

Effect of Biodiesel on NO_x Reduction Performance of Urea-SCR System

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ABSTRACT

The use of biomass fuels for vehicles has been a focus of attention all over the world in terms of prevention of global warming, effective utilization of resources and local revitalization. For the purpose of beneficial use of unused biomass resources, the movement of the use of bioethanol and biodiesel made from them has spread in Japan.

In Japan, biodiesel is mainly made from waste cooking oil collected by local communities or governments, and in terms of local production for local consumption, it is used as neat fuel (100% biofuel) or mixed with diesel fuel in high concentration for the vehicles. On the other hand, extremely low emission level must be kept for not only gasoline vehicles but also diesel vehicles in the post new long-term regulation implemented from 2009 in Japan. It is necessary for diesel vehicles to equip an advanced type of aftertreatment such as Urea-Selective Catalytic Reduction (SCR) system or lean NO_x trap (LNT) catalyst system in order to comply with this regulation.

In this study, engine bench tests were conducted to understand the emission characteristics in the use of high concentration of biodiesel for an engine system with the urea-SCR system which is expected to be equipped for a lot of heavy-duty vehicles in the near future.

The results indicated that NO_x emission in biodiesel operation increased compared with that in conventional diesel operation under Japanese JE05 mode test. This is because of

the NO_x emission increasing in the engine out and the NO_x reduction efficiency decreasing in the urea-SCR system. Especially, B100 (Neat biodiesel) increased NO_x emission over the New Long-Term regulation limit, even though this engine system complied with the new long-term regulation level enough. This was mainly affected by the decrease of NO_x reduction efficiency in urea-SCR system due to the decrease of NO₂/NO_x ratio at the inlet of urea-SCR.

The factor of the decrease in NO₂/NO_x ratio was considered to be the decrease in NO₂ concentration derived from the reduction of engine-out NO₂ emission and the deterioration of oxidizability of diesel oxide catalyst (DOC). As for the deterioration of oxidizability of DOC, it was thought to be due to the decrease in exhaust gas temperature, catalyst poisoning and reduction action by SOF adhered in DOC. Therefore, it was necessary to improve oxidizability of DOC in order to decrease NO_x emissions.

INTRODUCTION

Utilizing biofuel in automobiles has been attracting global attention in order to prevent global warming, to effectively utilize resources, and to activate regions. Also in Japan, there is an accelerating trend of utilizing, in automobiles, the bioethanol and biodiesel that are produced from the biomass resources that have not been effectively utilized.

In Japan, there are many examples of biodiesel that has been produced, as raw materials, from the waste edible oil mainly collected by local governments and regions. In many cases,

such biodiesel is utilized in 100% (neat fuel) or equivalent high concentration for automobiles, by considering a viewpoint of local production for local consumption. However, it is reported that utilizing the highly concentrated biodiesel in diesel vehicles has a demerit that the NO_x emission increases as compared with operation using conventional diesel fuel [1].

On the other hand, the exhaust-gas regulation (Post New Long-Term Regulation) that was enforced from 2009 specifies that also diesel vehicles must keep an extremely low exhaust emission level. As one of the measures to satisfy this regulation, it can be considered that NO_x-reducing, high-level exhaust aftertreatment devices such as urea-SCR system and lean NO_x trap (LNT) must be mounted.

Engine bench experiments of the engine system with the urea-SCR system, which will be mounted in many heavy-duty vehicles in the future, were conducted in order to investigate the exhaust-gas characteristics provided when using highly concentrated biodiesel. The experimental results are explained in the following chapters.

EXPERIMENTAL METHOD

EXPERIMENTAL APPARATUSES AND METHOD

Fig. 1 is a schematic diagram of the engine, aftertreatment devices, and exhaust-gas analyzers used in this research. Table 1 lists the specification of the test engine, and Table 2 lists the specification of the aftertreatment devices. The test engine is an in-line 4-cylinder diesel engine with a total displacement of 4009 cm³, with a turbocharger for a heavy-duty vehicle, and with a continuously regenerating diesel particulate filter (DPF) that conforms to the New Short-Term (2003) Regulation. By adding the urea-SCR system described in the reference documents [2], [3], [4], the NO_x emission amount of the test system is decreased to 0.85 g/kWh in the JE05-mode conventional diesel operation. The used SCR catalyst is made of zeolite. A diesel oxidation catalyst (DOC) (pre) is mounted at the upstream position of the catalyzed DPF, and the DOC (post) for preventing the NH₃ slipping is mounted at the downstream position of SCR. Urea solution is supplied by an injector mounted between DPF and SCR. The DOC (pre) of this system oxidizes a part of NO to NO₂, which helps continuous regeneration by DPF and contributes to the improvement of NO_x reduction by SCR. The details of the catalyst and the urea solution injection control are already explained in the reference document [2].

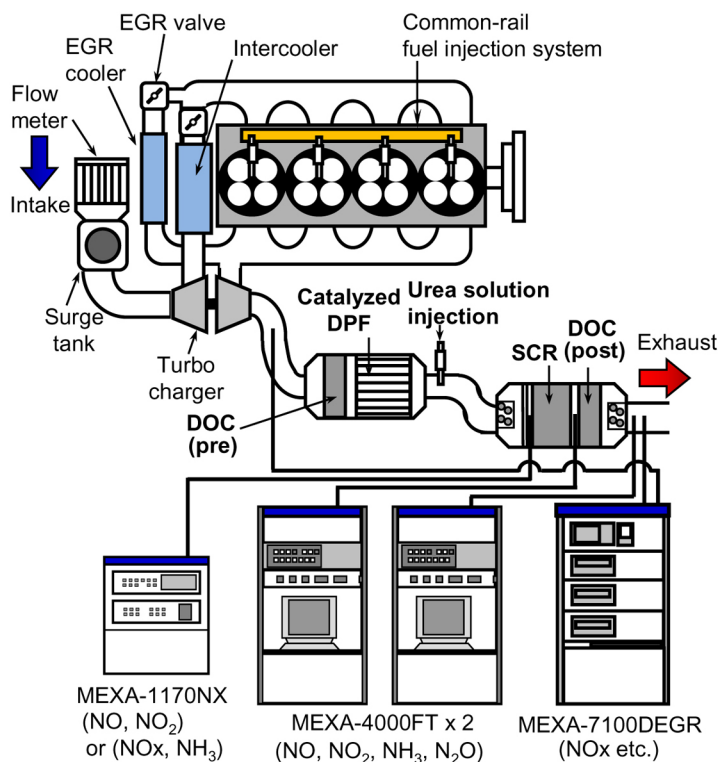


Fig. 1. Schematics of test engine, aftertreatments and exhaust gas analyzers

The test engine was evaluated by conducting the JE05-mode, which is the exhaust emission test mode for heavy-duty vehicles, on the engine bench test equipment. Exhaust gas at each exhaust pipe position was measured with the MEXA Series analyzers manufactured by HORIBA, Ltd. That is, the gas at the SCR entry was measured with MEXA-1170NX, the gas at the SCR exit was measured with MEXA-4000FT, and the gas at the DOC (post) exit was measured with MEXA-4000FT. In these measurements, both NO and NO₂ were measured simultaneously. NO_x was measured in the engine out or at the tail pipe point by using MEXA-7100DEGR.

TEST FUELS

The test fuels are made of the conventional diesel fuel and the biodiesel (FAME) produced from waste edible oil; these fuels are B0 (100% diesel fuel), B20 (80% diesel fuel and 20% biodiesel), and B100 (100% biodiesel). The tests evaluated the effect of the urea SCR on the NO_x reduction performance when using the highly concentrated biodiesel. Table 3 lists the properties of the test fuels. As shown in this table, the used biodiesel is higher than the diesel fuel in the kinematic viscosity, flash point, and distillation temperature. The used biodiesel satisfies JIS K 2390, regarding the characteristics that can be considered to affect the engine performance (i.e., density, kinematic viscosity, flash point, cetane number, and sulfur content).

Table 1. Specification 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 (Max.: 160 MPa) (ϕ 0.16 mm x 6 holes)
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
Urea water injection	ϕ 0.42 mm x 1 hole (Max.: 10 MPa)

Table 2. Specification of aftertreatments

	DOC (pre)	Catalyzed DPF	SCR	DOC (post)
Substrate volume L	2.2	5.8	4.3	2.2
Diameter mm (inch)	191 (7.5)			
Length mm (inch)	76 (3)	203 (8)	152 (6)	76 (3)
Cell density cpsi* ¹	300	260	400	400
Wall thick. mil* ²	8	12	6	6
Supported Pt g/L	3.0	0.5	0	0.5

*1cpai: cells per square inch

*2mil : 1/1000 inch (25.4 μ m)

RESULTS AND DISCUSSIONS

RESULTS OF JE05-MODE EXHAUST EMISSION TESTS

In order to confirm the exhaust emission performance of this test engine system with biodiesel, the JE05-mode exhaust emission tests were conducted and the NO_x emission characteristics were evaluated. Fig. 2 shows the comparison of the NO_x concentration between B100 and B0 at the tail pipe in the JE05-mode operation. As shown in this figure, the B100 operation at acceleration is extremely higher than the B0 operation in the NO_x concentration. Also in the idle operation (about 100 to 160 seconds or about 1100 to 1300 seconds after starting), the B100 operation is higher than the B0 operation in the NO_x concentration. Fig. 3 shows the effect of the biodiesel mixing ratio on NO_x emission in the

JE05 mode. In the B0 operation, a low NO_x emission rate close to the Post New Long-Term Regulation restriction (0.7 g/kWh) is acquired by the effect of the urea-solution injection control described in the reference document [2]. However, when the biodiesel mixing ratio becomes higher, the NO_x emission rate increases. In the B100 operation, the NO_x emission rate exceeds the New Long-Term (2005) Regulation restriction (2.0 g/kWh).