

Evaluation of Cu-Based SCR/DPF Technology for Diesel Exhaust Emission Control

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ABSTRACT

Recently, a new technology, termed 2-way SCR/DPF by the authors, has been developed by several catalyst suppliers for diesel exhaust emission control. Unlike a conventional emission control system consisting of an SCR catalyst followed by a catalyzed DPF, a wall-flow filter is coated with SCR catalysts for controlling both NO_x and PM emissions in a single catalytic converter, thus reducing the overall system volume and cost. In this work, the potential and limitations of the Cu/Zelite-based SCR/DPF technology for meeting future emission standards were evaluated on a pick-up truck equipped with a prototype light-duty diesel engine.

INTRODUCTION

The selective catalytic reduction of NO_x by urea (urea-SCR) is one of the most promising technologies for diesel engine NO_x emission control. Compared to the competing lean NO_x reduction technologies such as the NO_x adsorber technology (e.g., lean NO_x trap), it offers a number of advantages, including excellent NO_x reduction efficiency over a wide temperature range and overall lower system cost.

The SCR technology using ammonia as reductant (NH₃-SCR) has been proven effective and used commercially for the removal of NO_x emissions from stationary sources since the 1970s. Because of the challenges associated with storage, handling and transportation of NH₃ on a vehicle, urea is being considered as an NH₃ storage compound in the form of an aqueous urea solution for mobile applications [1]. When the aqueous urea solution is sprayed into a hot exhaust gas stream, urea is decomposed to release NH₃, which is then used to reduce NO_x over the downstream SCR catalyst.

A typical aftertreatment system for diesel engines using the SCR technology consists of an oxidation catalyst (DOC), an SCR catalyst, and a catalyzed particulate matter filter (CDPF), which are placed in a specific serial order to achieve a desired level of emission reduction performance: DOC+SCR+CDPF or DOC+CDPF+SCR. SCR ahead of the filter (i.e., DOC+SCR+CDPF) allows

the rapid warm-up of the SCR catalyst and thus the best NO_x reduction performance during the cold-start FTP. The exhaust system architecture of DOC+CDPF+SCR [2] results in difficulty controlling the NO_x emission during the cold start, especially from the larger engines. However, it is easier to regenerate the filter, which requires a periodic cleaning to remain effective.

Recently, the 2-way SCR/DPF technology has been developed by some catalyst suppliers. Unlike a conventional DPF catalyzed with the usual precious metals such as Pt and Pd, a wall-flow particulate matter (PM) filter is coated with SCR catalysts as shown in Figure 1. Thus, both NO_x and PM can be removed in a single catalytic converter, reducing the overall system volume, mass and cost. In addition, both the DPF and NO_x reduction functions are precious group metal free, resulting in further substantial cost savings. Compared to the system architectures described above, this technology allows rapid warm-up of the SCR catalyst during the cold-start period (vs. DOC+CDPF+SCR), and lower temperature exposure for the DOC and SCR catalysts during the PM filter regeneration (vs. DOC+SCR+CDPF).

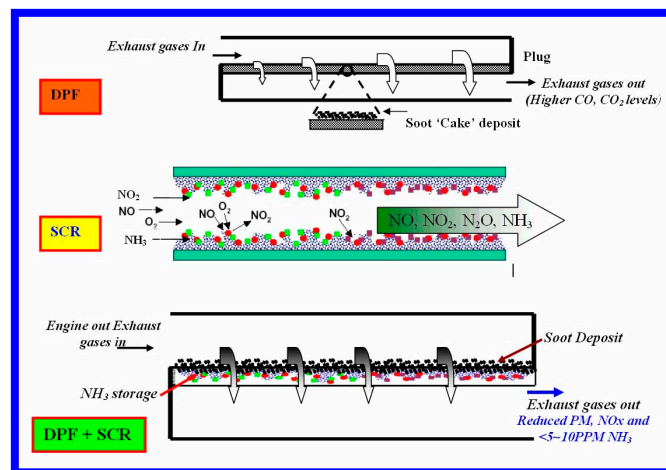


Figure 1. 2-way SCR/DPF Concept (Courtesy of Prof. C.J. Rutland, University of Wisconsin)

In this project, a Cu/Zelite-based SCR/DPF technology was evaluated on a pick-up truck equipped with a 4.9L



prototype light-duty diesel engine for its emission reduction performance during the cold-start FTP and US06 tests. Also examined were NOx reduction efficiency at high temperatures encountered during the filter regeneration by in-cylinder post injections, and the catalyst durability of the system following the regeneration.

EXPERIMENTAL

A Chevy Silverado pick-up truck equipped with a prototype 4.9L 6-cylinder diesel engine was used for this project. As shown in figure 2, the aftertreatment system included a close-coupled DOC (0.85L), an under-floor (U/F) DOC (2.3L), and the 2-way SCR/DPF catalyst. Most of the catalysts used in this study were aged in the oven to simulate low mileage (LM) and high mileage (HM) aging (shown in Table 1), mainly to capture high temperatures encountered during the DPF regeneration mode. For the injection of aqueous urea solution (32.5 wt.% urea), an airless urea dosing system was used. A static mixer was also used to improve the mixing of urea spray in the exhaust. Both the engine and the urea dosing system were controlled using ETAS INCA hardware and software, and all of the control algorithms were developed in-house using the ETAS ASCET rapid prototyping system. Ultra low sulfur diesel fuel (7-15 ppm S; Cetane number = 40-50) was used for the vehicle calibration work and emission tests.

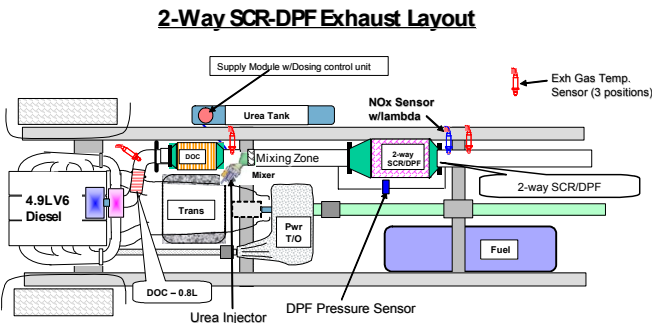


Figure 2. Exhaust system configuration

The exhaust system instrumentation included three temperature sensors for monitoring the exhaust gas temperature, and two NOx sensors for monitoring the NOx concentrations. In addition, K-type chromel-alumel thermocouples were installed at various locations. Figure 3 shows the construction details of the test samples used in this work. For this picture, the DPF substrate had a small section removed to allow examination of the component details. As can be seen in Figure 3, the 2-way SCR/DPF appearance is identical to a standard DPF.

All the emission tests were conducted at the GM Powertrain Emission Laboratories at the Milford Proving Ground. Four emission benches equipped with analyzers for NOx, THC, and CO were used to collect the modal data at the selected sampling locations, which

were then used for the engine and emission calibration development. At the tailpipe (TP) location, the dilution and proportional sampling method was used with various analyzers to collect the bag test results to report the tailpipe emissions of all the species, including NOx, THC (CH₄, NMHC), CO, CO₂, PM, NH₃, and N₂O. In addition, the carbon balance technique was used to estimate the fuel economy during the test.



Figure 3. 2-way SCR/DPF hardware

Table 1. Specifications and aging conditions of the U/F DOC and Cu/Zelite-based 2-way SCR/DPF used in this study

Sample ID	Size	Cell Density	PGM loading	Aging	Aging Condition
U/F DOC					
DOC(1)	2.3L (5"x8"x4")	400	1:0:0/70	low miles	300°C/38h + 500°C/19h on the engine
DOC(2)		400	1:1:0/120	low miles	700°C/3h in the oven*
SCR/DPF					
LM 2-way	8.0L (7.5"x11")	300	N/A	low miles	700°C/4h in the oven*
HM 2-way	8.7L (7.5"x12")	200		high miles	700°C/100h + 750°C/20h in the oven*

*Hydrothermal aging with 10% H₂O in air

FTP COLD START AND US06 PERFORMANCE

As listed in Table 2, when the 8.0L low-mileage-aged Cu/Zelite 2-way SCR/DPF (LM 2-way) was tested for FTP cold start, ~84% NOx conversion was obtained with just 5 mg/mi NH₃ slip. On the other hand, when the 8.7L high-mileage-aged 2-way SCR/DPF (HM 2-way) was used, ~82% NOx conversion was obtained with 3 mg/mi NH₃ slip. These test results were found to be very encouraging when compared with the NOx conversion performance of a 10L HM-aged Cu/Zelite SCR catalyst (HM Cu/Z). When the engine-out (EO) conditions (e.g.,