

Development of New High Porosity Diesel Particulate Filter for Integrated SCR Technology/Catalyst

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ABSTRACT

Since the implementation of Euro 6 in September 2014, diesel engines are facing another drastic reduction of NO_x emission limits from 180 to only 80 mg/km during NEDC and real driving emissions (RDE) are going to be monitored until limit values are enforced from September 2017. Considering also long term CO₂ targets of 95 g/km beyond 2020, diesel engines must become cleaner and more efficient. However, there is a tradeoff between NO_x and CO₂ and, naturally, engine developers choose lower CO₂ because NO_x can be reduced by additional devices such as EGR or a catalytic converter. Lower CO₂ engine calibration, unfortunately, leads to lower exhaust gas temperatures, which delays the activation of the catalytic converter. In order to overcome both problems, higher NO_x engine out emission and lower exhaust gas temperatures, new aftertreatment systems will incorporate close-coupled DeNO_x systems. Since the majority of current diesel emission control systems feature a close-coupled DOC+DPF converter, it seems to be a natural evolutionary step for NO_x emission reduction to integrate the SCR catalyst technology onto the DPF.

A high SCR catalyst loading will be required to have high conversion efficiency, however, higher loading amount causes high pressure drop for conventional DPF materials. Therefore a high porosity DPF design has been developed to overcome the tradeoff between high pressure drop, high washcoat loadings, and sufficient soot filtration efficiency. This paper will describe the advanced high porosity DPF for an integrated SCR concept including test results and future outlook.

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INTRODUCTION

The NO_x regulations for diesel vehicles are getting more stringent year by year. Particularly, there are plans to introduce RDE, which can simulate broader types of driving conditions in Euro 6c from 2017. Also in Europe, CO₂ emission regulation could change from the current 130 mg/km to 95 mg/km in 2020. Therefore, improvement of engine control and aftertreatment technology are desired because of these strict emission regulations.

As a mainstream of the current aftertreatment system, DOC+CSF+SCR layout has been adopted which adds a SCR under the floor to DOC+CSF layout that diesel passenger vehicles have widely adopted for regulation [1, 2]. In this system, the 1st brick, DOC, oxidizes HC and CO, the 2nd brick, catalyzed soot filter (CSF), collects soot and generates NO₂ and the 3rd brick, SCR, purifies NO_x.

However, the system has the following challenges:

1. It requires space to install the SCR and the pressure drop of the whole system increases because of the added SCR.

2. Since the SCR substrate is located downstream of DPF, temperature increase at cold start takes longer time, and SCR catalyst cannot convert NO_x during heat up.[3, 4]

Particularly, challenge 2 is a big challenge to comply with future regulations in which high NO_x conversion capability is required in a wide variety of driving situations including cold start. Additionally, engine exhaust gas temperature will be lower because engine developers will choose lower CO₂ engine calibration for future regulation.

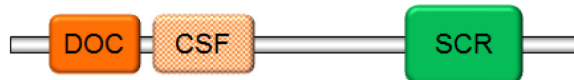
Accordingly, DOC+SCR on DPF layout has been adopted by an OEM [5, 6, 7]. SCR on DPF is the DPF coated with SCR catalyst, and it can not only collect the soot but also purify NO_x. The SCR on DPF enables a Close-Coupled (CC) layout, same as a conventional Catalyzed Soot Filter (CSF), and the SCR catalyst temperature increases quicker. Thus, NO_x purification capability at startup is improved, especially at cold start. Also, because it has the potential to eliminate the SCR substrate under floor (UF) arrangement, downsizing as well as pressure drop reduction as a whole system can be obtained.

A schematic figure of the system layouts is shown in Figure 1 and the differences between conventional CSF and SCR on DPF is shown in Table 1. A big difference is that the amount of catalyst (washcoat loading (WCL)) for SCR on DPF is largely increased. It causes a pressure drop increase because the pore in the substrate being filled with more catalyst than a conventional CSF.

EU5 Layout: DOC + CSF



EU6 Layout: DOC + CSF + SCR(UF)



EU6 Layout: DOC + SCR on DPF



Figure 1. Aftertreatment System layout

Table 1. DPF difference between CSF and SCR on DPF

	CSF	SCR on DPF
Washcoat loading	Low	High
Catalyst type	Oxidation catalyst	SCR
Position	Close-coupled	Close-coupled
Purification	Soot, HC, CO	Soot, NOx

In this paper, a DPF substrate designed for SCR on DPF is introduced with which the pressure drop does not easily increase, even with high WCL, and that provides filtration and durability performance equivalent to those of a conventional CSF.

MATERIAL CONCEPT

When the SCR catalyst is coated onto a DPF substrate for a conventional CSF, the catalyst with large grains blocks the pores, and pressure drop is increased. So, a way to suppress the pressure drop increase with a lot of catalyst becomes a challenge.

Table 2. Calculation condition of pressure drop

	DOC	CSF	SCR
Volume[2], L	1.5	2.9	1.0
Web thickness, mil*	4	12	4
Cell Density, cpsi**	400	300	400
Position	CC		UF
Gas temperature, deg.C	650		620
Gas flow, kg/hr	470		

*mil: 0.0254mm, **cpai: cells per square inch (= #/6.45cm²)

On the other hand, the SCR on DPF system can eliminate the SCR substrate in the under floor. Figure 2 shows the calculation result for system initial pressure drop with calculation conditions shown in

Table 2. In the DOC+CSF+SCR system [2], the pressure drop of the SCR shows half of that of the CSF. It means that, by eliminating SCR, the DOC+SCR on DPF system will show similar pressure drop as the DOC+CSF+SCR system if SCR on DPF has 1.5 times higher pressure drop than CSF. Therefore, a 150% pressure drop compared to the CSF is set as the target of an allowable pressure drop for the SCR on DPF.

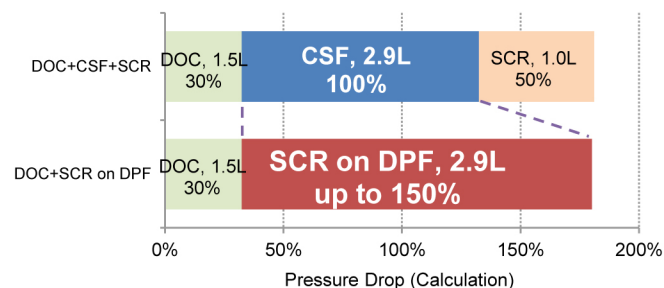


Figure 2. System initial Pressure drop comparison (calculation)

The mechanism for increased pressure drop by the SCR catalyst coating is caused by the pores in the DPF substrate being filled by the large amount of catalyst. In other words, it is caused by the reduction of pass channels in the wall for the gas permeation resulting from the decrease of porosity. Since zeolite-based materials are generally used for SCR catalyst [8], by calculating from a zeolite density (ca. 2g/cm³) and WCL for SCR on DPF (ca. 5 to 10 times as much WCL compared to CSF), it can be estimated that the porosity decreases roughly 15 - 20% by filling pores in DPF substrate with SCR catalyst. And porosity, measured by Mercury porosimetry, of coated SCR on DPF (more than 5 times higher WCL compared to CSF) was reduced by 17% than that of uncoated. Because the porosity of current mainstream CSF for European passenger car is about 40%, at least 55% or higher porosity is required for a substrate of SCR on DPF, considering the filling by catalyst.

Thus, development is driven with “55% or higher porosity” as the concept of substrate for SCR on DPF to achieve 150% or less pressure drop compared to CSF while maintaining soot filtration and durability performance.

MATERIAL OPTIMIZATION STUDY

Porosity

First, to see the impact of porosity on initial pressure drop, 5 coated samples, listed in Table 3, were investigated. The SCR catalyst is Cu-zeolite and there is a same WCL for SCR coated samples (A to D). Initial pressure drops of catalyst coated materials (Air flow: 10 Nm³/min, RT, cold flow bench) were measured and the relationship of those with porosity are shown in Figure 3. The relationship was confirmed that higher porosity correlates with lower pressure drop and it shows that more than 60% porosity is recommended from the view point of pressure drop.

Table 3. Sample information for Porosity optimization (Pressure Drop)

Sample	A	B	C	D	CSF from EU5 commercial application
Material	Si bond SiC (segmented) [9]				
Porosity, %	63	66	62	61	41
Mean Pore Size (MPS), μm	19	20	19	18	13
Catalyst	SCR Catalyst		Oxidation Catalyst		
Cell Structure	12 mil / 300 cpsi (Asymmetric)				
DPF volume	3L.				

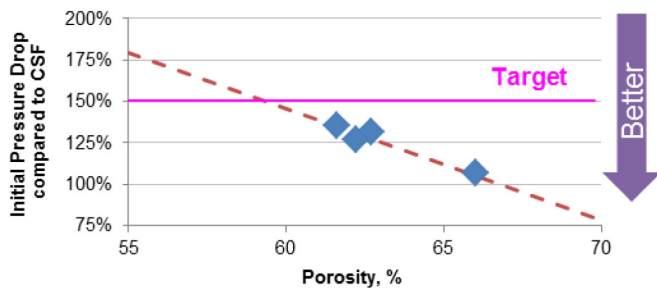


Figure 3. Influence of Porosity on Initial Pressure drop (coated) Air flow: 10Nm3/min, RT, Cold flow bench

Meanwhile, past findings clarified that the strength of the substrate decreases while its porosity increases; there is a concern if a higher porosity filter can maintain the strength necessary to be included in the exhaust system. Strength measurements were carried out at the levels shown in Table 4. The strength was evaluated by an isostatic strength measurement test with the machine shown in Figure 4, which applies hydrostatic pressure to DPF and the pressure at breakage is judged as the strength. The correlation is shown in Figure 5. The strength is shown on the vertical axis where 100% indicates the average strength target considered the required strength with deviation. As in the past findings, the strength exhibits a declining trend when porosity increases. Considering minimum strength (N=10) for each sample as worst case, the strength does not achieve the target above 65% of porosity.

Table 4. Sample information for Porosity optimization (Strength)

Sample	A	B	C	D
Material	Si bond SiC (segmented)			
Porosity, %	57	60	63	66
MPS, μm	23	20	19	21
Catalyst	no catalyst			
Cell Structure	12 mil / 300 cpsi (Asymmetric)			
DPF volume	3 Ltr.			
Number of measurement	10			

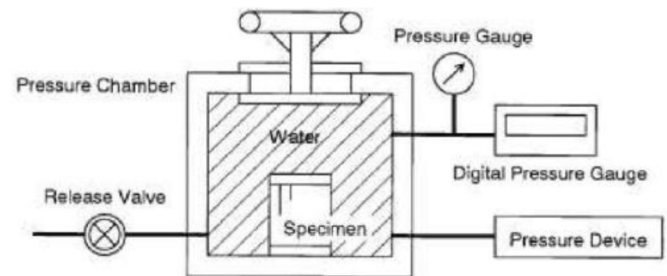


Figure 4. Schematic of Isostatic Strength Test

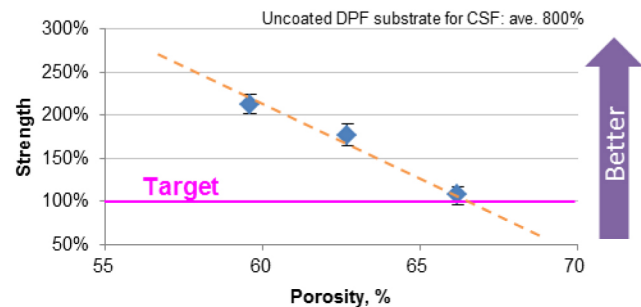


Figure 5. Influence of Porosity on Strength (uncoated)

Considering pressure drop and strength requirements, a range of 60-65% porosity was determined to be optimum for the filter for SCR on DPF applications.

MPS (Mean Pore Size)

Next, MPS influence over initial pressure drop and smoke leakage were evaluated by the conditions shown in Table 5. (SCR coating condition is the same in the previous section)

Table 5. DPF Characteristic

Sample	A	B	C	CSF from EU5 commercial application
Material	Si bond SiC (segmented)			
Porosity, %	64	64	64	41
MPS, μm	16	17	24	13
Catalyst	SCR Catalyst			Oxidation Catalyst
Cell Structure	12 mil / 300 cpsi (Asymmetric)			
DPF volume	3L			
Number of measurement	1			

Initial pressure drops of catalyst coated materials were measure by the same condition as the previous section (Air flow: 10 Nm3/min, RT, Cold flow bench).

For the smoke leakage test, the smoke was measured during a full load step up (FLST) mode shown in Figure 6 using an engine bench with a EU4 compatible 2.0L engine installed (Figure 7). Clean (without soot) DPFs were evaluated by FLST.