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Characteristics of Ammonia Slip in SCR System of Diesel Vehicle

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Abstract

For the NOx reduction there are several reduction technologies that have been developed in order to satisfy an emission standard Tier-4 or Euro-6. The Urea-SCR system has been developed mainly for heavy duty diesel vehicles so far. On the other hand, the LNT system has been applied to passenger diesel vehicles. More precise control in urea injection technology is required in order to apply the SCR system to passenger diesel vehicles. The study explores the performance of the SCR system and its NH_3 slip when it is applied to a 2200 cc diesel passenger vehicle. To do this, it is necessary to find an optimal ratio of NH_3 and NO_x to improve SCR performance and reduce urea slip. Over-dozed urea can be affected by various driving conditions for vehicles and urea injection strategies. Furthermore in urea injection strategies exhaust gas temperature, space velocity and ratio of NH_3 and NO_x are considered as important parameters. This preliminary result may provide in design of urea SCR and urea injection strategies for passenger diesel vehicles.

Keywords: SCR (Selective Catalytic Reduction), NO_x, PM (Particulate Material), NH_3 slip, NEDC mode, LNT (Lean NO_x Trap)

1 Introduction

Emission regulation for vehicles has been stringent gradually due to the global warming effect, depletion of fossil fuel and acceleration of environmental pollution [1]. Therefore, many global industries have focused on the development of technology of alternative energy and how to reduce the use of fossil fuel and exhaust emission from vehicles [2][3][4]. Since a diesel engine of international combustion engine has higher thermal efficiency heat and lower fuel consumption than a gasoline engine, the diesel engine must be a useful and powerful engine in the present and future [5][6][7]. However, since a diesel engine emits exhaust gases, such as PM (Particulate materials) and NO_x (Nitrogen Oxide), it is inevitable to develop and apply after-treatment system such as DPF or urea-SCR to diesel engines in order to satisfy stringent emission regulations [8][9][10]. In particular, the SCR system has been applied to medium and large commercial vehicles recently. However, the urea-SCR system has been known to be effective in reducing NO_x, but the urea-slip problem occurs when urea is injected as a reductant and secondary pollution will incur. Accordingly, this research focuses how to develop optimal injection technology considering emission temperature, engine load, engine speed, space velocity and α ratio of NH_3 and NO_x.

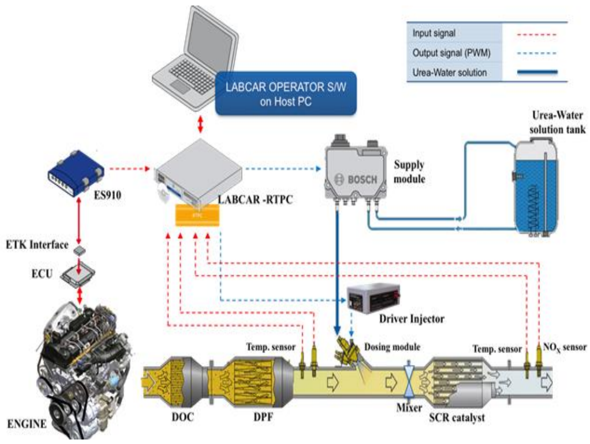

Fig 1. Schematic diagram of urea-SCR system

2 Experiments

The schematic diagram for the urea-SCR system is shown in Figure 1 and current research used a 2200cc, CRDI automobile engine as a test engine and its specification is shown in Table 1. Table 2 represents the specification of catalysts. The experimental conditions followed NEDC mode and engine speed and load conditions were set up after analyzing the most used operating driving route in NEDC mode which was and an emission test mode for European diesel passenger.

Coolant temperature was maintained to 85±2℃ and NO_x emission and temperature changes of emissions were measured and data were secured by RTPC. The test was conducted 5 times and an average value was shown as a result

Table 1. Specification of test engine

Type	4-stroke DOHC, CRDI
Number of cylinder	4
Bore (mm)	85.4
Stroke (mm)	96.0
Displacement volume (cc)	2199
Compression ratio	16:1
Firing order	1-3-4-2

Table 2. Specification of catalyst

Item	Spec.
Type	Cu-ZSM-5
Light-off Temperature	186
Diameter (in)	5.66
Cell density (cpsi)	400

3 Experimental Results

3.1 Characteristics of NO_x Emission Reduction

Fig. 3 represents NO_x concentration at the locations of front (F_NO_x) and rear (R_NO_x) and emission temperature with respect to engine speeds. NOx emission increased when engine speed and load increased. When emission temperature was lower than 200℃, NO_x reduction was lower, but NO_x reduction increases rapidly when emission temperature was more than 200℃. NO_x reduction rate was shown about 75% under the engine speed 1500rpm and engine load 3bar because emission temperature was 190℃ and did not reach a catalytic light-off temperature and then urea was not hydrolyzed. When engine load was increased to 4bar or 6bar from 3bar at the same engine speed of 1500rpm, emission temperature was increased to about 100℃ higher and NO_x reduction became more than 90%. This was because the emission temperature was about 300℃ and reached a range of catalytic light-off temperature. Similarly in engine speed of 1750rpm and 2000rpm, NO_x reduction was increased by increased emission temperature when engine load was increased. At higher engine loads of 8bar and 10bar, NO_x emission reduction ratio appeared to be more than 99%.

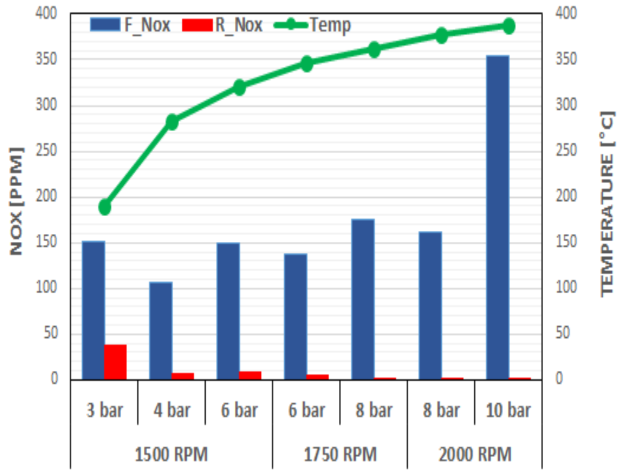

Fig 3. NOx emission in NEDC mode (α ratio =1.0)

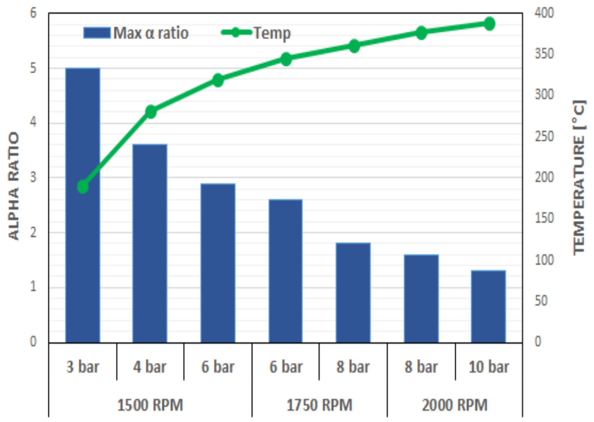

Fig 4. Maximum α ratio and emission temperature in NEDC mode

3.2 Characteristics of NH_3 slip

NH_3 slip was measured by increasing a ratio of NH_3 and NO_x at various engine driving conditions and maximum α ratio in which NH_3 slip did not occur were measured. Maximum α ratio gradually decreased when exhaust emission temperature increased. At 1500rpm and 3bar, maximum α ratio was 5.0 and at 2000rpm and 10bar maximum α ratio was 1.3 (See Fig. 4).

3.3 Performance of SCR System in NEDC mode

Fig. 5 represents NO_x emission and its temperature at α ratio 1.0. In city driving conditions, lower NO_x reduction ratio was shown since emission temperature did not satisfy to urea injection condition and did not reach a catalytic light-off temperature. On the other hand, in highway driving conditions, NO_x reduction efficiency was higher since emission temperature was above 200~300℃

which is higher than catalytic light-off temperature compared to one in city. The α ratio 1.2 where NH_3 slip did not occur through the entire route was selected for a NEDC driving mode and the results are represented in Fig. 6. NO_x reduction characteristics in NEDC mode was similar to the condition of alpha ratio 1.0, but NOx reduction ratio at α ratio 1.2 was higher than at α ratio 1.1 (See Fig. 10).
Table 3 represents NO_x emission and its reduction ratio in NEDC mode. At alpha ratio 1.0 NO_x emission and its reduction ratio were 0.088g/km and 68.8% respectively in entire NEDC mode. However, NO_x emission and its reduction ratio were 0.071g/km and 75.6% respectively at alpha ratio 1.2 and satisfied to EURO-6 emission standard. In city mode where emission temperature was lower than 200℃ NO_x reduction ratio at alpha ratio 1.0 and 1.2 were 52.8% and 63.7%. NO_x reduction ratio was increased to 10.9% by increasing urea injection ratio 20%. In highway mode where emission temperature was above 200℃ NOx reduction ratio at α ratio 1.0 and 1.2 were 86.4% and 88% respectively and the differences were 1.4% which was a very small amount.

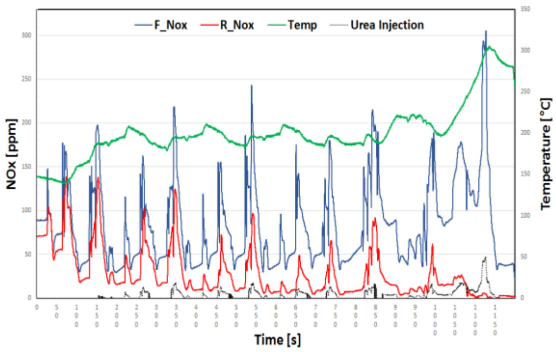

Fig 5. NOx concentration in NEDC mode (α ratio =1.0)

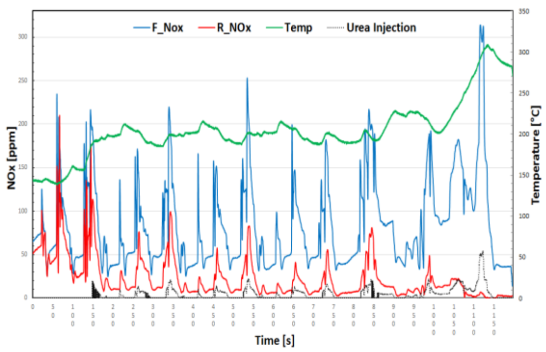

Fig 6. NO_x concentration in NEDC mode (α ratio =1.2)

Table 3. NO_x emission and NO_x reduction rate alpha ratio 1 and 1.2 in NEDC mode

Mode		α ratio (1.0)		α ratio (1.2)	
		Front of Catalyst	Rear of Catalyst	Front of Catalyst	Front of Catalyst
City	NO_x (g)	1.625	0.766	1.596	0.579
	NO_x Reduction (%)	52.8		63.7	
Highway	NO_x (g)	1.480	0.199	1.530	0.183
	NO_X Reduction (%)	86.4		88.0	
Total	NO_x(g/km)	0.088		0.071	
	NO_X Reduction (%)	68.8		75.6	

4 Conclusion

In this research, the urea-SCR system was installed to a passenger diesel engine and engine speed and load and ratio of NH_3 and NO_x were varied and the following conclusion was made.

NO_x reduction efficiency was less than 75% under the condition of lower engine speed and load since emission temperature was less than 200℃ and it did not reach catalytic light-off temperature. However, more than 90% of NO_x reduction efficiency was shown when emission temperature was more than 200℃. Maximum α ratio (NH_3/NO_x) in which NH_3 slip did not occur was decreased at higher emission temperature in general. When emission temperature was higher, performance of NO_x reduction increased, but absorption performance of NH_3 was decreased slightly. Therefore emission temperature played the dominant role. In NEDC mode, NO_x emission was 0.088g/km which did not satisfy the Euro-6 emission standard when a ratio of NH_3/NO_x was 1.0, but NO_x emission was 0.071g/km when a ration of NH_3/NO_x was 1.2 and satisfied the emission regulation. Furthermore, technology of the urea-SCR system might be extended to satisfy the Euro-6 or more stringent emission regulation by providing algorithm to determine precisely the urea injection quantity in the consideration of NH_3 absorption of catalyst.

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