PM and non-regulation components) of turbocharged CRDI(common rail direct injection) diesel engine and to compare the results with the neat diesel fuel operation case. The blends considered here were blends of diesel fuels with 0, 10 and 20% (by vol.) n-butanol.

2.Experimental Apparatus

The engine, specifications of which are given in Table 1, was operated on steady state cycle, ESC (European Stationary Cycle) test, with one of the three fuel, conventional diesel fuel (D100), blending diesel fuels with 10 %vol (BU10) and 20 %vol (BU20) n-butanol. An eddy current dynamometer (Fuchino, ESF-600) capable of adsorbing 440kW was used to measure power performance. The PM distribution was measured with SMPS(3080, TSI) and the concentrations of HC, CO, NOx, HCHO, HCOOH and NH_3 were also measured with analyzers(MEXA 6000FT-E, Horiba) from exhaust pipe directly. Both the particle size distribution and the emission characteristics were measured at the inlet and outlet of the after-treatment system; for the former, a scanning mobility particle sizer (SMPS) (Model 3080, TSI) [7] was used. Exhaust gas was diluted in an ejector-type dilutor because of the high particle number concentration. In this study, a part of the exhaust gas and filtered ambient air were mixed in the ratio of 1:132 through a dilutor system that the authors developed [3,4].

3.Results and discussion

For entire engine speed conditions, the torque and the power of BU10 mode were approximately 98% of the D100 mode, while those of BU20 mode were 96% of the D100 mode. It could be explained that butanol blending with diesel fuel reduces LHV (lower heating value).

Fig. 1 shows the effet of n-butanol/diesel fuel blends on THC(total hydrocarbon) emissions at the ESC test. It was observed that THC emissions increased with n-butanol/diesel fuel blends during all modes. The BU20 case showed higher amount of THC emissions than that of the D100 mode especially in low engine loading conditions of the 7^{th}, 9^{th}, 11^{th} and 13^{th} ESC modes. This is mainly due to the blend effects of the lower cetane number and higher heat of evaporation of the blends. To summarize, as the cetane number decreases, igntion timing is delayed, combustion gets unstable and THC emissions increase. Higher heat of evaporation of n-butanol/diesel fuel blends causes slower evaporating, which leads to increase the THC emissions. Fig. 2 presents the effet of n-butanol/diesel fuel blends on CO(carbon monoxide) at the ESC test. CO emissions emitted by n-butanol/diesel fuel blends engine were slightly high at low load conditions. It showed similar trend as THC emissions shown in Fig. 1. Fig. 3 illustrates the effet of n-butanol/diesel fuel blends on NOx emission at ESC test. It was observed that NOx emissions were increased with n-butanol/diesel fuel blends during all operation conditions. The highest NOx emissions were obtained in higher load conditions of 2^{nd}, 8^{th} and 10^{th} ESC modes of which exhaust temperatures are highest. The increasing oxygen content and lower centane number of the n-butanol/diesel fuel can help to the formation of NOx emissions. The lower cetane number of the n-butanol/diesel fuel blends causes to longer ignition delay, and so leads to higher combustion temperature in the premixed combustion mode.

Table 1. Specifications of test engine

Items	Specifications
Engine type	Common rail 4 cylinder
Bore × stroke (mm)	91 × 96
Displacement volume(cc)	2,497
Compression ratio	17.1 : 1
Max. power (kW/rpm)	95/3,800
Max. torque (N.m/rpm)	250/1500~3250
Intake system	Turbocharge & Intercooler
Engine model	Hyundai D4CB
Valves per cylinder	4

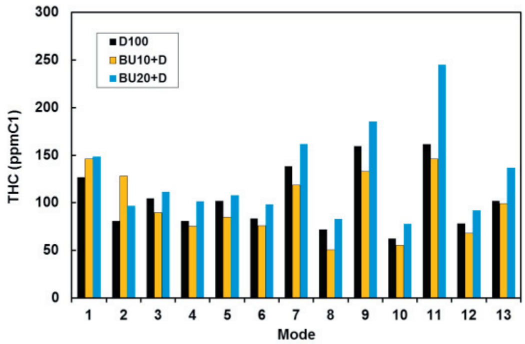

Fig. 1 THC emission

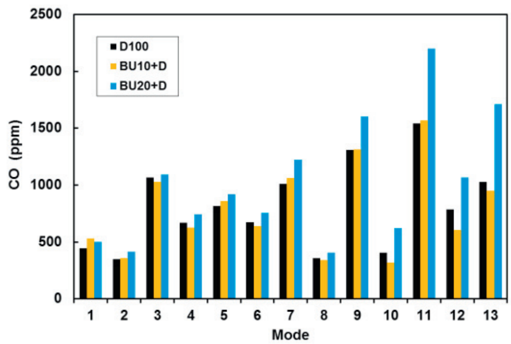

Fig. 2 CO emission

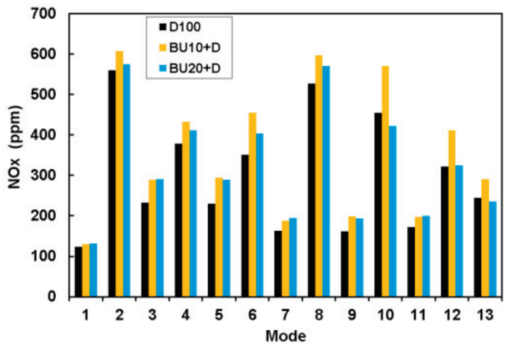

Fig. 3 NOx emission

Fig. 4 shows the effet of n-butanol/diesel fuel blends on HCHO emission at ESC test. BU20+D mode produced higher HCHO emissions at the lower engine load of 7th, 9th, 11th and 13th ESC modes than that of D100 case, due to the lower combustion temperature which is similar trend as THC and CO emissions. On the other hand, the HCHO emissions were low below 5ppm at the high engine load conditions of 2nd, 8th and 10th modes. It means that HCHO emissions, intermediate product of alcohol fuel combustion, increases due to the lower combustion temperature or the unstable combustion.

Fig. 5 show the size distribution and the emission number of PM for diesel fuels and n-butanol blend fuels at each ESC mode. For the PM diameter below 200 nm, the particulate number of BU10 mode was highest at the high engine load conditions of 2nd, 4th, 6th and 8th mode. In BU20 mode, the particulate number was slightly higher in the ultrafine particle below 100 nm comparing with that of D100 mode. However, the particulate number of D100 mode increased significantly more than that of n-butanol blended fuel modes for the PM diameter above ultrafine particles. Fig. 5-(n) shows the specific mass of total mass in these conditions. In both BU10+D and BU20+D modes, PM emissions decreased by 50-73% of the D100 case. n-butanol blending with diesel fuel could reduce the PM mass, but produce the small size of PM below the diameter of ultrafine particles slightly

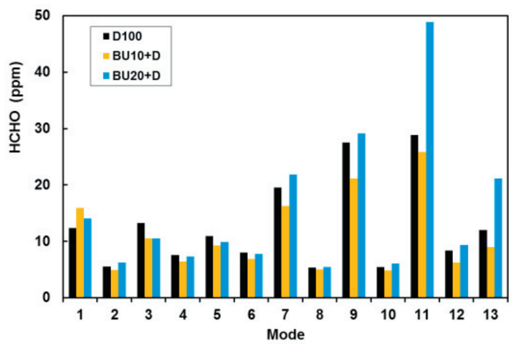

Fig. 4 HCHO emission

more. This might be due to the combustion process with oxygenated n-butanol fuel, which reduces the size of PM populated more in the small size and less in big size. This means total mass of PMs decreased, while total number of PMs increased. During the PM formation or oxidation process, n-butanol fuel might be maintained at smaller size, or decomposed.

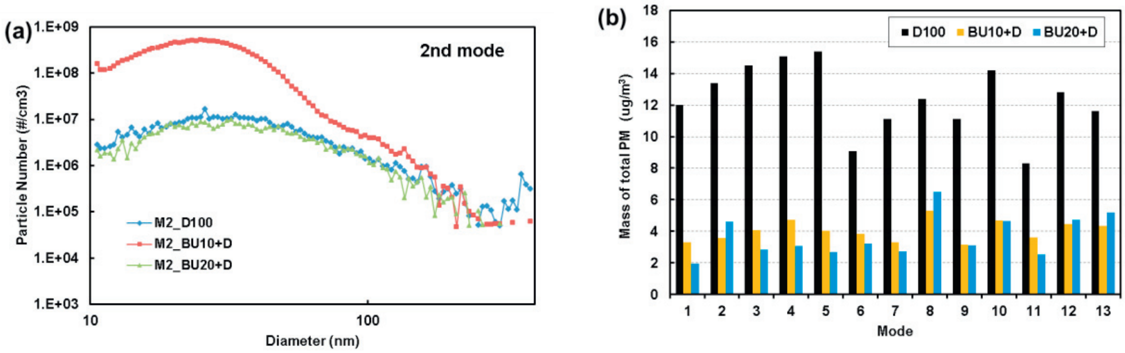

Fig. 5 PM emission of ESC test ((a) 2nd mode, (b) mass of PM for all modes)

4. Conclusions

The results of the study are summarized as follows:

(1) In the BU20+D mode, THC and CO emissions increased significantly more comparing with the D100 mode at the low engine load conditions of 7th, 9th, 11th and 13th ESC modes, because the cetane number decreased, the ignition timing delayed and the combustion instability increased.

(2) NOx emissions increased with n-butanol/diesel fuel blends during all operation conditions.

(3) In the BU20+D mode, HCHO emission was higher than that of the D100 mode at the low engine load conditions of 7th, 9th, 11th, and 13th modes, while they were lower at the high engine load.

(4) While n-butanol blending with diesel fuel reduced the PM mass by 50-73%, it produced slightly more the small size of PM below the diameter of ultrafine particles.

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Biography: Prof. Byungchul Choi finished his Ph.D. at Hokkaido University in Japan on 1990. He worked for Japan Automobile Research Institute in Japan and Institute for Advanced Engineering in Korea. Now he is teaching and researching of combustion engineering and an after-treatment system for vehicles.