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Effect of diesel fuel blend with n-butanol on the emission of a turbocharged common rail direct injection diesel engine

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HIGHLIGHTS

- For the n-butanol blend, NOx emission increased compared with the neat diesel fuel case.
- At the case of 20% butanol, THC and CO emissions increased significantly, and HCHO increased in the low loading conditions.
- Higher blending ratio (>20%) of butanol fuels contributes to the precursor of PAHs formation such as toluene.
- BU5 blend could be a better option to reduce the PM mass and the emissions of nano-sized PM under 50 nm.

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ABSTRACT

The objectives of this study are to investigate the effect of diesel fuel blend with n-butanol on the emission of turbocharged common rail direct injection (CRDI) diesel engine and to compare the results with the neat diesel fuel operation case. The blends considered here were blends of diesel fuels with 10% and 20% (by volume) n-butanol. Engine performance and emission characteristics were measured by the European Stationary Cycle (ESC) test. Emissions of HCs, CO, NOx, HCHO, HCOOH and NH_3 were measured by Fourier Transform Infrared Spectroscopy (FTIR). Size and number distribution of particulate matter (PM) were measured by the Scanning Mobility Particle Sizer (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 under the low loading of ESC 7, 9 and 11 mode compared with the neat diesel fuel case. Higher blending ratio (>20%) of butanol fuels could contribute to the precursor of PAHs formation such as toluene and benzene in diesel combustion. BU5 blend could be a better option to reduce the PM mass and the emissions of nanosized PM under 50 nm.

1. Introduction

Alcohol fuels can be used as oxygenated fuel additives with fossil-based fuels for diesel engines as a clean alternative fuel source to reduce the greenhouse gas emissions, renewable energy utilization in various areas [1]. They have studied the effect of n-butanol/diesel fuel on engine performance and regulated emissions in a diesel engine at limited rpm and loads [2–5]. Using n-butanol significantly improved the reduction of emissions. The premixed phase combustion was amplified and distinguishable with increase of shared volume of n-butanol in diesel [2–5]. Low percentage of alcohol in diesel fuel does not require any modifications in the engine fuel system. Many researchers have studied the compression ignition engines to observe engine performance and exhaust emission by using alcohol/diesel blended fuels [6,7]. Previous studies showed that alcohol fuel blends can improve some exhaust emissions of smoke, carbon monoxide (CO) and nitric oxides (NOx) and decrease the diesel engine performance [2–5], and increase the break specific fuel consumption (BSFC). However, there have been few detailed studies about the number of particulate matter (PM) which is one of the main problems in recent diesel engine development, especially about the emission characteristics of aldehydes which have not been regulated yet.

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Nomenclature

BSFC	break specific fuel consumption	HCs	hydrocarbons
CO	carbon monoxide	IHC	individual hydrocarbon
CRDI	common rail direct injection	NOx	nitrogen oxides
EGR	exhaust gas recirculation	PAH	polycyclic hydrocarbon
ESC	European Stationary Cycle	PM	particulate matter
FTIR	Fourier Transform Infrared Spectroscopy	SMPS	Scanning Mobility Particle Sizer
HCHO	formaldehyde		

Butanol is one of the primary alcohol kinds, which has more advantages than ethanol and methanol as an alternative fuel for internal combustion engines. The fuel properties of butanol are closer to fossil-based fuels. Butanol has a lower auto-ignition temperature of 385 °C than that of methanol and ethanol (479 °C and 434 °C respectively). Therefore, butanol can be ignited more easily when burned in diesel engines. And butanol is much less evaporative and releases more energy per unit mass than ethanol and methanol. Butanol has also a higher cetane number, thus making it a more suitable additive than ethanol and methanol for diesel fuel. Butanol is less corrosive and the energy content of butanol is higher than ethanol and methanol [8,9]. In addition, butanol can be blended with diesel fuel without phase separation. These physical and chemical properties of butanol indicate that butanol has the potential to overcome the limitations brought by low-carbon alcohols. Since transportation of bio-ethanol through a pipe line is difficult because of its strong affinity for moisture and corrosion inside the fuel pipe line of the engine, biobutanol is expected to solve these problems of ethanol as an alternative fuel [10]. Butanol can be produced by fermentation of biomass, especially wasted wood materials containing cellulose that could not be used for food.

Table 1
Specifications of test engine.

Items	Specifications
Engine type	Common rail 4-cylinder
Bore × stroke (mm × mm)	91 × 96
Displacement volume (cm^3)	2497
Compression ratio	17.1:1
Max. power (kW/rpm)	95/3800
Max. torque (N m/rpm)	250/1500–3250
Intake system	Turbocharger & intercooler
Engine model	Hyundai D4CB
Valves per cylinder	4

Several research groups have explored the use of butanol in diesel engines for automotive applications [11–16]. However, there have been few works on the emission characteristics of butanol-blended diesel engine for passenger cars, especially about formaldehyde (HCHO), individual hydrocarbon (IHC) and nano-sized PM [17,18].

The objectives of this study are to investigate the effect of diesel fuel blend with biobutanol on the emissions (NOx, IHC, CO, nano-sized PM and non-regulation components) of a turbocharged common rail direct injection (CRDI) 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%, 5%, 10% and 20% (by vol.) n-butanol.

2. Experimental apparatus

The experimental system used in this study consisted of a four-cylinder diesel engine equipped with a common rail fuel injection system, cooled exhaust gas recirculation (EGR) and intercooler turbocharger system, a PM distribution meter, an exhaust gas analyzer and a data acquisition system as schematically shown in Fig. 1. The engine, specifications of which are given in Table 1, was operated on the steady state cycle, European Stationary Cycle (ESC) test 13 mode, with one of the following four fuels, conventional diesel fuel (D100), blending diesel fuels with 5 vol% (BU5), 10 vol% (BU10) and 20 vol% (BU20) n-butanol. An eddy current dynamometer (Fuchino, ESF-600) capable of adsorbing 440 kW was used to measure power performance. The resolutions of the measurements facilities were within ±1.0% of full scale. And the standard deviations of measurements were as follows: ±1.6% for torque and BSFC, ±0.85% for temperature, ±3.6% of CO, ±4.2% of NOx, ±14.2% of IHC and HCHO.

Properties of conventional diesel fuel and blending diesel fuels (BU10, BU20) with n-butanol are given in Table 2. The properties

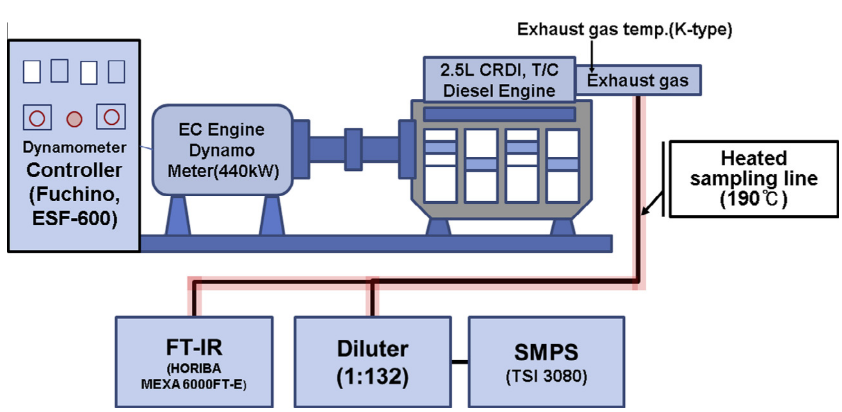

Fig. 1. Experimental apparatus for engine test.