

A Study on NO_x Emission Characteristics When Using Biomass-derived Diesel Alternative Fuels

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ABSTRACT

Utilization of biofuels to vehicles is attracting attention globally from viewpoints of preventing global warming, effectively utilizing the resources, and achieving the local invigoration. Representative examples are bioethanol and biodiesel.

This study highlights biodiesel and hydrotreated vegetable oil (HVO) in view of reducing greenhouse gas emission from heavy-duty diesel vehicles. Biodiesel is FAME obtained through ester exchange reaction by adding methanol to oil, such as rapeseed oil, soybean oil, palm oil, etc. As already reported, FAME has fuel properties different from conventional diesel fuel, resulting in about 10% increase in NO_x emission [1],[2],[3]. Suppression of such increase in the NO_x emission during operating with biodiesel requires adjustment of the combustion control technology, such as fuel injection control and EGR, to the use of biodiesel. However, designing of vehicles and engines for dedicated use of biodiesel cannot be expected much because of the development cost. Besides, biodiesel suffers deterioration in low-temperature fluidity in cold climate, so that certain users use diesel fuel only in such cold climate. In this way, many issues must be solved before the vehicles and engines use only biodiesel. On the other hand, HVO is fuel produced by the hydrotreating reaction used in the oil refining process. It is possible for any fatty oil to be raw oil of this fuel. In addition, HVO is able to be used in substitution for conventional diesel fuel since it mainly consists of paraffinic hydrocarbon.

In this study, NO_x emission was investigated when FAME and HVO were used for heavy-duty diesel engine under steady-state condition and JE05 driving cycle. From the results of this study, it was confirmed that the fuel injection volume had increased compared to the hydrocarbon fuels such as HVO and diesel fuel because the FAME had small lower heating value (LHV) per unit volume. It was thus confirmed that the combustion control state such as the EGR ratio and the fuel injection pressure had changed. This was presumed to be one of the factors causing the increase in NO_x. It was revealed that FAME and the hydrocarbon fuel could suppress the increase in the NO_x emission because the higher the H/C ratio of a fuel was, the more the flame temperature decreased. The above results showed that HVO having the LHV per unit volume equivalent to diesel fuel with the high H/C ratio was the biomass-derived diesel alternative fuel which could suppress the increase in NO_x emission.

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INTRODUCTION

In order to reduce the dependence of automobile fuel on petroleum, the popularization and spread of the biomass fuel and synthetic fuel are inevitable. Among them, the fatty acid methyl ester (FAME) made by the ester exchange reaction from vegetable oil as the raw material, the hydrotreated vegetable oil (HVO) made by hydrotreating also from vegetable oil and the synthetic diesel fuel (BTL) made from the gasified biomass followed by the Fischer-Tropsch process

are attracting attention as diesel alternative fuels. FAME is also called as biodiesel fuel in general. HVO and BTL are produced as paraffinic hydrocarbon fuels. It has already been reported that the synthetic diesel fuel can be applied to the conventional diesel engine without any modification to the fuel supply system because the impact on the deterioration of the fuel supply system is equivalent to the diesel fuel [4].

Recently, the emission gas regulations have become stricter year after year so that even alternative fuels must

clear the same emission regulations as the diesel fuel. For diesel vehicles, reducing both NO_x and PM at the same time is the critical issue.

This study focuses on FAME and HVO which are biomass-derived diesel alternative fuels, and has clarified how the differences in their fuel properties influence on the NO_x emission characteristics of the diesel engine for heavy-duty vehicle. Thus, this report discusses about the possibility of reducing exhaust emissions when using the diesel alternative fuels described above.

EXPERIMENTAL METHOD

EXPERIMENTAL APPARATUS AND METHOD

This study used the engine bench setup shown in [Figure 1](#) and conducted the JE05 driving cycle emission test and the steady state test. Specifications of the test engine are shown in [Table 1](#). This engine is the production model of an inline four-cylinder turbo intercooler diesel engine with total displacement 4009 cm³. This engine is equipped with the exhaust emission reduction technologies of cooled exhaust gas recirculation and the variable nozzle turbocharger together with the DPNR (Diesel Particulate-NO_x Reduction) system having both functions as the NO_x storage reduction (NSR) catalyst and the diesel particulate filter (DPF). With these technologies, this engine not only complies with the new short-term regulation (Japanese 2003 regulation) but has the low emission gas performance compliant with the new long-term regulation (Japanese 2005 regulation).

This study had evaluated the effect of the differences in combustion characteristics on the NO_x emission characteristics by measuring the emission gas that was sampled before the DPNR catalyst (at engine-out) and measured with the Emission Measurement System (HORIBA: MEXA-7100DEGR). Because the amount of PM emissions of FAME and HVO is sufficiently low compared to diesel fuel, this study did not evaluate it. The rate of heat release (RHR) was calculated from the average data of the cylinder pressure, which was measured with the combustion pressure sensor, of 100 cycles of the steady state test. The combustion characteristics were analyzed from the calculated data.

In the actual experiments, the JE05 driving cycle emission test was performed after understanding the basic combustion and NO_x emission characteristics by conducting the steady state test under the relatively frequent conditions (engine speed: 1400 rpm and torque: 120 Nm) in the JE05 driving cycle. Note that the engine control state may change when the fuel properties are changed because the test engines were equipped with the production model ECU for the combustion control in both tests.

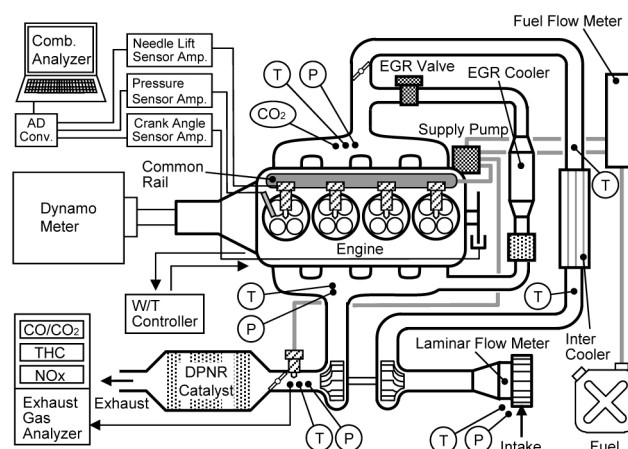


Figure 1. Experimental setup

Table 1. Specifications of test engine

Engine type	Water cooled, In-line 4-cylinder, 4-stroke cycle
Intake system	Turbocharged with intercooler
Fuel supply system	DI Common-rail
Displacement cm ³	4009
Compression ratio	18.0
Bore x Stroke mm	104 x 118
Max. power kW/rpm	110 / 3000
Max. torque Nm/rpm	392 / 1600

TEST FUELS

In addition to the two types: FAME and HVO, the conventional diesel fuel (hereunder abbreviated ULSD) was tested in the study. The fuel properties of FAME, HVO and ULSD used in this study are shown in [Tables 2](#) and [3](#). HVO and ULSD are classified under the same category of hydrocarbon fuel. Two types of FAME that are the soybean oil methyl ester (hereunder abbreviated SME) and the palm oil methyl ester (hereunder abbreviated PME) are used. These two types have significantly different components among FAME, which create a certain differences in the cetane number and in the H/C ratio of the fuel. Since HVO does not contain any aromatic component, HVO has the superior ignition characteristics and the significantly high cetane number compared to ULSD of the same hydrocarbon fuel. It has the higher H/C ratio. When the four types of fuels: FAME, HVO and ULSD are compared, it is found that they have different densities and LHVs. It suggests that they have different LHV per unit volume.

Table 2. Properties of FAMES

Fuel	SME	PME	Method
Density (15 deg.C) g/cm ³	0.8855	0.8777	JIS-K-2249
Kinematic viscosity mm ² /s (@40 deg.C)	4.089	4.437	JIS-K-2283
Flash point deg.C	180.0	181.0	JIS-K-2265
Cetane number	52.6	61.7	JIS-K-2280
Distillation temp. deg.C	IBP	271.0	JIS-K-2254
	10%	347.0	
	50%	355.0	
	90%	358.0	
CHO wt.%	C	77.2	ASTM D5291
	H	11.8	
	O	11.0	
Pour point deg.C	-2.5	10.0	JIS-K-2269
Sulfur content ppm	0.42	1.2	JIS-K-2541
Lower heating value kJ/kg	37030	36880	JIS-K-2279
LHV per unit volume kJ/cm ³	32.79	32.37	-

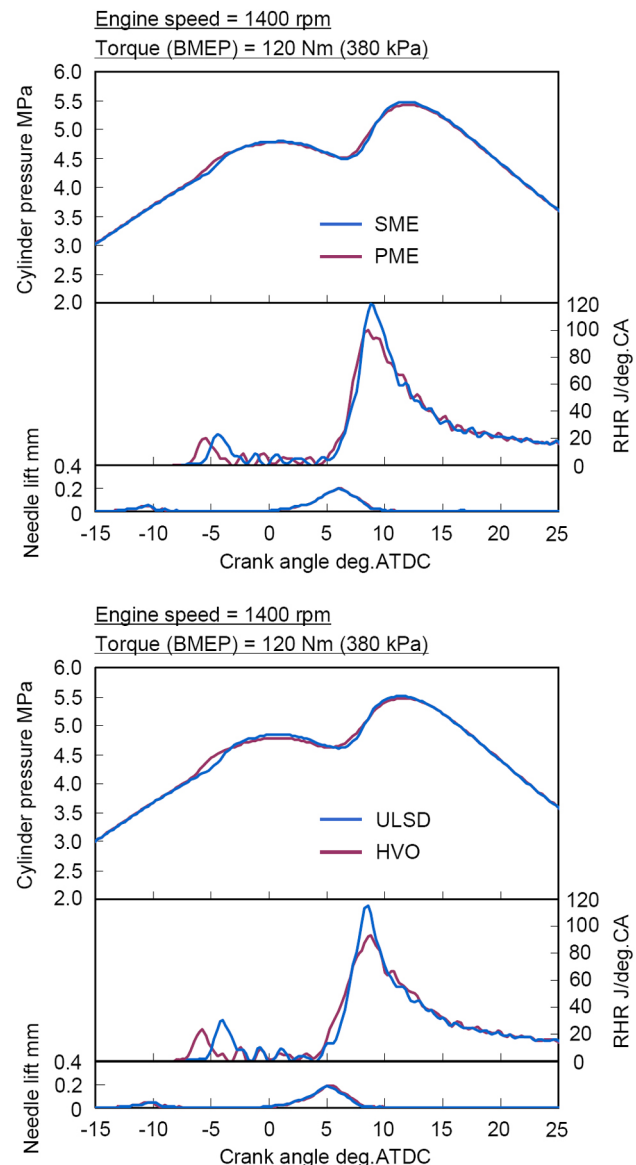
Table 3. Properties of hydrocarbon fuels

Fuel	ULSD	HVO	Method
Density (15 deg.C) g/cm ³	0.8295	0.7798	JIS-K-2249
Kinematic viscosity mm ² /s (@30 deg.C)	3.655	3.708	JIS-K-2283
Flash point deg.C	68.0	91.0	JIS-K-2265
Cetane number	54.6	85.8	JIS-K-2280
Distillation temp. deg.C	IBP	168.0	JIS-K-2254
	10%	210.0	
	50%	279.5	
	90%	337.5	
CHO wt.%	C	86.1	ASTM D5291
	H	13.7	
	O	<0.1	
Pour point deg.C	-22.5	-15.0	JIS-K-2269
Sulfur content ppm	8	<1	JIS-K-2541
Lower heating value kJ/kg	43170	44110	JIS-K-2279
LHV per unit volume kJ/cm ³	35.81	34.40	-

RESULTS AND DISCUSSION

BASIC COMBUSTION AND NOX EMISSION CHARACTERISTICS OF THE VARIOUS FUEL TYPES UNDER THE STEADY STATE CONDITION

In order to obtain the basic combustion characteristics of the respective types of fuel, the steady state test was performed and the RHR was analyzed. The cylinder pressure, the RHR and the needle lift during the operations on FAME and the hydrocarbon fuel are shown in Figure 2. When FAME was used, the start of combustion had changed in both of the pilot combustion and the main combustion with both SME and PME. It was confirmed that PME showed the early start of combustion because it had the higher cetane number and the superior ignition characteristics. The same was true in the hydrocarbon fuel that the HVO having the higher cetane number showed the early start of combustion compared to ULSD. As a result, the initial combustion timing of the main combustion became slow and the maximum value of the RHR had lowered.

**Figure 2. Comparisons of cylinder pressure, RHR and needle lift between SME, PME, ULSD and HVO**

The NOx emission concentration at the engine-out under the same condition is shown in Figure 3. When FAME was used, the amount of NOx emissions with PME became lower than that with SME. When hydrocarbon fuel was used, the amount of NOx emissions with HVO became almost equal to that with ULSD. When FAME and the hydrocarbon fuel were compared, the amount of NOx emissions with hydrocarbon fuel generally showed the lower value. From these results, it is considered that the same amount of NOx emissions as ULSD can be maintained with HVO.

W. A. Eckerle, et al. indicated that increase of NOx emission with FAME was due to two effects, one was the difference of basic combustion characteristics, and the other was the change of engine control setting [5]. Furthermore, C. J. Mueller reported that NOx emission of FAME operation