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INVESTIGATION ON SPRAY BEHAVIOR AND NOx CONVERSION CHARACTERISTIC OF A SECONDARY INJECTOR FOR A LEAN NOx TRAP CATALYST

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ABSTRACT−Lean NOx trap (LNT) catalyst has been used to reduce NOx emissions from diesel engines. The LNT absorbs NOx in lean condition and discharges N2 by reducing NOx in rich conditions. Thus, it is necessary to make exhaust gas lean or rich conditions for controlling LNT system. For making a rich condition, a secondary injector was adopted to inject a diesel fuel into the exhaust pipe. In the case of secondary injector, the behavior of spray is easily affected by high temperature (i.e., 250 ~ 350 °C) occurred in the exhaust manifold. Therefore, it is needed to investigate the spray behavior of diesel fuel injected into an exhaust manifold, as well as the conversion characteristics for a lean NOx trap of a diesel engine with LNT catalyst. The characteristics of exhaust emissions in NEDC (New European Driving Cycle) mode were analyzed and spray behaviors were visualized in various exhaust gas conditions. The results show that as the exhaust gas mass flow increases, the spray cone angle becomes broad and the fuel is directed to the flow field. Besides, the cone angle of spray is decreased by centrifugal force caused in exhaust gas flow field. In addition, the effects of nozzle installation degree, injection quantity, and exhaust gas flow on NOx conversion performance were clarified.

KEY WORDS : Diesel engine, HC-LNT catalyst, After-treatment, Spray behavior, RMS image, Secondary injector

1. INTRODUCTION

To cope with the severe exhaust gas emission and fuel economy regulations for internal combustion engines in the near future, the demand for lower emissions and higher thermal efficiency engine technologies need to be increased. Compared to other engine systems, diesel engines have become more popular due to excellent thermal efficiency and durability. It is well known that diesel engines minimize green house gases because low fuel consumption leads to lower CO_2 emissions. However, the nitrogen oxides (NOx) and particulate matter (PM) are generated in diesel engine combustion. Thus, the after-treatment systems can be a solution for satisfying strengthening exhaust gas regulations (Shoji *et al*., 2004).

Alternatively, after-treatment systems such as lean NOx catalyst (LNC), lean NOx trap (LNT) catalyst and selective catalytic reduction (SCR) catalyst can be used; these after-treatment systems have the advantage that the current engine and combustion technologies and mechanisms do not need to be altered. However, correct application of after-treatment systems is critical for them to reduce exhaust gas emissions.

Among them, the lean NOx trap (LNT) is an effective after-treatment system. Periodic rich or lean conditions of exhaust gas are required for reducing NOx emission because NOx is absorbed in lean condition and N_2 is discharged in rich condition. In NOx conversion process, HC concentration generated from diesel combustion is insufficient to make rich condition because the most of diesel combustion is operating under a lean condition. Therefore, injection of post fuel to the exhaust gas was proposed in order to make a rich air to fuel ratio (Alimin *et al*., 2009; Han and Lee, 2015). In this research, a secondary injection system attached in the exhaust pipe was designed for forming the rich condition in the HC-LNT catalyst. The atomization and distribution characteristics of the spray injected from a secondary injector are key technologies for obtaining a high NOx conversion efficiency because inhomogeneous droplets of injected diesel fuel cause not only high fuel consumption, but also increased NOx emissions. Spray characteristic is very important in LNT system because poor spray behavior causes poor atomization and wall-wetting in the exhaust manifold. Both of these phenomena decrease the NOx conversion efficiency and increase fuel penalty of secondary injector. Therefore, clarification of spray structure and uniform distribution of fuel-air in the exhaust pipe is needed to accomplish an effective conversion process in the HC-LNT catalyst (Hiroyasu and Arai, 1990; Ko *et al*., 2014; Lee *et al*., 2010;

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Kang *et al*., 2003).

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 system. The atomization and distribution characteristics of the spray injected from a secondary injector are key factors for obtaining a high NOx reduction and for reducing reductant consumption. The optimal spray structure that is necessary to achieve a uniform reductant-air distribution within the exhaust manifold results in an efficient purification process using the current HC-LNT catalyst. the spray characteristics of a secondary injector and the effect of an injection condition on LNT performance were investigated. The reductants are injected over the exhaust pipe that contains the high-temperature exhaust gases, resulting in evaporation of the reductants. The reductant evaporation results in a decrease in the local temperature, and the evaporated reductant travels through the catalytic converter and converts the NOx in a chemical reaction. Therefore, optical diagnostics were also applied to investigate the spray characteristics, as well as a fuel behavior in the vicinity of lean NOx trap in a diesel engine with an LNT catalyst. In addition, the conversion characteristics of exhaust emissions in New European Driving Cycle (NEDC) mode were analyzed using the engine dynamometer. From these results, the spray behavior and distribution characteristics of injected fuel from secondary injector for the flow field of an HC-LNT catalyst system were clarified.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

2.1. Secondary Injection System

The LNT catalyst system is commonly used for the HC-LNT system, which uses hydrocarbon (HC) as the reductant. Since the HC-LNT system utilizes fuel, there is no need for an additional fuel. Therefore, the HC-LNT system can be used for engines smaller than 2.5 liters. HC-LNT systems involve the unavoidable disadvantage of low fuel efficiency, so efforts have been made to maximize fuel efficiency. The LNT catalyst system that is commonly used is the HC-LNT system, which uses HC as the reductant. Since the HC-LNT system utilizes fuel, there is no need for an additional reductant tank and, therefore, it is applicable to engines of 2.5 liters or less capacity. Since it involves the unavoidable disadvantage of low fuel efficiency, however, efforts are put forth in order to maximize the fuel effects with a fuel penalty under 2 % (Park *et al*., 2010). The secondary fuel injector used in this study was fabricated especially for use in research and is used to inject diesel fuel into the exhaust pipe as a reducing agent. The injector nozzle is opened and closed depending on the fuel pressure, and the injector produces a solid-cone type spray pattern (Oh *et al*., 2008a). The injection system is operated at a much lower injection pressure (maximum of 10 bar) than those in conventional diesel fuel injection systems. The injection system composed of a low pressure electric pump that can increase the pressure to 7 bar, a filter, a pressure regulator, and an injection unit.

An active high TTL command signal is provided to the metered valve driver. The driving pulse signal of a solenoid valve is sent to a delay pulse generator, and the delayed pulse signal is used as a trigger to start the high-speed video camera or high-resolution CCD camera. All of the experiments were performed with diesel fuel.

2.2. Spray Visualization System with a Transparent Exhaust Pipe

To investigate the macroscopic and microscopic spray characteristics of a secondary injector, a spray visualization system was established. Spray development processes were observed using direct photography with a high-speed video camera illuminated by a xenon lamp (Chaves and Hentschel, 1996; Arcoumanis *et al*., 1991; Lee and Reitz, 2004). In addition, a delay pulse generator was used to synchronize a high-speed video camera with the injector driver. The specifications of the high speed camera are summarized in Table 1.

A cylindrical lens and a 500-mW ND-YLF portable laser were used to make laser sheet. The fuel was injected to the laser sheet vertically for visualization of horizontal spray pattern. The specification of the portable laser can be shown in the Table 2.

The averaging method of spray images is typically applied to the quantitative way for spray characteristics. Enough time and repetition of many spray images are needed to get the quantitative spray information stably. In this study, a high speed camera is used to record the spray images and an image processing method which is coding by Matlab software is conducted to measure the quantitative characteristics of spray (Jeong and Lee, 2006; Shao *et al*., 2003; Cronhjort and Wahlin, 2004).

A root-mean-square called as RMS images method was

Table 1. Specifications of the high-speed camera.

Description	Specification
Model	Phantom 7.0 (Vision research)
Sensor	800 × 600 pixel, 24bit color array
Sensitivity	1200 ISO/ASA color
Pictures per second (PPS)	Full sensor: to 4800 pps, 512 × 384 to 10000 pps
Exposure time	Variable to 2 ms, independent of sample rate (pps)
Trigger	Continuously variable pre/post
Lens mounts	Nikon mount standard
Sync image	TTL pulse

Table 2. Laser specifications.

Description	Specification
Center wavelength	532 nm
CW output power	1000 mW
Beam diameter	< 3 mm
Beam mode	TEM00
Power stability	< 5 % (RMS, over 8 hours)
Warm-up time	< 10 min.
Operating temperature	15 ~ 35 ºC
Cooling system	Air

applied to spray images during a one injection period. The RMS method is easy to figure out the periodicity of spray with producing high-contrast images. In case of mean averaging image, producing high contrast image is hard compared to RMS method. Therefore, RMS images helps to confirm the distribution and angle of spray.

The arithmetic mean image (S_{mean}) can be calculated with the arithmetic mean number of image pixels by Equation (1). And the RMS average image (S_{RMS}) is the value of pixels during the image frames and it can be obtained using Equation (2).

$$S_{mean}(x, y) = \frac{\sum_{k=1}^{n} S_k(x, y)}{n} \quad (1)$$

$$S_{RMS}(x, y) = \sqrt{\frac{\sum_{k=1}^{n} \{S_k(x, y) \times S_k(x, y)\}}{n}} \quad (2)$$

where, $S_{mean}(x, y)$ and $S_{RMS}(x, y)$ mean the averaged image and the RMS averaged spray image, respectively. $S_k(x, y)$ is base image which have corrected and removed noise, and n indicates the number of images.

It is difficult to visualize the spray pattern in a real engine manifold due to the presence of PM generated during combustion and the vibration of the exhaust pipes due to fluctuating pressure in the exhaust gas. Therefore, a transparent exhaust manifold was manufactured to allow for observation of the gas flow and spray behavior during combustion. The exhaust manifold was constructed of pyrex tubing in order to endure high temperature condition because the exhaust gas temperature was approximately 250 ~ 350 °C.

Figure 1 shows the experimental setup for measuring the parallel and cross-sectional spray patterns using the transparent exhaust manifold system. The parallel spray patterns were divided into lateral and upper sectional spray patterns, respectively, relied on the position of the high speed camera as shown in Figreu 1. A blower supplied

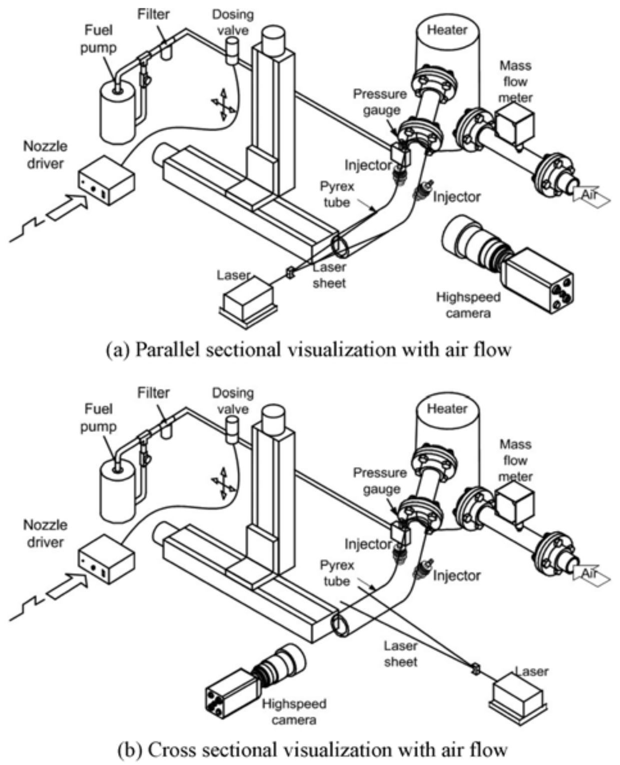

Figure 1. Spray visualization systems in the exhaust pipe flow.

ambient air to the heater in order to simulate the exhaust gas temperature. The air flow rate was controlled by changing the motor speed using the inverter. The mass flow rate of the air was measured using a mass flow meter, and the air was heated by a 25 kW electric heater.

A 1-W Nd-YVO4 portable laser source and a cylindrical lens were used for spray visualization test, and a high-speed camera recorded the spray image. Mass flux distribution and the spray cross-section pattern could be analyzed qualitatively with visualization test results, because density and diameter of droplet affect the intensity of dispersed lights. In the previous study, the parallel and cross-sectional spray patterns in the transparent pipe, the experimental device was constructed. The Scattered light intensity depends on the droplet diameter because the intensity and the quality of these visualization results, the spray section and the mass flux distribution pattern were

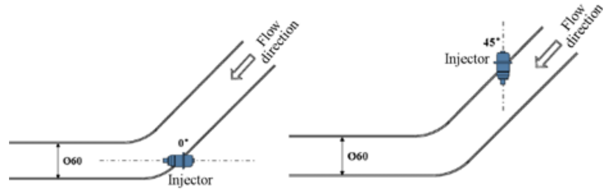

Figure 2. Definition of installation angle of injector in the Pyrex tube.

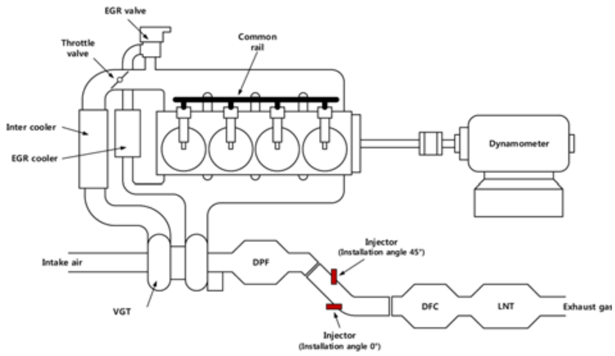

Figure 3. Configuration of engine and after-treatment system.

confirmed (Oh *et al*., 2008a).

It is well known that a high level of atomization and vaporization of injected droplets must be affected by wall-wetting. Thus, the optimal position and angle of installation should be selected to prevent wall-wetting. For this purpose, injector was installed in the 45° and 0° angles as shown in Figures 2 (a) and (b) to examine the effect of installation angle on wall-wetting in the pipe.

2.3. Experimental Apparatus with an Engine

Figure 3 shows the configuration of the test engine and LNT catalyst system. The engine used for this study was a 1991-cc, 4-cylinder diesel engine with four valves per cylinder, a common rail direct fuel injector (CRDI), and a variable geometric turbocharger (VGT). Table 3 lists the specifications of the engine. Also, the engine was coupled to an eddy current type DC dynamometer (ESF-H-150, HUSINO Inc.).

The exhaust after-treatment includes a diesel particulate filter (DPF) after the turbocharger and the secondary injector nozzle which located between the DPF and LNT. Thus, the visualization window using the Pyrex tube has an installation point for an injection nozzle after the bottom of 10 cm. Therefore, an exhaust gas analyzer (MEXA-DEGR7100, HORIBA) was used to measure the performance of the lean NOx trap.

Table 3. Specifications of the test engine.

Description	Specification
Engine type	4-stroke turbo-charged DI diesel engine
Number of cylinders	4
Bore × Stroke (mm)	83 × 92
Displacement volume (cc)	1991
Max. power (ps/rpm)	146 / 4000
Max. torque (kg·m/rpm)	32 / 1,800 ~ 2,500

Table 4. Nozzle specifications.

Description	Specification
Nozzle type	Outwardly opening pintle
Spray geometry	Solid cone
Supply pressure	Max. 10 bar
Fuel temperature	Max. 90 °C
Operating frequency	Max. 50 Hz
Duty cycle	Max. 95 %
Operating voltage	12 ~ 14 V

2.4. Experimental Procedure

The secondary injector nozzle was designed as a prototype to endure under high temperature condition in the exhaust pipe. To provide overheating of the system, a diesel dosing valve (DDV) was installed between the nozzle and the fuel pump. DDV was operated by pulse width management (PWM) that controls the pulse width, duration of injection and the period. When DDV opened, the pressure of pipe became larger than opening pressure of the injection. And then, injection started with opening the nozzle. After injection completes, this process became reversed. The shape of nozzle is an outwardly opening pintle type for preventing effect of coking and leakage. These phenomena are mainly caused by impurity in the pipe and it makes a solid-cone spray pattern. Table 4 shows the specifications of the nozzle.

The experimental conditions of visualization test for spray developing process which the injection pressure was changed from 4 bar to 7 bar, and the injection durations were set 35 ms and 65 ms, respectively, and the ambient pressure was set in atmosphere pressure.

For measurement of spray sectional pattern, the fuel injection pressure was changed from 4 bar to 7 bar and injection duration was set at 35 ms. The sectional images were taken 60 mm away from the nozzle tip in the axial direction.

The experimental conditions were carried out the transparent exhaust manifold for investigating the vertical and horizontal pattern in the flow field. The injection pressure was 4.5 bar, the injection duration was set at 35 ms and ambient pressure was atmospheric pressure. To simulate the exhaust gas condition of real engine, the speed of blower motor was changed for controlling the air mass flow rate, and it changed from 10 g/s to 50 g/s. The laser sheets were formed away from the nozzle tip with 5 cm intervals for measuring the horizontal pattern.

Figure 4 shows the results of engine speed, gas flow and temperature of DPF for the exhaust gas analyzer. These values were measured in the NEDC mode by the engine dynamometer. The gas flow rate was the sum of the air intake flow rate and the rate of fuel injection at each point.

The inlet temperature of DPF and the exhaust gas flow

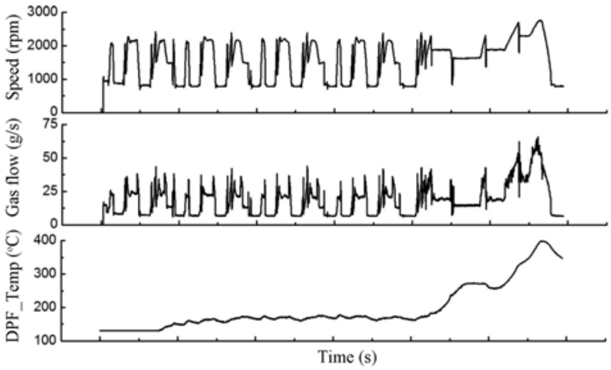

Figure 4. Gas flow properties in NEDC mode.

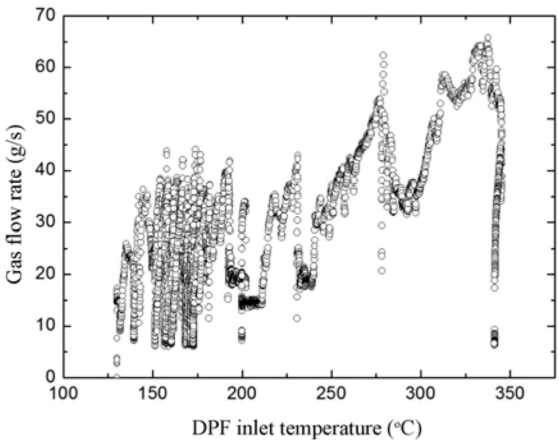

Figure 5. DPF inlet temperatures vs Gas flow rate in NEDC mode.

rate in New European Driving Cycle (NEDC) mode are shown in Figure 5. These results revealed that the exhaust temperature was 125 ~ 300 °C and the gas flow rate ranged from 10 ~ 60 g/s.

The NOx conversion performance was affected by injection condition of reducing agent (Diesel fuel) according to the engine operation. Consequently, we used the experimental engine conditions shown in Table 5 to utilize the exhaust gas analyzer. The oxygen concentration was controlled by setting the intake air of throttling below 10 % in order to increase the LNT conversion efficiency.

Table 5. Experimental engine conditions.

Eng. speed (rpm)	Fuel (g/min)	Reductant (g/min)	Penalty (%)			Emission (ppm)	
			2.17	3.25	4.33	NOx	HC
1850	59.2	2.17	3.67	5.49	7.31	44.6	53.5
2100	67.2	3.25	3.23	4.84	6.44	51.8	53.8
2300	73.6	4.33	2.94	4.41	5.88	43.5	55.9

Previous study has used various experiments to investigate the effect of the conditions of the injection pressure, duration and frequency. The shape of spray pattern in secondary injector is solid-cone and the distribution of spray mass flow is concentrated to the central axis. This shape is affected by the surface tension of high viscosity diesel fuel injected from a secondary injector with low pressure (Oh and Lee, 2014). Therefore, the fuel supply pressure was 4 bar, and the injection duration was 30 ms at 20 Hz. These conditions mean that injected droplets are finely atomized and vaporize fast. The number of injections was controlled by the amount of the injection rate at an intermittent rate of one injection per minute.

3. RESULTS AND DISCUSSION

3.1. Fuel Distribution Characteristics in the Transparent Exhaust Manifold

Figure 6 shows the RMS images of parallel sectional spray pattern in the flow field with angle of installation 0°. The fuel was distributed all over the upside and downside section of the pipe symmetrically when the rate of mass flow was low. However, the injected fuel flows downward and shape of spray cone angle became narrowed with

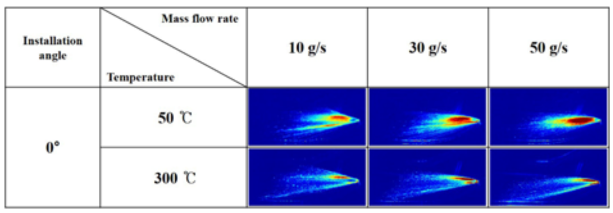

Figure 6. RMS images of spray parallel sectional pattern in the flow field (0°).

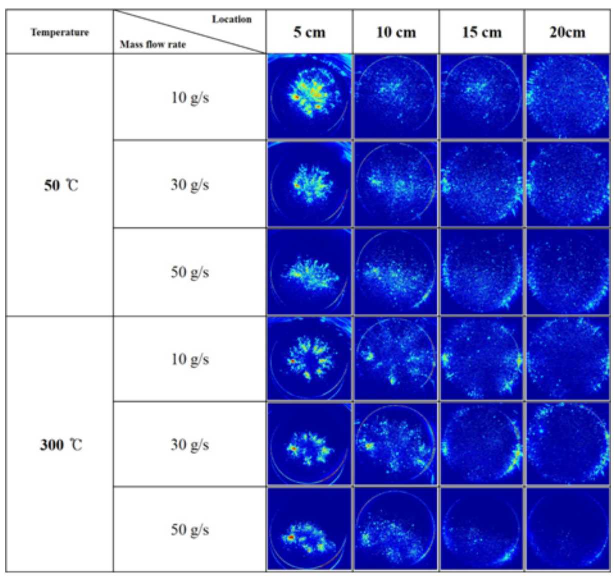

Figure 7. Spray cross sectional pattern.

increasing the rate of mass flow. The wall-wetting phenomenon was happened in the downside of pipe at 50 g/s due to a centrifugal force which affects the flow field curved.

For comparing the characteristics of spray distribution, the distance from the nozzle tip was changed and the spray images were recorded by a high-speed camera and RMS images were obtained by image processing. Figure 7 shows the spray cross sectional pattern in the pipe. The brightness of droplets was appeared brighter at 50 ℃ ambient gas temperature than that of 300 ℃ ambient gas temperature.

As distance of location increases, this phenomenon was appeared clearly. Under the 15 cm of distance from the nozzle, the intensity of distributed droplets appeared weakly. The distance of 15 cm is enough to evaporate the droplets at the ambient gas temperature 300 ℃. The injected fuel distributed at the downside of pipe as the rate of air mass flow increased and it can be verified in the vertical section pattern of the spray. As the mass air flow rate and temperature increased, reductant was distributed over a wider area, but the pattern became unstable because it impinged upon the inside of the exhaust pipe and concentrated toward one side depending on the mass air flow rate and temperature.

To investigate the effect of position and angle of installation on spray behavior, we selected two angles such as 0° and 45° which are shown in Figure 2. The reason for selecting this position and installation angle made clear the effect of exhaust gas flow because 0° angle is parallel direction to the flow and 45° angle is vertical direction to the flow. Thus, 45° angle is easy to be affected by gas flow. Figure 8 shows RMS average images of the spray behavior at an installation angle of 45°. The RMS image processing method was used to make clear spray pattern in the transparent exhaust pipe. As seen in this figure, the effect of flow field in case of 0° is less than that of 45° case and amount of wall-wetting in case of 0° is also less than that of 45°. In the installation angle of 45°, the wall-wetting occurred under the 30 g/s of mass flow rate and it almost disappeared at 50 g/s. Also, in this case of 45°, the breakup length of the liquid sheet get shorter and the distribution of the image intensity get smaller as the rate of mass flow increases. Therefore, increasing the mass flow rate makes the atomization of the spray droplet better, reduces a chance of the wall wetting effect and narrows the angle of spray cone gradually.

In addition, characteristics of spray behavior by changing ambient temperature were investigated in both cases of angles. The liquid area of spray in the transparent exhaust pipe at both angle conditions got shorter with increasing the temperature. Since surface tension of the liquid sheet is decreased as ambient gas temperature increases, the breakup speed is quickened and the fuel mass is decreased. As a result, characteristics of evaporation in the droplets strengthened and fuel was vaporized more.

From these results, it is known that the installation angle

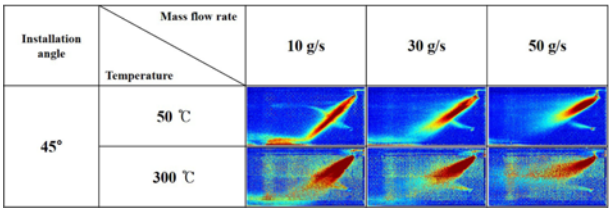

Figure 8. RMS images of spray parallel sectional pattern in the flow field (45°).

has a great effect on the spray behavior. The large angle of installation tends to produce the wall-wetting and easy to being affected by gas flow field. Therefore, the large installation angle is not appropriate in view of uniform fuel distribution within the exhaust pipe. Though, in case of large installation angle caused by limitation of exhaust pipe layout, the high gas temperature is effective to reduce wall-wetting phenomenon due to fast evaporating the injected fuel and high gas flow rate is also useful to reduce wall-wetting.

3.2. NOx Conversion Characteristics of the LNT Catalyst

It was already clarified by the effect of installation angle on spray behavior in previous study (Oh *et al*., 2008b; Nam *et al*., 2007). In this study, the effect of installation angle on NOx reduction was investigated by engine test. Three small installation angles such as 0°, 5°, and 10° were selected to find optimal installation angle for reducing NOx in this experiment because the results as shown in Section 3.1 indicated that the injected fuel would reduce the wall impingement at small installation angle, on the other hand the large angle produced wall-wetting in the pipe. The effects of the installation angle on NOx reduction without the installation angle of 45° were shown in Figure 9. Because the installation angle of 45° is not appropriate in view of uniform fuel distribution within the exhaust pipe. In this figure, the conversion characteristics at these angles were compared at the condition of 3.25 g/min and 1850 rpm. The results show that NOx levels are different from

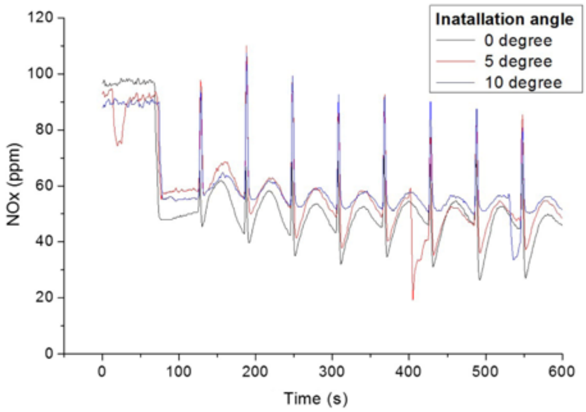

Figure 9. Effect of installation angle on NOx reduction.

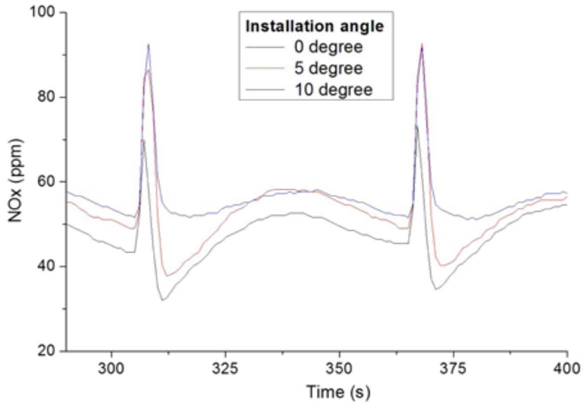

Figure 10. Close-up about the injection point of 275 ~ 400 sec.

each installation angles. But, the differences are very hard to figure out in these graphs. Thus, the figures are rewritten in a large range.

Figure 10 shows a close-up result about the injection point of 275 to 400 seconds. It was revealed that the each injection has maximum peak of NOx in all cases periodically. These results showed that the absorbed NOx was gradually reduced with an elapsed time after injection. After reduction, the NOx values were decreased and installation angle of 10° showed minimum NOx level. It was also shown that NOx affected the wall fuel flow, which determined the rate of fuel evaporation. It meant that fuel evaporation did not produce the ambient conditions which are necessary for absorption. When the fuel was completely evaporated, the NOx values were decreased because of the absorption. When the characteristics resulting from the different installation angles were compared, the same trends are shown for NOx. In particular, for an installation angle of 5°, the peak NOx value for injection was increased. It was confirmed that the conversion pattern was slightly different with changed installation angle.

Figure 11 shows the mean NOx value at LNT inlet and outlet and the conversion efficiency according to the

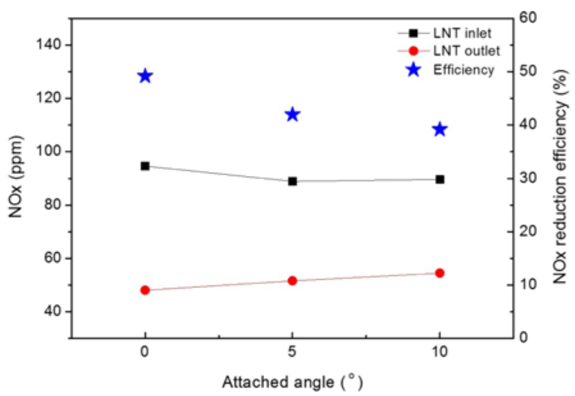

Figure 11. Comparison of mean NOx with installation angle.

installation angle. With regard to conversion efficiency, the efficiency decreased as angle became large. The conversion efficiency of 0° and 10° angles were 49 % and 39 %, respectively. This is believed that large the injection angle is easy to impinge the wall according to fluid direction. The wall impingement causes poor atomization which produces lower conversion efficiency. From this result, selecting optimized installation angle of secondary injector can improve the NOx conversion efficiency of the LNT catalyst system.

To analyze HC and NOx concentrations, we compared different injection quantities of reductant in the outlet of LNT. This comparison was carried out at an engine speed of 1850 rpm and injection conditions of 20 Hz and 10 ms per minute, which repeated at 40, 50 and 60 times (2.17 g/min, 3.25 g/min and 4.33 g/min) by increasing injection quantity.

Figure 12 shows the effects of injection quantity on HC emissions. As the injection quantity was increased from 2.17 g/min to 4.33 g/min, HC emissions increased rapidly. After that, HC decreased slowly until the next injection and the small HC peak increase was often occurred during this decreasing period. The reason of this trend was assume that the wall impingement in the exhaust pipe would be

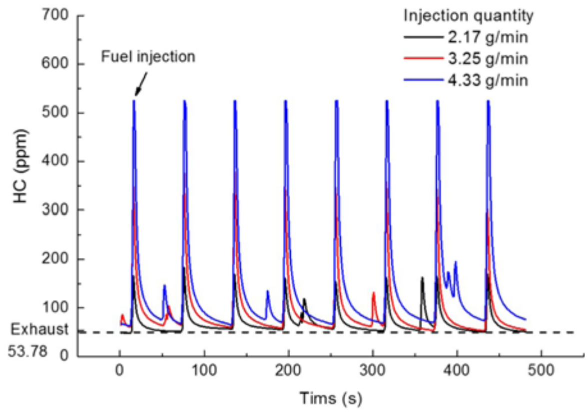

Figure 12. Effect of injection quantities on HC emissions.

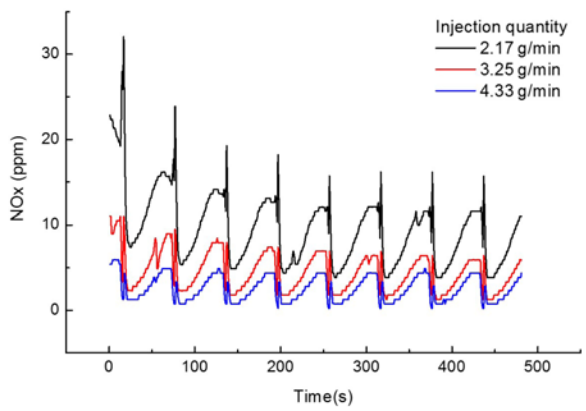

Figure 13. Effect of injection quantities on NOx emissions.

evaporated at the duration of decreasing concentration.

The effect of injection quantity on NOx emissions is shown in Figure 13. This figure revealed that NOx was sharply reduced at every reductant injection and then NOx increased slowly when NOx was absorbed into LNT. At an injection quantity of 2.17 g/min, NOx increased after reductant injection due to slipped NOx because ambient condition was not enough to deoxidize NOx. Therefore, as the injection quantity increased, NOx reduction performance improved. It was also known that NOx reduction rate in case of small injection quantity was decreased compared to the large injection quantity case.

It was difficult to carry out an experiment according to changes in the engine conditions because the exhaust gas properties were also changed by operating condition. The oxygen concentration was kept at 9 % in this study. Figure 14 shows effect of gas flow rates on HC emissions. This figure shows that engine speed has a great effect on HC emission. Since the gas flow rate was increased according to the increase in engine speed, the HC slip rate was significantly decreased with the increase of engine speed in the case of a same injection quantity. Generally, HC emission levels from diesels vary widely with operating conditions. Low speed operation produces significantly higher hydrocarbon emissions than high speed operation (Heywood, 1988).

Figure 15 shows the effect of gas flow rate on NOx emissions. Generally, the higher engine speed results in the larger NOx emission because of increased combustion pressure and temperature. However, it was found that NOx emission was slowly decreased.

Figure 16 shows the comparison of NOx reduction efficiency with regard to injection quantity and engine speed. Increasing the injection quantity of reductant improved the conversion efficiency. However, the conversion efficiency at an injection quantity of 60 times (4.33 g/min) was less than the other two conditions in terms of the injection quantity rate.

Figure 17 shows the comparisons of NOx reduction quantity according to injection quantity. In case of 2.17 g/min, NOx reduction was higher at every engine speed, and it had a similar decreasing rate at 4.33 g/min.

Consequently, increasing injection quantity of reductant has the increasing NOx reduction rate. But, it was necessary to optimize the injection quantity of reductant in

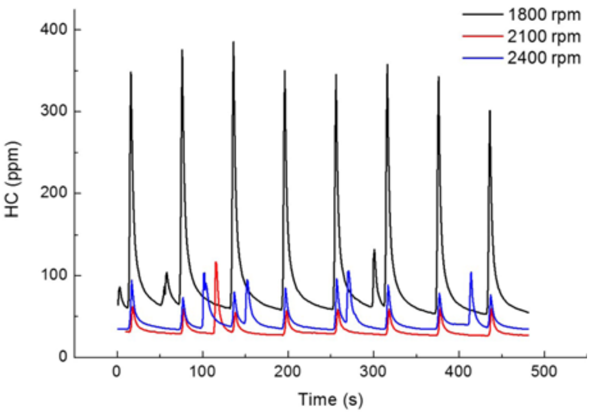

Figure 14. Effect of gas flow rates on HC emissions (Reductant: 3.25 g/min).

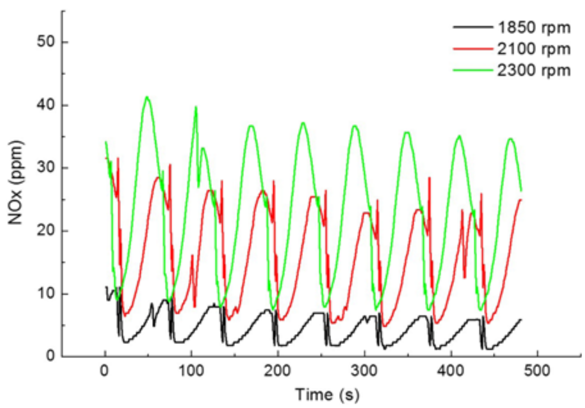

Figure 15. Effect of gas flow rates on NOx emissions (Reductant: 3.25 g/min).

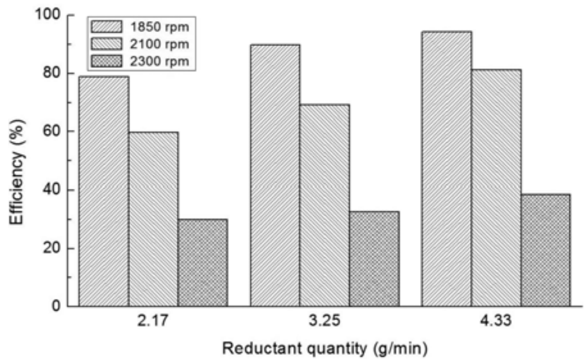

Figure 16. Comparison of NOx reduction efficiency between reductant quantity and engine speed.

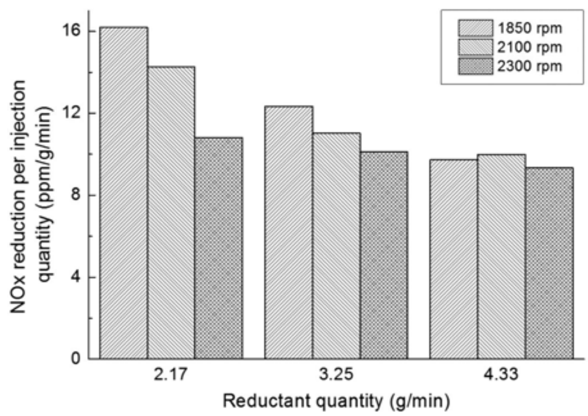

Figure 17. Comparisons of NOx reduction per reductant quantity.

order to minimize the fuel consumption.

4. CONCLUSION

In this study, the characteristics of behaviors and distributions of fuel in secondary injector for a LNT system were investigated. After that, the conversion characteristics of exhaust gas emission were analyzed in NEDC test mode. The conclusions obtained from the study are follows:

(1) The injected fuel distributed to the upside and downside of all sections in the pipe under low mass flow. As increasing mass flow, the spray cone angle getting smaller. With these result, the centrifugal force was the main factor to affect the curved flow filed of the spray.

(2) The large angle of installation tends to produce the wall-wetting and easy to being affected by gas flow field. The large installation angle is not appropriate in view of uniform fuel distribution within the exhaust pipe. Therefore, the installation angle of injector has an effect on the conversion efficiency. Experimental results revealed that the wider installation angle increases NOx emissions.

(3) As the engine speed is increased, the HC slip rate is significantly decreased under same injection quantity condition. Also, the higher engine speed results in the larger NOx emission value.

(4) The large injection quantity of reductant tends to increase NOx reducing rate. To reduce fuel consumption rate, injection quantity must be optimized.

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