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ABSTRACT

Catalyzed soot filters are being fitted to an increasing range of diesel-powered passenger cars in Europe. While the initial applications used silicon carbide wall-flow filters, oxide-based filters are now being successfully applied. Oxide-based filters can offer performance and system cost advantages for applications involving both a catalyzed filter with a separate oxidation catalyst, and a catalyzed filter-only that incorporates all necessary catalytic oxidation functions. Advanced diesel catalyst technologies have been developed for alternative advanced oxide filter materials, including aluminum titanate and advanced cordierite. In the development of the advanced catalyzed filters, improvements were made to the filter material microstructures that were coupled with new catalyst formulations and novel coating processes that had synergistic effects to give enhanced overall performance. This paper discusses relevant system performance criteria including pressure-drop, emissions, thermal-mechanical influences and the overall system durability in tests under certain controlled test conditions.

INTRODUCTION

Over the past decade, there has been considerable progress made to reduce particulate emissions from diesel vehicles. Advances in diesel engine design and control have allowed substantial reductions in the engine-out particulate matter (PM) levels. In addition, fitment of flow-through oxidation catalysts further reduced the overall level of PM from modern diesel engines. So-called wall-flow diesel particulate filters (DPFs) achieve further significant reductions of PM and in recent years there has been substantial development of catalyzed diesel particulate filters, and most European car manufacturers now offer models with catalyzed filters. The majority of initial filter systems were located in the under-floor position on the car because of space constraints. However, where space constraints allow, it is desirable to design the engine compartment so filter systems can be incorporated either close-coupled or near-coupled to the turbocharger. Moving the filter closer to the turbocharger enables more rapid catalyst light-off compared with under-floor configurations. This improves CO and HC oxidation, and NO oxidation to NO_2 that can react with retained soot in the filter under normal driving conditions (a process termed passive regeneration). The close-coupled location significantly reduces the loss of heat in the exhaust gas piping especially during forced regeneration of the filter (termed active regeneration) compared to underbody location of the filter. In addition, these systems often allow the use of smaller upstream diesel oxidation catalysts (DOC) or even integral DOC functionality on the filter itself (no separate DOC). Such systems reduce overall system and operating costs by having more efficient filter active and passive regeneration processes. This allows the use of smaller advanced filters; with catalyst functionality that does not require a large separate DOC, and hence requires less precious metals than otherwise would be the case.

Advanced oxide filter technologies based on aluminum titanate [1-5] and advanced cordierite [6] have the following technical characteristics:

(a) low expansion and therefore filters can be made as a monolith and do not require segmentation, thus simplifying filter manufacture

(b) low thermal conductivity and therefore low heat loss to the environment, allowing faster catalyst light-off

(c) low backpressure as a consequence of the monolithic design which does not have the volume losses associated with a segmented and cemented design

New catalyst formulations and novel filter coating processes have been developed to give enhanced catalyst performance [7-9]. These new catalyst coatings have demonstrated advantageous thermal durability and low back pressure in the clean and soot loaded conditions. They have been adapted specifically for each oxide filter type. This paper provides some insight into the performance of technologies for applications of advanced catalysts on advanced oxide diesel particulate filters. The filters in this study where based on advanced cordierite materials and aluminum titanate materials. Unless otherwise stated, the advanced cordierite referred to in this paper is Corning DuraTrap® AC filters (abbreviated AC) with nominal 300 cells per square inch (cpsi) and 15 thousands of inch wall thickness (mil), and the aluminum titanate filter is Corning DuraTrap® AT filters (abbreviated AT) with nominal 300 cpsi and 13 mil wall thickness. All Corning filter products were catalyzed with Johnson Matthey catalyst technology. In some presented data reference products are included which were catalyzed from the OEM source.

CATALYZED FILTER FUNCTIONALITY

PRESSURE DROP

As stated previously, these advanced oxide products can have lower pressure drop than their SiC counterparts, in part because the segmented SiC filter design takes a proportion of the overall volume of the filter as cement joints. Further reductions in filter backpressure in the soot and ash loaded state over the lifetime of the filter can be achieved by the use of larger inlet and smaller outlet channel designs [10-11], asymmetric cell technology (abbreviated ACT). This lower pressure drop provides benefits in both lifetime power and fuel economy. In addition, the advanced coatings applied to these oxide materials have been designed to minimize the pressure drop impact on the filter in the clean and soot-loaded condition. Several examples of pressure drop tests from engine dynamometer and vehicle tests are provided below.

<u>Applications with a Separate DOC</u>

Figures 1-2 show pressure drop comparisons measured on an engine dynamometer for catalyzed advanced oxide filters and reference segmented SiC filters. Advanced oxides show pressure drop advantages in both the bare and soot-loaded states.

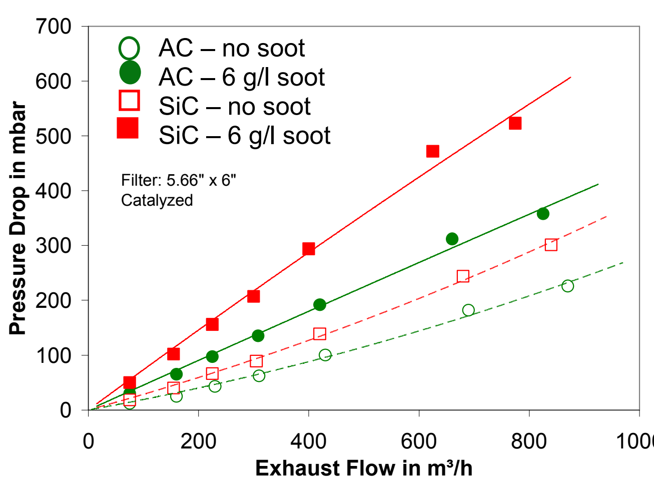

Figure 1: Filter pressure drop as tested on engine dynamometer - reference 200 cpsi segmented SiC and advanced cordierite with ACT at 0 g/liter and at ~ 6.5 g/liter soot (at increasing speed and load to increase flow rate)

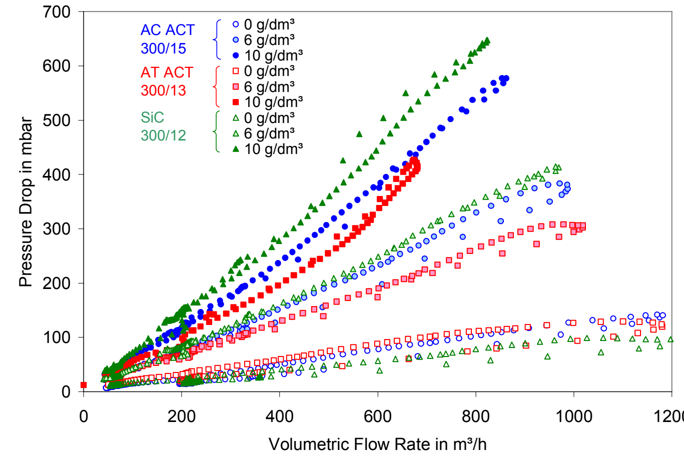

Figure 2: Pressure drop measured on an engine dynamometer, for reference there is 300 cpsi segmented SiC filter, advanced cordierite with ACT and aluminum titanate with ACT at 0, 6 and 10 g/liter soot

This pressure drop advantage is seen when the catalyzed filters are used on a vehicle and tested under different exhaust gas flow rates, as demonstrated in Figure 3.

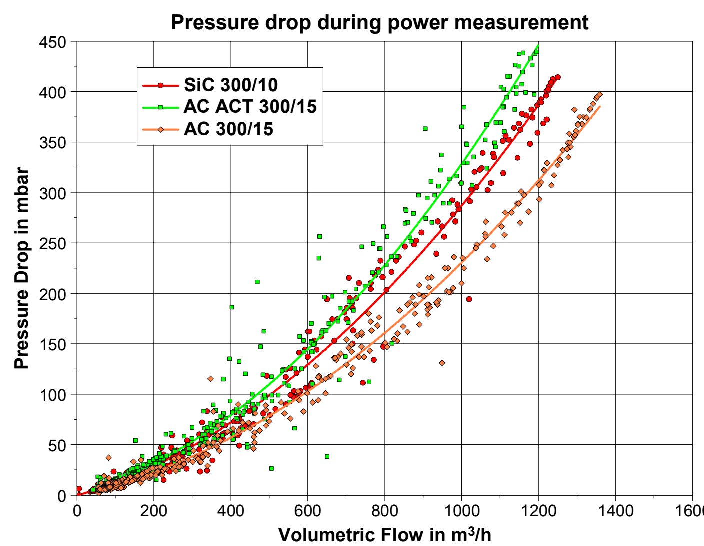

Figure 3: Pressure drop measurements in the “nearly clean” state (<40 km on new filter), as tested on a 3.0 liter diesel vehicle. OEM reference SiC filter and AC filter had 4.6 liter and 4.1 liter volume, respectively.

<u>Applications with an Integral DOC</u>

With filter-only applications the DOC function is integrated in the filter. Highly active catalyst coatings are required and washcoat loadings are generally higher than those used on under-floor catalyzed filters. Higher washcoat loadings provide the necessary thermal durability for efficient HC and CO oxidation. Again, advanced coatings were developed specifically for these advanced filter materials that have advantaged pressure drop performance. Engine dynamometer and vehicle work were reported previously, verifying this advantage [3-5]. An additional example for AT (see Figure 4) shows pressure drop comparisons versus reference segmented SiC filters, where the advanced oxide shows a pressure drop advantage in both the bare and soot-loaded state.

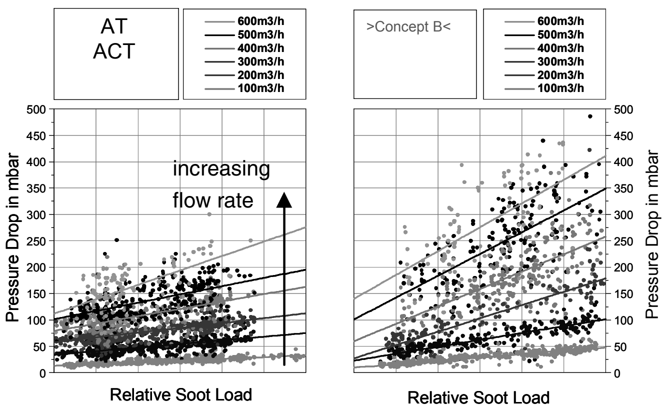

Figure 4: Pressure drop measurements as a function of soot loading at various flow rates for an aluminum titanate filter with ACT and “concept B” an OEM reference 300 cpsi segmented SiC filter – high porosity, as tested on a 2.0 liter diesel vehicle. Both filters had a 3.0 liter volume [3]

EMISSIONS

Gaseous and particulate emissions over the European MVEG-B (NEDC) test cycle were evaluated with both advanced oxide materials. Results were assessed against the relevant European emissions standards for that vehicle.

Advanced Cordierite

Two different vehicles had the OEM filter system replaced with a catalyzed advanced cordierite filter system. Vehicle 1 had a 2.2 liter engine. The original equipment DOC, uncoated filter and fuel additive were removed and replaced with a single unit catalyzed cordierite filter with integral oxidation function. The single unit filter system was located in a mid-coupled position, located 8 inches from the turbocharger. No changes were made to the calibration. The vehicle was driven over the AMA cycle for 60,000 km and emissions measurements were taken at various intervals (see Figure 5). Very high emissions conversions were found especially when considering no change was made to the engine calibration.

An additional vehicle study was completed on a 3.0 liter diesel engine vehicle to measure particulate emissions from a DOC and separate catalyzed filter system. Figure 6 shows the MVEG-B test cycle PM emissions data from this vehicle fitted with three different catalyzed advanced cordierite filters.

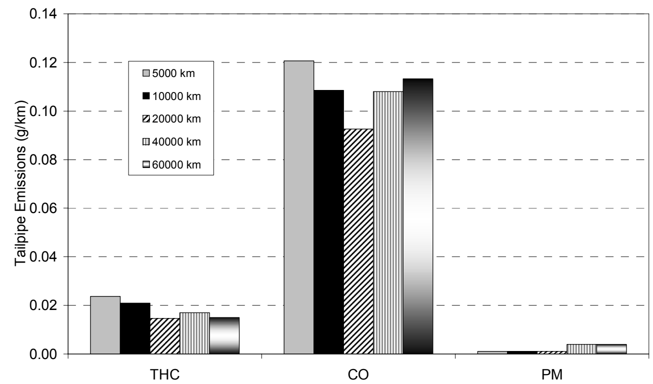

Figure 5: Tailpipe emissions over the MVEG-B test cycle from a 2.2 liter vehicle originally equipped with a fuel additive system and bare SiC filter, but retrofitted with a single unit catalyzed advanced cordierite filter

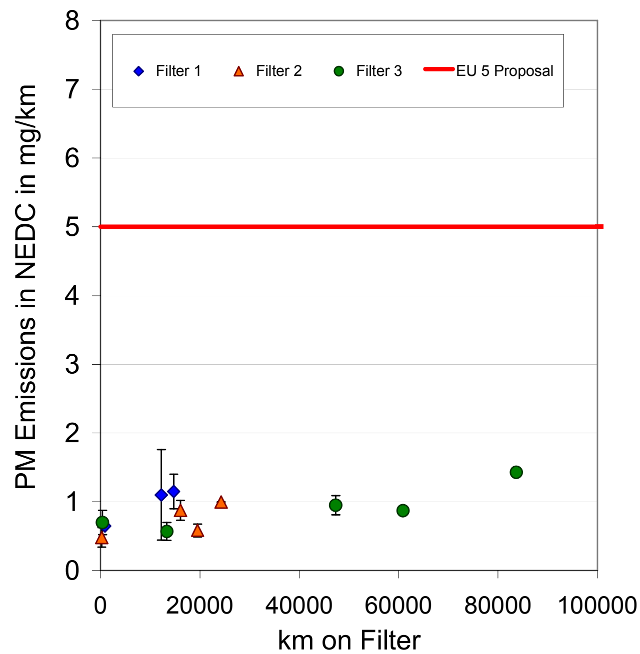

Figure 6: PM emissions over the MVEG-B test cycle for a DOC and catalyzed cordierite filter fitted on a European vehicle with a 3.0 liter diesel engine

Aluminum Titanate

Several 1.9 and 2.0 liter vehicles equipped with an aluminum titanate filter catalyzed with integral DOC function were tested for long distance durability. The catalyzed filters were positioned close-coupled to the turbocharger to enable rapid catalyst light off. Chassis dynamometer and real world driving were used to assess the emissions performance under different driving conditions. Dynamometer testing was carried out using the low speed AMA cycle to present more challenging soot regeneration conditions. Figure 7 shows emissions performance for Vehicle A over 24,000 km of AMA cycle aging.

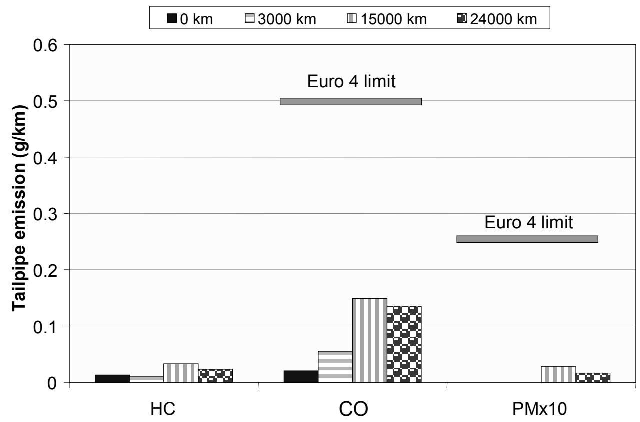

Figure 7: MVEG-B test cycle emissions for catalyzed aluminum titanate filter-only on a 1.9 liter Vehicle A over 24,000 km of AMA cycle ageing

The catalyzed filter on Vehicle A showed very good durability. Tailpipe gaseous and PM emissions remained well within the Euro 4 limits, demonstrating the robustness of the catalyzed filter to repeated soot regenerations.
Vehicle B was equipped with a similar system, but with a more advanced catalytic coating. Pt/Pd catalysts can offer improved thermal stability [7] because of the stabilizing effect of the Pd. Figure 8 shows the emissions performance of Vehicle B fitted with a Pt/Pd catalyzed filter-only system over 20,000 km of AMA cycle ageing.

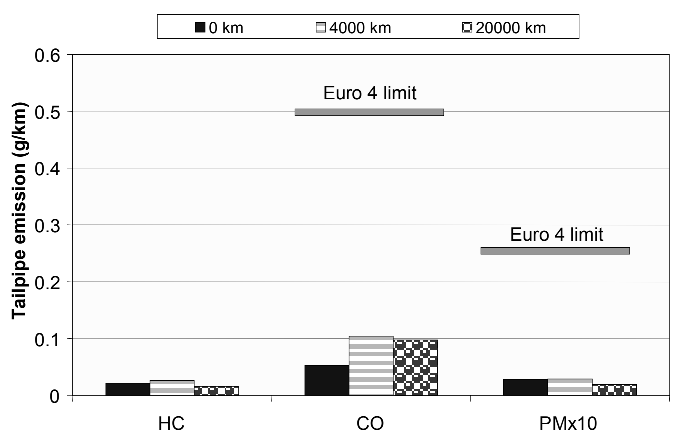

Figure 8: MVEG-B test cycle emissions for Pt/Pd catalyzed aluminum titanate filter-only on a 2.0 liter Vehicle B over 20,000 km of AMA cycle aging

After some initial stabilization of the catalyst on Vehicle B at 4,000 km there was no further increase in tailpipe emissions up to 20,000 km. All tailpipe emissions remained very low throughout the entire aging cycle.

Two further vehicles were used to demonstrate durability under real world driving. Vehicle C contained a catalyst containing a “normal” precious metal content. This vehicle was run to 240,000 km in a mixed driving cycle, which included city, country road and autobahn driving (limited to 130 km/hr). The emissions data as a function of distance (up to 240,000km) are shown in Figure 9. Remarkable emissions performance was achieved with no separate DOC. Vehicle D had a similar system and is currently collecting mileage. The precious metal loading on this system is lower than for Vehicle C because it has the advanced Pt/Pd catalyst technology. The MVEG-B test cycle emissions for the first >150,000 km are shown in Figure 10, and are also quite good.

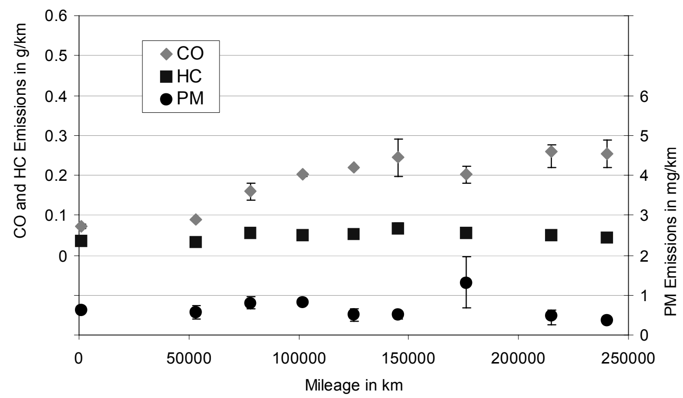

Figure 9: MVEG-B test cycle emissions for catalyzed aluminum titanate filter-only on a 2.0 liter Vehicle C over 240,000 km of real-world driving

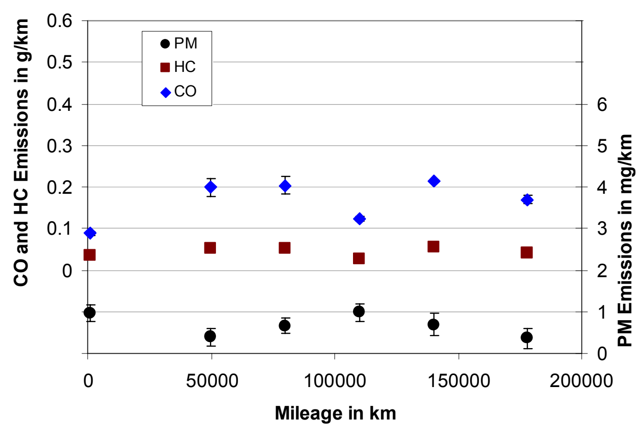

Figure 10: MVEG-B test cycle emissions for Pt/Pd catalyzed aluminum titanate filter-only on a 2.0 liter Vehicle D over >150,000 km of real-world driving

THERMAL-MECHANICAL DURABILITY

It is important that the composite filter system (filter and catalyst) exhibit excellent long-term durability. Given the likelihood that future emissions regulations may extend the mileage limits further [12], and that additional regulations may also include particulate number measurements [13], careful attention must be given to durability aspects when developing catalyzed filter systems.

The catalyzed filter should have an acceptable balance of physical properties including strength, elastic modulus and coefficient of thermal expansion [14]. Extensive work on both cordierite and aluminum titanate has been jointly completed to provide a combination of physical properties to contribute to long-term durability. To verify the viability of such composite systems, a variety of tests were conducted including, physical property measurement on the coated filters, extreme drop-to-idle (DTI) tests to evaluate temperature gradients limits and peak temperature limits, and repeated, extreme DTI tests to evaluate long term durability. To determine the number of extreme DTI tests required the following assumptions were made. It was assumed for a passenger car application with an extended lifetime of 240,000 km (150,000 miles) up to 600 regenerations could occur. It was also assumed less than ten percent of these regenerations are uncontrolled DTI regenerations (< 60 regenerations). Therefore these systems were tested in DTI conditions to exceed this limit. Data collected in real world driving suggested the real percentage of such conditions is much smaller (~2%) [15].

In addition to emissions durability, which has thus far, been excellent, a second level of durability has been considered. Oxide-based filters have excellent thermal and mechanical properties. Further specifics of durability will be dealt with in a sister paper [16].

CONCLUSION

Advanced catalysts when properly applied to advanced oxide filters can provide an effective and durable solution for future aftertreatment needs. Corning's new oxide-based materials with specifically developed advanced catalysts have been demonstrated in DPF applications with both a separate DOC and a filter-only with integral DOC function. These systems offer the possibility of compact packages with high efficiencies.

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REFERENCES

1. S. Ogunwumi and P. Tepesch, "Aluminum-Titanate Based Materials for Diesel Particulate Filters," 28th International Cocoa Beach Conference on Advanced Ceramics & Composites (2004)
2. S. Ogunwumi, P. D. Tepesch, T. Chapman, C. J. Warren, I. M. Melscoet-Chauvel and D. L. Tennent , "Aluminum Titanate Compositions for Diesel Particulate Filters," SAE 2005-01-0583 (2005)
3. L. Kercher, D. Rose, T. Boger, W.A. Cutler, T. Dusterdiek R. Dorenkamp and G. Kahmann, "Application of a New Filter Material in Volkswagen's Diesel Particulate Filter Systems," Emission Control, Dresden (2006)
4. T. Boger, A.K. Heibel, D. Rose, W.A. Cutler and D.L. Tennant, "Evaluation of New Diesel Particulate Filters based on Stabilized Aluminum Titanate,".MTZ (66) No. 9 (2005)
5. A. Heibel, J. Schultes, R. Bhargava, T. Boger, D. Rose and O.A. Pittner, "Performance and Durability Evaluation of the New Corning DuraTrap® AT Diesel Particulate Filter – Results from Engine Bench and Vehicle Tests," Aachen, 2005, 193-218
6. M. Pidria, E.M. Borla, A. Gioannini, T. Boger, W.A. Cutler, and A. Valentini, "Experimental Characterization of Diesel Soot Regeneration in Cordierite Filters," Fisita F2006P247 (2006)
7. A.F. Chiffey, P.R. Phillips, D. Swallow, M.V. Twigg, W.A: Cutler, T. Boger, D. Rose, and L. Kercher. *Performance of New Catalyzed Diesel Soot Filters Based on Advanced Oxide Filter Materials*. 4th FAD Conference "Challenge – Exhaust Aftertreatment for Diesel Engines"; Dresden 2006.
8. P.G. Blakeman, A.F. Chiffey, P.R. Phillips, M.V. Twigg and A.P. Walker 2003, "Developments in Diesel Emissions Aftertreatment Technology", SAE 2003-01-3753
9. A.F. Chiffey, W.A. Cutler, G.A Merkel, P.R. Phillips, T.Tao, M.V. Twigg, A.P. Walker, 9th DEER conference, "New Cordierite Diesel Particulate Filters for Catalysed and Non-catalysed Applications" (2003)
10. D. Young, D. Hickman, N. Gunasekaran and G. Bhatia, "Ash Storage Concept for Diesel Particulate Filters," SAE 2004-01-0948 (2004)
11. A. Heibel, et. al., "Advanced Diesel Particulate filter Design for Lifetime Pressure Drop Solution in Light Duty applications," SAE 07SFL-60 (2007)
12. European Parliament's Committee on Transport and Tourism Meeting Notes, June (2006)
13. EU Commission Proposal {SEC(2005) 1745}
14. W. Cutler, "Overview of Ceramic Materials for Diesel Particulate Applications," Ceram. Eng. Sci. Proc. 25 [3] 421-430 (2004)
15. T. Boger, unpublished data from fleet tests (2006)
16. T. Boger, et. al., "On Road Durability and Field Experience Obtained with Corning's New DuraTrap AT Diesel Particulate Filter," SAE 07PFL-118 (2007)