

Turbulent Flow Metal Substrates: a Way to address Cold Start CO Emissions and to optimize Catalyst Loading

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ABSTRACT

Modern Diesel Engines equipped with Common-Rail Direct Injection and EGR are characterized by an increasingly high combustion efficiency. Consequently the exhaust gas temperature, especially during a cold start, is significantly reduced compared to typical values measured in previous engine generations. This leads to a potential problem with CO emission limit compliance. The present paper deals with an experimental investigation of turbulent-flow metal substrates, carried out on a vehicle roller bench using a production 1.3 Liter diesel engine equipped passenger car. The tested metal supported catalysts proved to yield extremely high conversion rates both during cold start and in warm operation phase. The improved mass transfer efficiency of the advanced metal substrates is related on one hand to the optimized coating technology and, on the other hand, to the enhanced flow performance in the single converter channels which is caused by structured metal foils. Additionally different cost saving scenarios have been analyzed by means of both catalyst volume reduction and decreased PGM loading.

INTRODUCTION

The Diesel engine exhaust aftertreatment development has been focused in the past and present years on easily control HC and CO by means of close coupled DOCs and on the development of DPF, using fuel additive [1] or catalyzed soot filters [2].

Due to the evolution of legislation limits on one hand and the new combustion processes on the other hand, in the near future there will be a need to control NO_x engine emissions. This will lead to increased HC and CO raw emission. As a consequence highly improved DOCs will be required in the near future [3].

This Paper presents the results of an investigation carried out on a typical modern diesel engine, the 1.3l M-Jet Fiat, comparing the production EU3 system with

two optimized EU4 systems using innovative metal substrate structure and dedicated washcoat technology.

Besides the more and more important thermal management of the DOC during cold start [4], [5] the mass transfer coefficient of the substrate will play a primary role for the total conversion efficiency [6].

The advantages of the innovative structured foils LS and PE have been already described in many publications (i.e. [6], [7], [8], [9]). A 300-600LS/PE structure will be used in this work as an alternative to the ceramic baseline.

Due to the special structure of the 300-600LS/PE substrate dedicated catalyst formulations specially adapted for this substrate type were used. The adaptation of well-known EU4-DOC technologies was done in preliminary tests.

Furthermore an investigation on the PM Filter-Cat has been carried out as a retrofit device for both EU3 vehicles and specific EU4 applications [6].

LS AND PE STRUCTURED FOILS

LS-DESIGN

The LS structure is characterized by a secondary corrugation (LS-Blade) obtained during the fabrication process with the aim to locally enhance the mass transfer coefficient and therefore the total catalytic efficiency of the system.

The advantages of LS substrates, along with the higher mass transfer coefficient, are:

1. Lower thermal mass
2. Low frontal cpsi that prevents potential PM plugging problem
3. Better use of the PGM

These advantages along with general properties of Metalit allow the use of extreme Diameter/Length ratio that is very useful in close coupled position where typically the available packaging space is an issue.

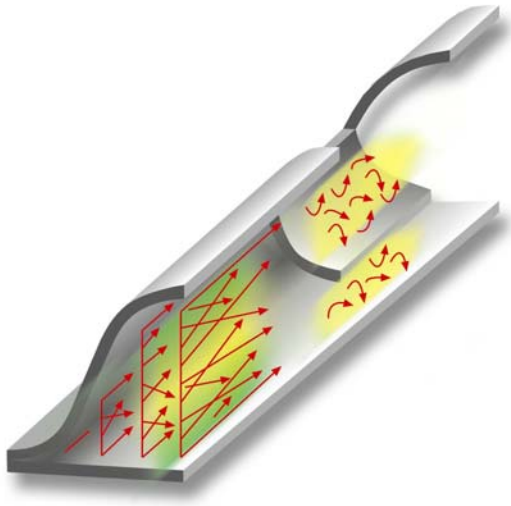


Fig. 1: LS-Design

The Fig. 1 is a schematic representation of a single LS channel. The functional principle, which has been the target of the development of LS is apparent in this picture: bringing the active surface to the pollutant instead of bringing the pollutant to the wall.

Moreover, the creation of turbulent like flow increases the diffusion process that usually drives the catalytic process in a laminar flow.

PE-DESIGN

The PE structure is characterized by the presence of 8mm diameter holes on both flat and corrugated foils. During the winding process the holes create some cavities (Fig. 2) within the substrate, which act as a mixing chamber causing a turbulent like flow distribution.

The presence of cavities allows radial flow that has a very positive influence on flow distribution and backpressure [9].

The principal advantages of PE substrate can be summarized as follow:

1. Backpressure reduction
2. Homogeneous distribution of flow and pollutant concentrations
3. Reduction of heat capacity



Fig. 2: The structure of PE substrate with the formation of cavities

To better understand the influence of structured foils on catalytic efficiency, in the following chapter a brief explanation about mass transfer coefficient is given.

MASS TRANSFER COEFFICIENT FOR LS AND PE DESIGN

It is well known that the mass transfer coefficient value rapidly decreases along the channel, after the inlet zone where the flow is not yet fully developed [10].

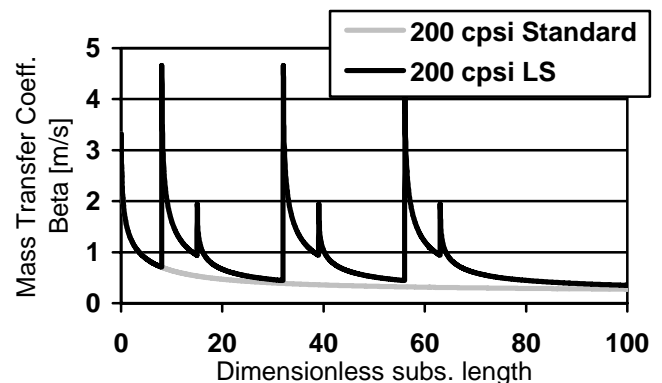


Fig. 3: Mass transfer coefficient value along the channel for Standard and LS substrate.

It is possible to observe in Fig. 3 how the mass transfer coefficient of a standard 200cpsi substrate (grey line) rapidly decreases after the inlet zone and then remains constant [11].

It is also possible to observe how the mass transfer coefficient of a 200cpsi LS substrate presents some locally increased values due to the presence of the LS-Blade.

A similar graphic including values for PE substrate is showed in Fig. 4 where it is possible to observe how the PE structure presents some locally higher mass transfer coefficient values as well. On the other hand, the presence of the cavities creates zones with very low mass transfer coefficient.

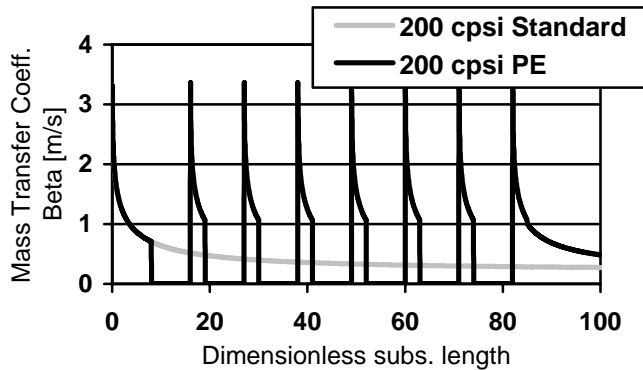


Fig. 4: Mass transfer coefficient value along the channel for Standard LS substrate and PE substrate.

Several results ([8], [9]) show that the use of a PE substrate usually leads to an improvement of total catalytic efficiency due to the better mixing of exhaust gas within the substrate and the higher exploitation of the entire catalytic volume.

PRINCIPLE OF PM METALIT

The PM Metalit is a metal supported substrate, consisting of flat and corrugated foils stacked and wound in the same way as standard metallic substrate, even though there are some major differences. The corrugated foils are structured with shovels to deviate the flow towards the flat layers. These consist of a porous metal fleece, which actually traps the Particulate Matter present in the exhaust gas [Fig. 5].

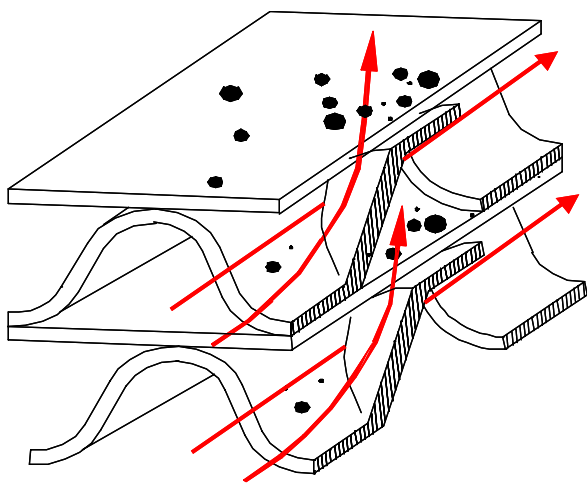


Fig. 5. Flow deviation and temporarily PM trapping through metal fleece.

The temporarily trapped particles are subsequently oxidized by means of NO_2 . Detailed description of operating principles of the PM Metalit have been already presented [12, 13, 14].

Due to its design, the PM Metalit is a partial flow filter. Therefore there could not be any excessive ash or soot accumulation, which otherwise might lead to channel clogging. This feature makes the PM Metalit suitable for relatively cold applications, which would have major regeneration problems in case of traditional wall flow Particulate Traps.

DESCRIPTION OF TEST MATRIX

The baseline is the production system, a 350cpsi / 5.5mils ceramic substrate with 70g/ft³ Pt only coating. The substrate has a diameter of 118.3mm and a length of 127mm with a total volume of 1.397l.

The proposed metallic substrate is a Ø127x55.3mm with 300-600LS/PE foils structure and a total volume of 0.7l.

Two different Washcoat technologies have been used, both supplied by Umicore.

- The first is a 100g/ft³ giving a total PGM content of 2.474g that is 29% lower than the production value (3.455g).
- The second is a 200g/ft³ giving a higher value of PGM content with respect to the production system, combined with PM Metalit underbody.

The goal of the first metallic proposal is to test whether is possible to reduce the PGM content using innovative washcoat technology and turbulent-like metallic substrates.

On the other hand, the second is a proposal for a system suitable for applications where only 30% - 40% PM reduction is needed.

| | Dimension | Volume |
|-----------|-----------------------------|--------|
| BASELINE | Ø118.3x127/350/5.5mils | 1.397l |
| LS/PE-100 | Ø127x55.3/300-600LS/PE/40µm | 0.7l |
| LS/PE-200 | Ø127x55.3/300-600LS/PE/40µm | 0.7l |

Table 1: Test matrix of DOCs

DESCRIPTION OF TEST SET UP

For the tests on the vehicle a 48" compact roller dynamometer has been used with a maximum braking power of 153 kW (sustained) or 258 kW (peak). The test rig allows testing speeds of up to 250 km/h. Aerodynamic drag has been simulated with a blower with the flow controlled in proportion to the speed of the vehicle. For control, monitoring, and data recording of the exhaust gas tests, the automation system PELE (PEUS) has been used in combination with an INCA PC data recorder.

The emission tests have been performed with the help of a variable Venturi CVS system (CVS 7200 S). Three modal measuring lines (MEXA 7500-D) have been used, allowing raw emissions sampling, as well as sampling of the emissions between two catalysts and tailpipe emissions. At the same time a dilution tunnel has been used to measure bag emissions and particulate emissions during a test run. HC, CH₄, NO_x, CO, CO₂, and O₂ have been sampled and analyzed. Using CVS allowed a comparison between the integrated modal result and the total result of the bag measuring line and thus a check of the results. The particulate has been sampled with a PMU 7000 from Horiba. Sulfur-free fuel (< 10 ppm) has been used.

The vehicle emissions of all tested systems have been evaluated over the standardized new European driving cycle (NEDC). The systems shown in Table 1 have been measured after aging. The aging procedure adopted in the present work is used by several OEM's: the catalysts are aged hydrothermally in a continuous furnace with a gas flow of 0.3 Nm³/h and a relative humidity of 10 Vol.-% in air. In this case aging was carried out for a total of 70h at a temperature of 550 °C.

A Fiat Doblo' 1.3l M-Jet vehicle has been used for the emission measurement tests. The engine has a power of 70Hp and the car has a gross weight of 1310Kg.

DESCRIPTION OF RESULTS WITH AGED LS/PE-100

This system is proposed as a solution for future low temperature engines, with special focus on cold start problems and, at the same time, as a possible cost reduction strategy for this particular application.

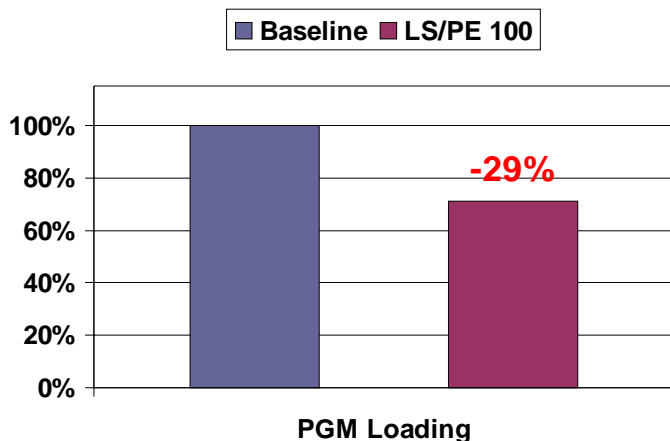


Fig. 6. PGM Loading reduction for the LS/PE 100.

Fig. 6 shows the lower PGM content of the LS/PE 100 catalyst in comparison with the baseline system: 29% lower PGM contents.

The increase of HC can be seen as not critical, considering the very low tailpipe level of both HC and

NO_x. On the other hand, it should be stressed the result concerning CO: 35% lower tailpipe emission. (Fig. 7)

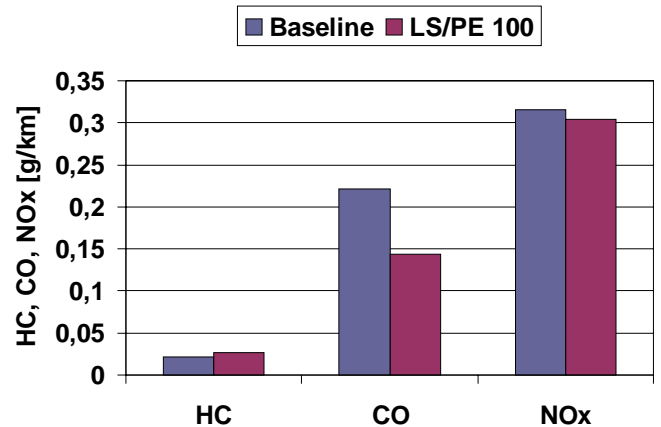


Fig. 7. Tailpipe emission comparison between baseline and LS/PE 100.

The lower thermal mass of the LS/PE 100 plays a very important role during cold start, allowing the substrate to reach the light off very quickly (Fig. 8). Another important aspect is the high thermal exchange ratio between exhaust gas and substrate, due to the particular structure of the foils.

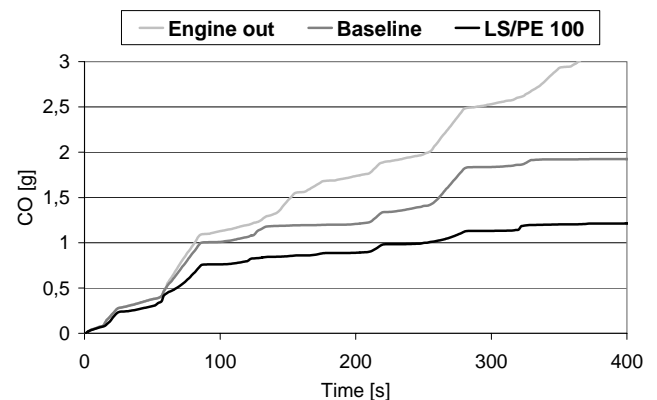


Fig. 8. Modal CO measurement in the first 400 seconds for baseline and LS/PE 100.

The bigger diameter and the shorter length of the metallic substrate have also a positive impact on substrate backpressure. The calculated backpressure (@ 300kg/h, 20°C and 1 bar) is 5mbar for the Baseline substrate and 3mbar for the LS/PE 100. On the other hand, the backpressure difference has no influence on engine out emission, as can be seen from the NO_x value.

DESCRIPTION OF RESULTS WITH AGED LS/PE 200 + PM-METALIT

This system is a proposal for applications that need only a 30% - 40% PM reduction to reach the EU4 limits and, on the other hand, are particularly sensitive to cold start.

Fig. 9 shows the HC, CO and NOx tailpipe emission. It is apparent how this system presents an improvement in both HC and CO. The improvement in CO tailpipe concentration is remarkable: 71% lower CO tailpipe.

It should be also noticed how the LS/PE 200 reaches the light off temperature earlier and, even with a much lower volume, maintains the advantages along the entire cycle. [Fig. 10]

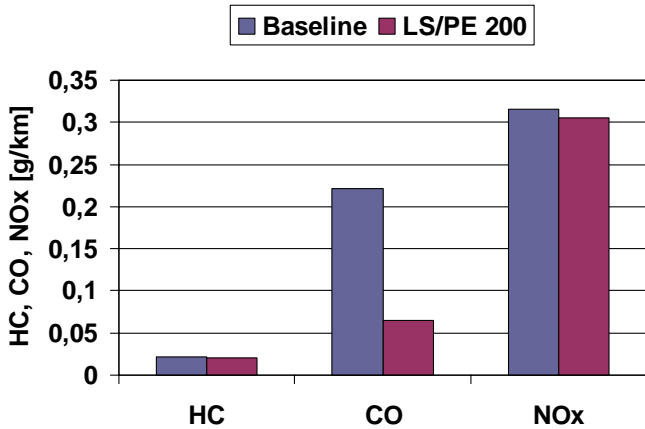


Fig. 9. Tailpipe emission comparison between baseline and LS/PE 200.

The high CO efficiency results obviously from the high specific PGM load, the washcoat technology and the high efficient foil structure.

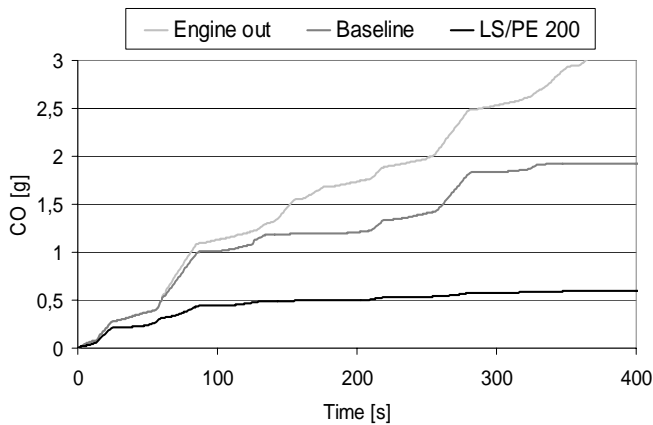


Fig. 10. Modal CO measurement in the first 400 seconds for baseline and LS/PE 200.

The system LS/PE 200 combines the Ø127x55.3mm with 300-600LS/PE foils structure as DOC with an underbody Ø98.4x150mm uncoated PM-Metalit. Fig. 11 shows the relative efficiency of this system: 32% lower PM tailpipe.

The results is positive considering the very cold temperature profile during NEDC in front of the PM-Metalit (Fig. 12) that doesn't reach 250°C until almost 1000 seconds of the cycle.

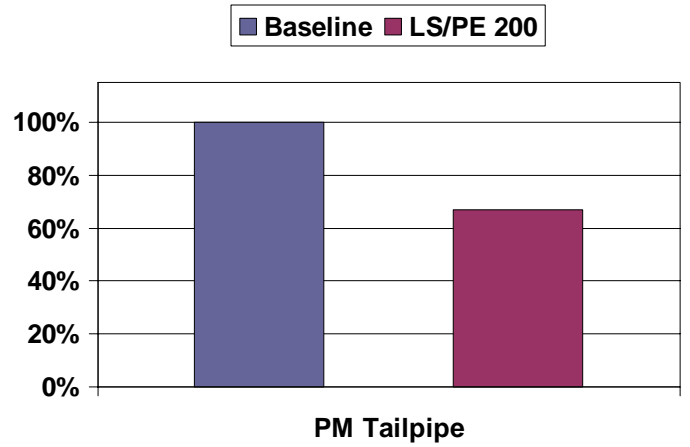


Fig. 11. PM tailpipe emission comparison between baseline and LS/PE 200 + PM-Metalit

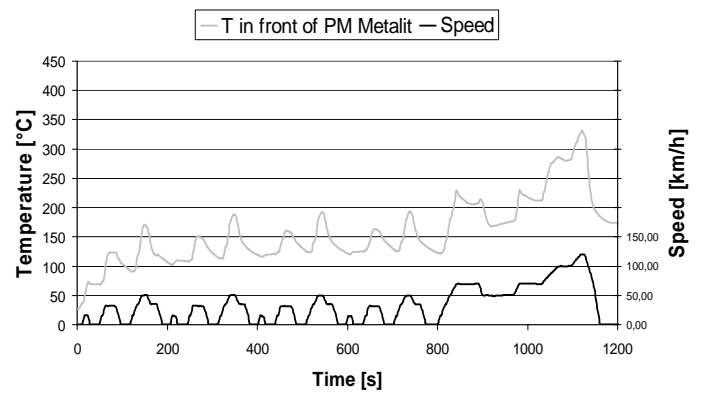


Fig. 12. Temperature in front of PM Metalit.

On the other hand even the NO₂ level should be controlled in order to better understand the result. Fig. 13 shows how the NO₂ downstream the PM-Metalit is approximately 25% lower compared to the inlet value. This indicates how NO₂ is consumed within the PM-Metalit to oxidize the trapped soot [15].

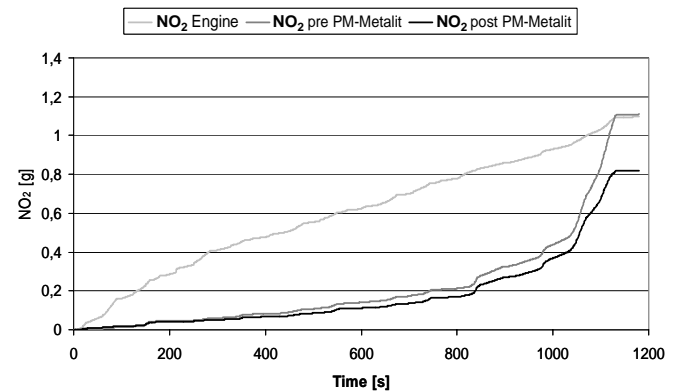


Fig. 13. NO₂ concentration out of engine, in front and behind PM-Metalit.

This system can be optimised, trying for example to shorten the distance between DOC and PM-Metalit to

have a higher PM-Metalit inlet temperature, but even this configuration is a cost effective solution for an original equipment system, which needs only 30% - 40% PM reduction or for retrofit.

CONCLUSION

Two different systems under aged condition have been tested in this work.

The first consisting in the replacement of the 1.4l ceramic close coupled DOC with a 0.7l metal supported substrate in the same position, proving that it is possible to combine the increase of the catalytical performance with a decrease of PGM loading. To this aim a new washcoat technology adapted to the LS/PE foils has been used. As a matter of fact tailpipe CO has been reduced by 35%. This system represents a cost saving potential.

The second system was tested to further investigate the efficiency of the LS/PE technology using a higher PGM loading with the same substrate. Furthermore an uncoated PM-Metalit was included. Results show that the CO tailpipe level can be decreased of about 71% and a PM reduction of about 32% could be demonstrated. This system can be considered suitable for future EU V application even in combination with close coupled DPF.

The use of an uncoated PM-Metalit shows potential for cost reduction for application that need only 30% - 40% PM efficiency or for retrofit.

REFERENCES

1. O. Salvat, P. Marez and G. Belot, : "Passenger Car Serial Application of a Particulate Filter System on a Common Rail Direct Injection Diesel Engine", SAE Paper 2000-01-0473.
2. A. Sanguedolce, Fiat-GM Powertrain, M. Ranalli, ArvinMeritor, N. Yamamura, Ibidem, A. Punke, Engelhard, "Fiat-GM Powertrain development of exhaust system with catalysed particulate filter for diesel passenger car applications", Paper 04A5023, ATA Symposium, Bari (Italy) 2004.
3. R. Imarisio, B. Peters, G.M. Rossi Sebastiano, J. Pinson, G. Boretto, R. Buratti, Fiat GM Powertrain, "Diesel Strategies towards Fuel Neutral European Emission Standards", Paper 04A5010, ATA Symposium, Bari (Italy) 2004.
4. P. Spurk, F.-W. Schütze, E. Lox, Umicore, R. Brück, A. Schatz, Emitec, Potential strukturierter Metallträger und fortschrittlicher Beschichtungen, getestet an einem EU4 2,2 l Dieselfahrzeug, 2. Emission Control 2004, Dresden.
5. Katrin Schaper, Roman Konieczny, Rolf Brück, Emitec G.m.b.H., Deutschland; „Diesel catalytic converter with hybrid substrate structure“ Haus der Technik e. V., Essen, 15. und 16. Juni 1999
6. Lorenzo Pace, Roman Konieczny, Manuel Presti, Emitec, "Metal Supported Particulate Matter-Cat, a Low Impact and Cost Effective Solution for the FIAT 1.3 JTD Euro IV Engine", SAE Paper 2005-01-0471
7. M. Bollig, J. Liebl, R. Zimmer, BMW Group, M. Kraum, O. Seel, S. Siemund, Engelhard Technologies GmbH, R. Brück, J. Diringer, W. Maus, Emitec, „Next generation catalysts are turbulent: development of support and coating“, SAE Paper 2004-01-1488.
8. M. Ganz, S. Hackmayer, quattro GmbH, C. Kruse, A. Reck, Emitec GmbH, „Innovatives Katalysatorsystem für den Audi RS6, 8 Zyl, 4,2ltr, 331 KW mit LEV Zertifizierung“, Wiener Motoren Symposium, 29-30.April 2004
9. Corrado Iotti, Vincenzo Rossi, Luca Poggio, Ferrari S.p.A., Mathias Holzinger, ArvinMeritor, Lorenzo Pace, Manuel Presti, EMITEC GmbH, "Backpressure Optimized Close Coupled PE Catalyst - First Application on a Maserati Powertrain", SAE Paper 2005-01-1105
10. Y.Miyairi, T.Aoki, S.Hirose, Y.Yamamoto, M.Makino, S.Miwa and F.Abe NGK Insulators,Ltd., Effect of Cell Shape on Transfer of Mass and Pressure Loss, SAE Paper 2003-01-0659.
11. Dipl. Ing. Wolfgang Maus, Dipl. Ing. Rolf Brück, „Die Zukunft der heterogenen Katalyse im Automobil; „Turbulente“ Katalysatoren für Otto- und Dieselanwendungen“, Wiener Motorensymposium 2005
12. Rolf Brück, Peter Hirth, Meike Reizig, Peter Treiber, Jürgen Breuer, Emitec GmbH; „Metal Supported Flow-Through Particulate Trap; a Non-Blocking Solution“; SAE Paper 2001-01-1950
13. Dr. E. Jacob, Dr. N. D’Alfonso, A. Döring, S. Reisch, D. Rothe, MAN Nutzfahrzeuge AG; R. Brück, Dr. P. Treiber, Emitec GmbH „PM-Kat: Nichtblockierende Lösung zur Minderung von Dieselruß für Euro IV-Nutzfahrzeugmotoren“; 23. Internationales Wiener Motorensymposium April 2002
14. F. Diefke, M. Lundgren, P. Nilsson, Volvo Car Corporation; R. Brück, C. Kruse, S. Schaper, Emitec GmbH; „Neue Dieselmotorsysteme zur Erreichung der europäischen Grenzwerte 2005 – Getestet an einem Volvo S60 Personenkraftwagen“; 24. Internationales Wiener Motorensymposium
15. Dr. E. Jacob, MAN Nutzfahrzeuge AG; Emissionslimits zukünftiger Nfz-Motoren:Balanceakt zwischen Möglichkeit und Nutzen; 26. Internationales Wiener Motorensymposium.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

EGR: Exhaust Gas Recirculation

DOC: Diesel Oxydation Catalyst

DPF: Diesel Particulate Filter

LS: Longitudinal Structure

PE: Perforated foils

PM Metalit: Particulate Matter metallic wall through filter

cpsi: cells per squared inch

mils: 1/1000 inch → 25.4µm