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Effects of various mixer types on the spatial distribution of a De-NOx reductant

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ABSTRACT

De-NOx catalytic systems generally perform better in rich or stoichiometric engine operating conditions due to high hydrocarbon (HC) concentrations in the exhaust gas. However, the hydrocarbon concentration in a diesel engine is typically low, so post or supplemental fuel injections into the exhaust gas have been employed in order to increase the HC concentration. A hydrocarbon-type lean NOx trap (HC-LNT) catalyst system that is a De-NOx system based on NOx-absorbing catalyst has also been developed to optimize control of the external HC injection into the diesel exhaust pipe. The system has a secondary injector that injects diesel fuel (HC) into an exhaust manifold. The typically high temperature (250–350 °C) in the exhaust manifold affects the spray behavior of the secondary injector, and the high temperature also makes it particularly difficult to achieve uniform distribution of the reducing agent in the manifold. Thus, it is necessary to use a mixer to improve the fuel distribution in the exhaust manifold. In this study, the effects of various mixer types on the spatial distribution of the LNT reducing agent were investigated to improve the performance of the LNT catalyst system. While the LNT reducing agent was injected directly toward the mixers in a transparent manifold, spray images were collected using a high-speed camera, and the spatial distribution of the spray was analyzed using image processing techniques. The analysis on the spatial distribution of the spray represented that mixers were beneficial to achieve uniform distribution of the reducing agent in exhaust pipe and improve the performance of LNT catalyst system.

1. Introduction

The direct injection (DI) diesel engine has become a prime candidate for future engine technology because of its high thermal efficiency. However, nitrogen oxide (NOx) increases in the high temperature regions of premixed diesel combustion, and particulate matter (PM) also increases in the diffusion flame region of diesel engines [1]. Recently, emission regulations for diesel engines have become very strict, so many researchers are trying to reduce NOx and PM using new combustion concepts such as PCCI and LTC. However, combustion technology alone cannot satisfy severe regulations such as Euro 6 in Europe or Tier 2 in the USA. Therefore, an after-treatment system is mandatory for use in recent clean diesel engines.

PM can be removed easily using a diesel particulate filter (DPF), but NOx is very difficult to reduce with an oxidation catalyst because diesel engines usually operate in lean conditions. Since the oxidation catalyst cannot be activated in this lean condition, it is necessary to create a rich mixture condition around the catalytic converter. Thus, the demand for suitable after-treatment systems has increased [2]. This research is focused on the secondary injector used in a lean NOx trap catalyst. The uniform distribution of the secondary injection is a key technology for the improvement of NOx conversion efficiency.

In general, NOx-absorbing catalysts are based on the concepts of NO storage and release, which allow for decreases in the NOx emissions under net oxidizing gas conditions. This technology is promising because it offers a high NOx conversion efficiency, and it can use diesel fuel as a reducing agent. This De-NOx system, the hydrocarbon-lean NOx trap (HC-LNT) catalyst, absorbs NOx under lean exhaust gas conditions and releases NOx under rich exhaust gas conditions. When the NOx is released in the presence of a sufficient supply of the reducing agent, the released NOx is converted to N_2. However, if the concentration of the reducing agent is insufficient, the released NOx will pass through the system without conversion. Excessive amounts of reducing agent will pass through the LNT without conversion and will cause additional emission problems. Thus, the appropriate amount of reducing agent should be supplied to the catalytic converter [3–5].

In this study, a secondary injection system was designed to inject diesel fuel into the exhaust manifold in order to create stoichiometric conditions for the HC-LNT catalyst. The atomization

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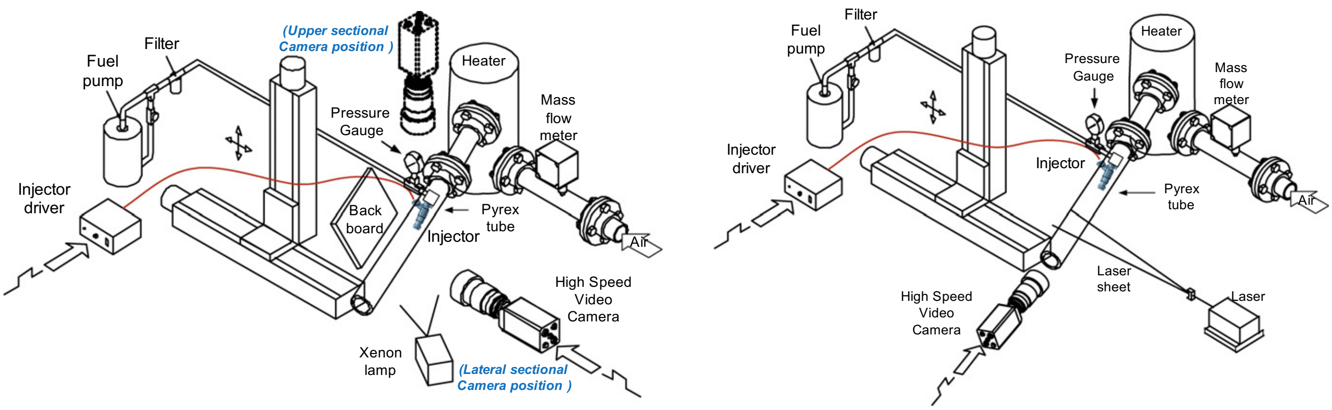


(a) Parallel sectional visualization with air flow (b) Cross-sectional visualization with air flow.

Fig. 1. Spray visualization systems in the exhaust pipe flow.

(a) Mean average. (b) RMS average. (c) Mean of probability density.

Fig. 2. Various types of averaged images.

Table 1
Results of the digital image processing.

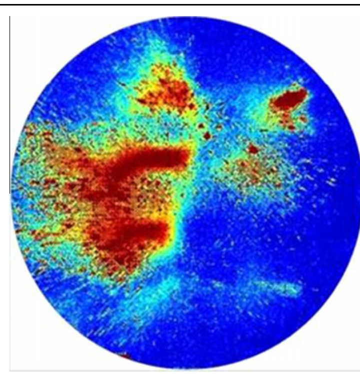
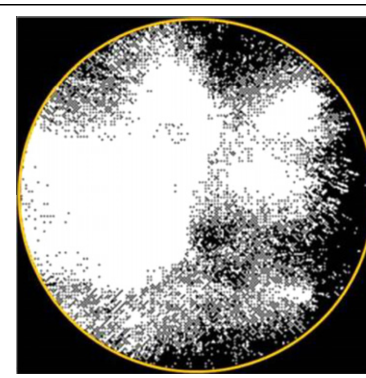
Specification	RMS	Integral (thresholding level 0.1)
Image	 Intensity calculation impossible	 Sum of all droplet's intensity for injection duration

Table 2
Specification of ISO4113 compared to diesel fuel.

Property	Units	Diesel	ISO4113
Flash point	°C	62–74	85
Density	kg/'m^3	800–860	822
Kinetic viscosity	mm^2/s	1.9–4.1	3.9
Surface tension	mN/m	27.2	28.4

Table 3
Experimental conditions for the transport exhaust manifold.

Air mass flow	20, 40, 60 (g/s)
Temperature	50, 100, 200, 300 (°C)
Spray section measuring distances	70,100,150 (mm)
Photography	10,000 fps, 90 μs exposure

and distribution characteristics of the spray injected from a secondary injector are key factors for obtaining a high NOx conversion and for reducing fuel consumption. The optimal spray structure that is necessary to achieve a uniform fuel–air distribution within the exhaust manifold results in an efficient purification process using the current HC-LNT catalyst [6–9].