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Lorenzo Pace, Roman Konieczny, Manuel Presti
EMITEC GmbH

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400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel.: (724) 776-4841 Fax: (724) 776-5760

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ABSTRACT

Modern Diesel Engines equipped with Common-Rail Direct Injection, EGR and optimized combustion technology have been proven to reduce dramatically engine raw emissions both in terms of Nox and Particulate Matter.

As a matter of fact the recently introduced FIAT 1.3 JTD 4 Cylinder Engine achieves Euro 4 limits with aid of conventional 2-way oxidation catalyst. Nevertheless some special applications, such as platforms with relatively higher gross vehicle weight possibly yield to PM-related issues.

The present paper deals with the development program carried out to design a cost effective aftertreatment solution in order to address particulate matter tailpipe emissions. The major constraint of this development program was the extremely challenging packaging conditions and the absolute demand to avoid any major impact on the system design.

The flow-through metal supported PM Filter Catalyst has been extensively tested on the specific vehicle application with aid of roller bench setup. Partial engine load soot loading, continuous regeneration and long term soot trapping efficiency have been addressed during the present work.

INTRODUCTION

The Diesel Emission Legislation is a highly discussed topic nowadays. Especially the suspected health issues related to particulate emissions derived by the massively increased market success of diesel powered vehicles are currently one of the most important topics.

In the recent years the introduction of wall flow Particulate Traps has been considered to be the only acceptable way to comply with legislation and political discussion. Consequently several car manufacturers introduced wall flow particulate filters as original equipment in different applications, with special attention to heavier vehicles such as segment D/E cars, which otherwise might not achieve Euro 4 limits.

Meanwhile it has become more and more apparent that such aftretreatment systems might come along with major design and engineering challenges, hence conflicting with the increasingly stringent cost reduction targets, especially in lower segments passenger cars. Consequently several car manufacturers are investigating alternative avenues, such as flow through filters.

In the present paper the application engineering of a Metal supported PM-Filter Catalyst on a production 1.3 L 4-Cylinder Diesel Engine is discussed with aid of experimental data, in order to present a cost effective and low-impact aftertreatment solution, which can be easily fitted in an already designed exhaust system as original equipment.

PM FILTER CATALYST – BASIC PRINCIPLES

The PM-Filter Catalyst is a metal supported substrate, consisting of flat and corrugated foils similar to well known metal, even though there are some major differences. The corrugated foils are structured with blades or shovels to deviate the flow towards the flat layers. These consist of a porous metal fleece, which actually trap the Particulate Matter present in the exhaust gas. The temporarily trapped particles are subsequently oxidized by means of NO_2 (Fig. 1, Fig. 2, Fig. 3,).

Detailed description of operating principles of the PM Filter Catalyst have been already presented [1, 2, 3].

Due to its design, the PM-Filter Catalyst is a partially open structure, which cannot clog due to excessive soot accumulation. Therefore it can be installed in relatively cold applications, which would have major regeneration problems in case of traditional wall flow Particulate Traps.
Furthermore flow through devices, such as the PM Filter Catalyst, are not sensitive to ash accumulation issues.

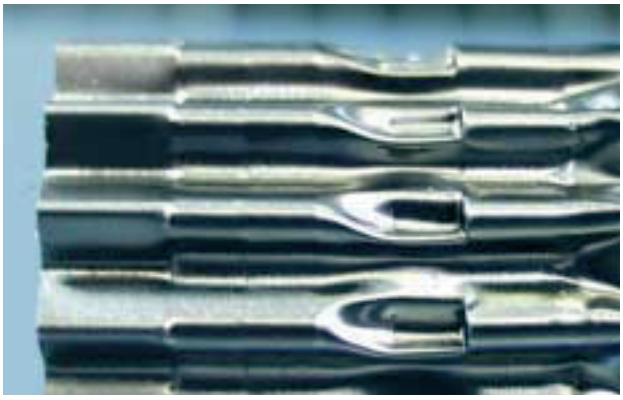

Fig. 1 – Corrugated layer of the PM Filter Catalyst

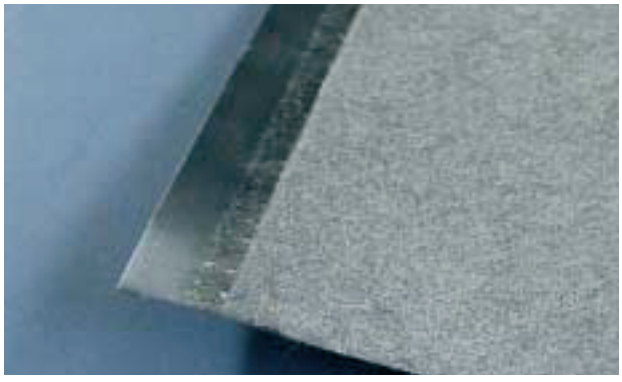

Fig. 2 – Flat layer (porous fleece) of the PM Filter Catalyst

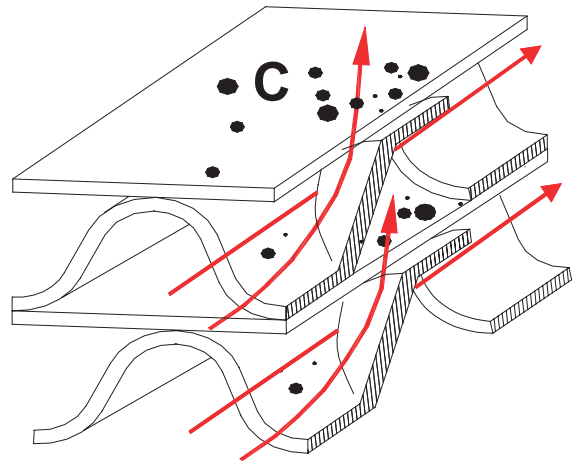

Fig. 3 – Operating principle of the PM Filter Catalyst

EXPERIMENTAL SETUP

The PM-Filter Catalyst has been already tested and successfully proved on several engine applications, from medium size passenger cars up to heavy duty commercial trucks [4, 5]. In the recent years one evident market trend in Europe is the increasingly successful introduction of very small diesel engines (less than 1.5 L displacement) on a relatively broad range of passenger cars.
These modern engines, equipped with EGR and high pressure fuel injection, easily comply with Euro4 emission limits both with respect of HC/CO as well as NO_x/PM. On the other hand, due to the high specific power and torque of such powertrains, they often equip relatively heavy vehicles such as microvans, hence leading to potential issues with respect of overall PM emissions.

In order to investigate this kind of application, a FIAT Doblo' vehicle, equipped with a 1.3 L JTD Diesel Engine has been tested on a roller bench rig. Both CVS bag and modal data have been measured during the ECE Test Cycle with particular focus on NO_2/C Ratio, PM Trapping efficiency and soot loading stability.

The tested engine is equipped with a Euro3 Stage calibration. The baseline exhaust system consists of a close coupled catalyst (4.66"x5"/350/5.5) loaded with 70gr/ft^3 Pt.

TEST PROCEDURE

Each catalyst system before being tested with respect to HC/CO conversion efficiency and PM Trapping efficiency, has undergone a preconditioning cycle consisting of three EUDC modules repeated in row. This procedure is finalized to eliminate any soot residuals in the PM Filter Catalyst.

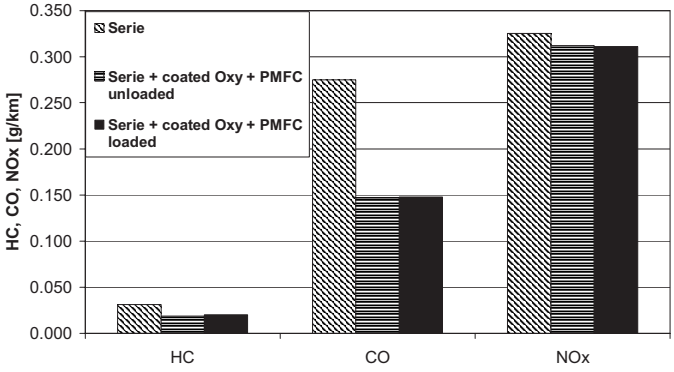

Fig. 12 - HC, CO and NOx tailpipe emissions of the baseline system compared with a system retrofitted with a coated LS oxicat and an uncoated PMFC.

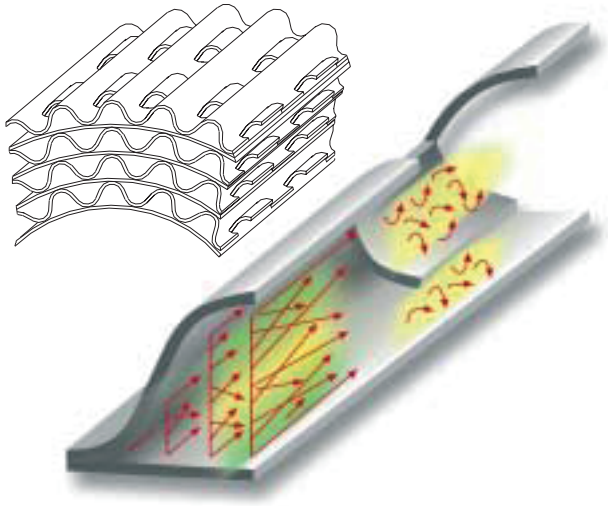

Fig. 13 – Operating principle of the LS substrate. Turbulent-like flow is created along the channel axis, improving mass transfer properties

This reason is twofold: on one side the LS blade creates a secondary cell increasing the effective overall cell density of the substrate; on the other hand the fully developed laminar flow is repeatedly interrupted. This means that the flow, which would otherwise be fully laminar and therefore with diffusion governed mass transfer, can now be considered turbulent-like with consequent convection governed mass transfer.

Once the CO amount has been significantly reduced, is of utmost importance to increase NO2 content in the exhaust gas to ensure long-term PM trapping efficiency.
It is apparent from Fig. 15 that the 300LS oxidation catalyst improves the NO2 concentration by 16% in addition to the highly increased CO conversion.

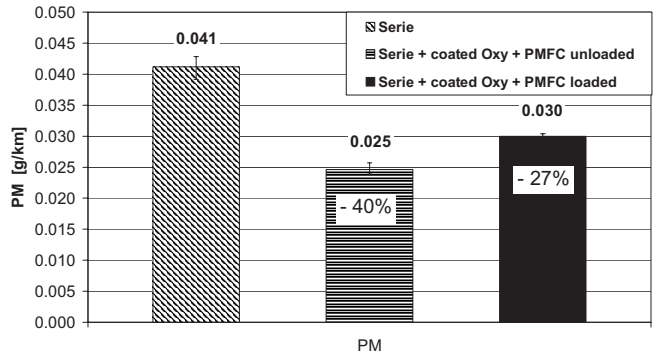

Fig. 14 – PM tailpipe emissions of the baseline system compared with a system retrofitted with a coated PMFC.

As a result the PM Trapping efficiency is improved to a level of ~40% in fresh condition and ~27% in loaded conditions.

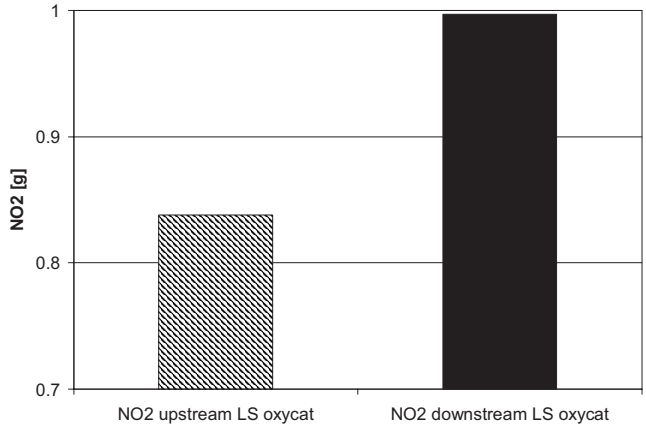

Fig. 15 – NO2 improvement by implementation of 300LS oxycat upstream the PMFC.

Close-coupled DOC-PM Filter Catalyst System

In the present work a close-coupled hybrid system, consisting of a 300LS oxicat and a PMFC have been installed replacing the production CC oxicat.

The baseline close-coupled 350cpsi DOC has a volume of 1.4L and is loaded with 70 gr/ft^{3}Pt while the DOC 300LS-PMFC system has been loaded with 100 gr/ft^{3}Pt and 30 gr/ft^{3}Pt respectively. The DOC 300LS is a 127x50.8mm and the PMFC is a 127x74.5mm substrate, therefore the total Pt loading on the new system is lower compared to the baseline system. Even with that reduction of PGM loading the conversion efficiency of the system is unchanged. Considering that the baseline DOC has a cell density of 350 cpsi and the PMFC of 200cpsi, it can be concluded that a coated

PMFC acts as a highly efficient DOC (Fig. 16) by keeping quite a PM filtering performance (Fig. 17).

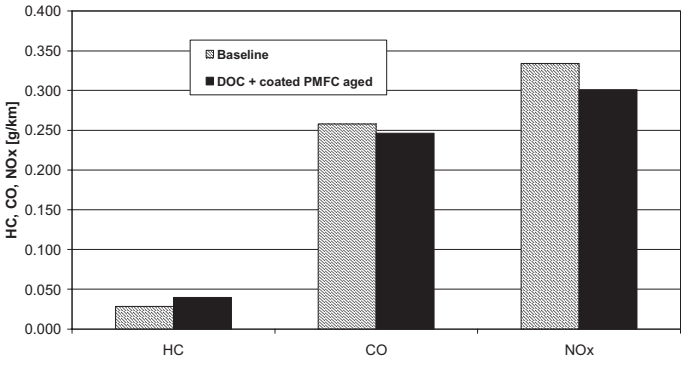

Fig. 16 – Conversion efficiency of the LS-DOC/PMFC System compared to the baseline system.

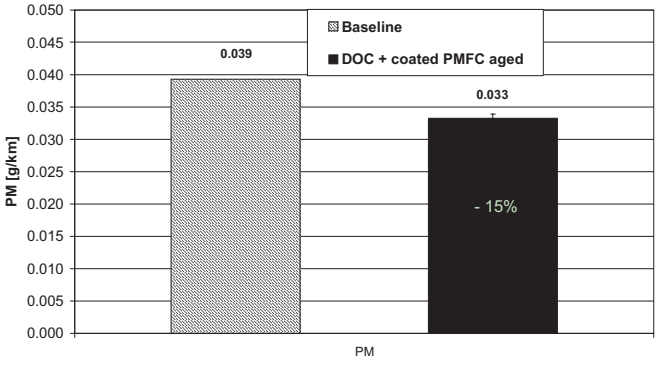

Fig. 17 – PM Trapping efficiency of the coated LS-DOC/PMFC System compared to the baseline system.

The relatively low PM trapping efficiency of the Close-coupled PMFC compared to the UFC PMFC system can be easily explained considering that the CC PMFC has 15% less volume and a different diameter/length ratio compared to the UFC PMFC. It has been observed that smaller diameters tend to lead to higher trapping efficiencies. Furthermore the washcoat might negatively affect the filtering porosity of the device itself.
Moreover a close-coupled DOC-PMFC system consisting of a 300 LS DOC and an uncoated PMFC has been investigated. An overall PM filtering performance of ~ 25% can be achieved (Fig. 18) with this system, proving that the coating process of the PMFC needs some optimization steps.

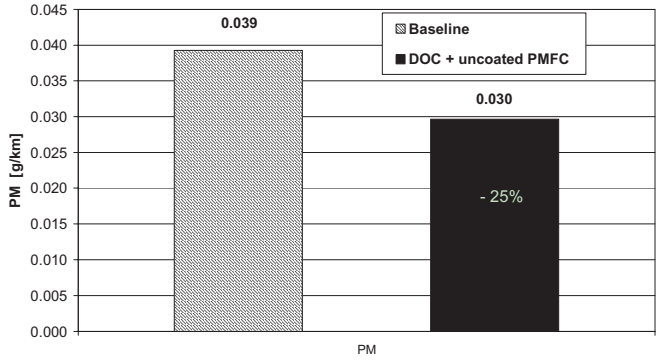

Fig. 18 – PM Trapping efficiency of the uncoated LS-DOC/PMFC System compared to the baseline system.

The interesting results is given by the remarkably high CO conversion efficiency of the DOC LS itself. As a matter of fact, the DOC has 54% lower volume than the conventional 350cpsi baseline DOC and 34% lower Pt content. Even so the CO conversion efficiency in fresh condition is significantly lower than the conditioned baseline system (Fig. 19). This result can be explained by the flow properties in a conventional converter compared to a LS substrate. While in the former laminar flow leads to strictly diffusion governed mass transfer mechanism, in the latter a “turbulent-like” flow enhances mass transfer to the catalytic wall (Fig. 13).

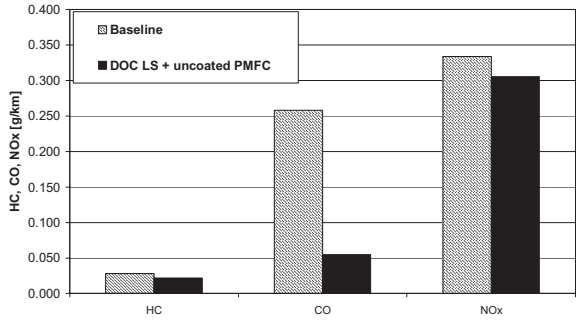

Fig. 19 – Conversion efficiency of the fresh LS-DOC compared to the baseline system.

CONCLUSION

A production 1.3 L 4 Cylinder engine equipped with Euro 3 Stage application has been investigated on a roller bench.

In particular the baseline exhaust aftertreatment system consisting of a close-coupled oxidation catalyst has been integrated with an underfloor PM Filter catalyst with the main purpose to prove the feasibility of a retrofit solution towards PM reduction incentives in Europe.

The PMFC has been tested both in uncoated and coated version, after being preconditioned. Afterwards each system has been tested in fresh conditions to define the baseline values.

Being the on-road compliance of utmost importance for a PM reducing device, a soot loading procedure, consisting of 12 hrs of ECE modules (low load and low exhaust gas temperature) has been performed.

Afterwards the preconditioning has been repeated and subsequently the systems have been tested on the EC Driving Cycle to determine long term PM trapping efficiency at loaded conditions.

The results show that the introduction of the uncoated PMFC does not negatively affect the HC/CO and Nox emissions, while the PM tailpipe emissions have been reduced by ~ 31% in fresh condition and ~ 17% in loaded conditions. These relatively low values lead to the conclusion that further optimization of the retrofit system is needed.

A first step of modification consisted in coating the PMFC, therefore improving CO emissions by ~20%. On the other side PM Tailpipe emissions are reduced similarly to the uncoated PMFC version. Being the PM trapping efficiency strongly dependant on NO_2 available at the PMFC inlet, an additional optimization step has been developed consisting of an UFC Oxicat with LS technology upstream the uncoated PMFC.

CO Emissions are significantly improved by 47% while PM Emissions are reduced by 40% in fresh and 27% in loaded conditions. These results show that the PMFC represents a low impact solution, which can be easily installed on an existing exhaust aftertreatment system. In particular, considering the Euro3 Stage engine calibration, it can be stated that the PMFC represent an optimal system to achieve Euro4 emission limits, provided that minor calibration tuning is performed on the engine.

This is considered to be a significant result as tax incentives policies are increasingly popular in the EC countries for EU4 compliant Diesel powered vehicles. In this case, an aftertreatment system, which is not causing major vehicle cost increases, might represent the optimal solution.

Furthermore, being the system cost challenges more demanding in the future, packaging considerations have been made. In particular, a close-coupled system consisting of a LS DOC and a PMFC have been investigated, in order to eliminate any UFC canning.

Even though the PM trapping efficiency has not been improved due to different flow properties in the PMFC itself (bigger diameter compared to the previous UFC system) a remarkable improvement in CO conversion efficiency has been observed.

This is considered a very important result, as the trubulent-like flow induced by LS structured foils in the DOC has positively influenced overall efficiency, hence allowing for catalyst volume reduction of 54% and a Pt loading reduction of 34% compared to the baseline system.

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