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Innovative Metal Supported Catalysts for EU V Diesel Engines

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Innovative metal supported catalysts for EU V Diesel Engines

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ABSTRACT

Future stringent emission levels for NOx and PM will lead to the introduction of innovative combustion processes for diesel engines, such as premixed combustion, with the results to enhance the engine out emission of HC and CO. Therefore very efficient oxidation catalyst will be needed to face this possible issue. This paper deals with the optimization of a EU IV exhaust system by means of innovative metal supported catalyst, as for example the Pre Turbo Catalyst and the Hybrid Catalyst in combination with dedicated catalyst coatings. Moreover a base study over the use of PM-Filter Catalyst has been made, to show the efficiency of such a device with EU IV engine calibration. The second part of the paper deals with the turbulent like structured foils substrates to have an even more efficient diesel oxidation catalyst with very high volumetric efficiency.

INTRODUCTION

The constant improvement on diesel engine technology, such as the introduction of high pressure fuel injection, multiple fuel injection and cooled EGR for example, has made cars equipped with diesel engines attractive not only for the well known consumption advantage, but also for the so called “fun to drive”.

Besides the research of better performance, a major part of the future development of diesel engine technology will be related to both engine raw emissions and exhaust gas aftertreatment.

A possible way to comply with future emission limits is related to the development of the pre-mixed combustion. This new combustion process has a positive effect on NOx and PM engine emission but, on the other hand has a negative impact on HC and CO engine emissions [1, 2]. Therefore it is necessary to develop very efficient DOCs.

This paper deals with the optimization of the production exhaust system of the Honda 2.2. I-CDTi. This engine has a power output of 103 kW @ 4400 rpm and has an intercooled turbocharger, cooled EGR and common rail injection. The optimization of the metal supported catalyst (substrate and catalytic coating) shows some potential cost savings or, on the other hand, the possibility to reach lower tailpipe emission, if needed. The second part illustrates how turbulent like substrates allow to reach even higher volumetric efficiency. In particular a test carried out on the Fiat 1.3l M-Jet engine shows a very high potential for the structured foils support.

TEST SET UP

The Honda 2.2 I-CDTi was selected because it is equipped with a metallic support. The serial catalyst system consists of a total of three converters. Close to the turbocharger a catalyst with a capacity of 0.7-l (Ø 98.4 x 95) and a precious metal loading of 90 g/ft³ is used. Two catalysts are installed downstream (Ø110x100mm, 1.0 l and Ø110x130mm, 1.2 l) with a precious metal loading of 90 g/ft³ and 54 g/ft³. Honda already demonstrated the potential for optimization through innovative metal substrates in 2003 [3]. Based on these results, a test program was created that contained both specific substrate designs and different coatings. In addition to the optimization of costs, the emissions potential was also examined with respect to future legislation limits [11].

The Fiat Doblo’ has a 1.3l M-Jet engine with EU III calibration and a power of 51kW. The mass production system uses a ~1.4l ceramic support in close coupled position. The test carried out on this engine has the goal to demonstrate how a lower volume metallic substrate with the Structured Foils can achieve higher efficiency.

EXPERIMENTAL MEASUREMENTS ON THE HONDA I-CDTI

MASS PRODUCTION SYSTEM - The first measurement that was carried out, was the temperature in front of the close coupled catalyst and in front of the underfloor catalyst during the NEDC Cycle (Fig. 1).

It can be easily noticed the low temperature level in front of the underfloor catalyst and the very fast temperature transient in front of the close coupled catalyst. The temperature of the close coupled catalyst is constantly above 120°C after 150 sec. of the cycle. This means that the thermal management and the light off behavior of the close coupled catalyst plays a key role determining the efficiency of the entire system in the first seconds.

The second measure to characterize the performance of the serial production system was carried out by sampling the engine out emissions, the emissions after the close coupled catalyst and the tailpipe emissions in fresh condition.

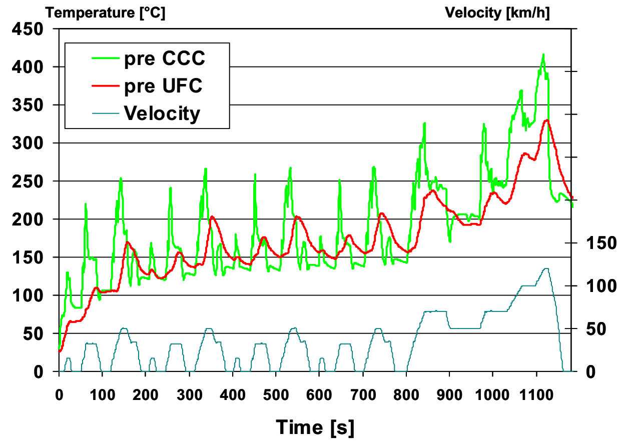

Fig. 1: Temperature measurement during the NEDC

It can be observed (Fig. 2) how the engine out emissions are very low for NOx while HC and CO need a very efficient aftertreatment.

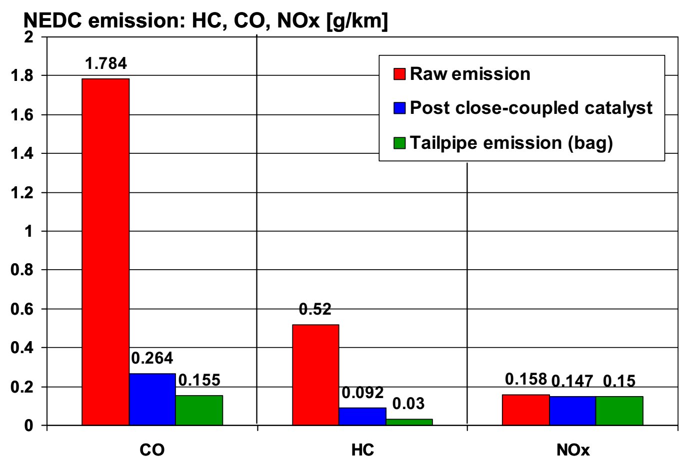

Fig. 2: HC, CO, NOx emission on NEDC.

It can be also noticed how the close coupled catalyst is very efficient: the conversion rate is about 85% and 82% for CO and HC respectively. The PM tailpipe emission is very low: 0.015 g/km.

DESCRIPTION OF INNOVATIVE TECHNOLOGY – In order to improve the light off performances of the system, two different strategies have been applied.

Hybrid Catalyst – The ideal behavior of a DOC in the light off phase is to reach very fast the light off temperature and then to maintain that temperature during the deceleration or idle phases.

That means that the support should have a low thermal mass to easily reach light off and a high thermal mass to store the thermal energy and stay over light off during the low temperature phases. This apparent contradiction can be solved using the Hybrid catalyst: it is composed by two matrixes installed in one mantel [4]. The first matrix is usually very short and consists of thin foils (30µm usually), while the second matrix is longer and is made out of thicker foils (80µm usually) (Fig. 3).

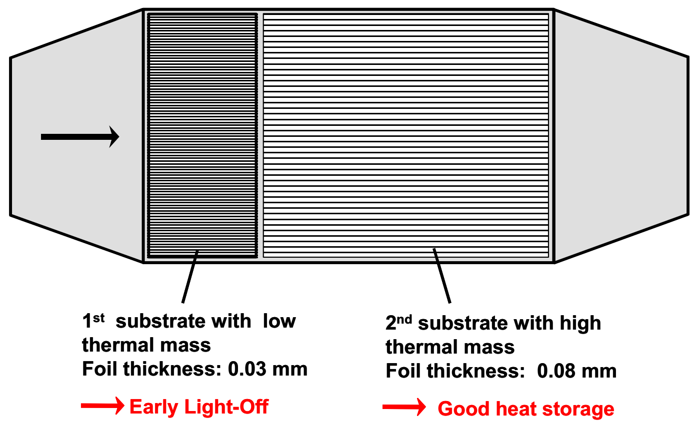

Fig. 3: Operating principle of the hybrid catalyst

Pre Turbo Catalyst – The better catalyst position to exploit the exhaust gas temperature is very close to the outlet ports and upstream the turbocharger. The space constraint in that position limits the available catalyst volume. One possible solution is to put a little catalyst (volume lower than 0.05l) between the manifold outlet and turbo casing inlet. Another approach is to use a fabricated manifold and put a bigger substrate (volume ~0.1l) between the exhaust manifold and the turbocharger. In this paper the first approach is investigated (Fig. 4).

Fig. 4: The Pre Turbo Catalyst

The volume constraint is overcompensated by the very high specific efficiency of such a little support, due to the turbulent flow and high temperature level [5].

PM Filter Catalyst – The above described DOCs can help to improve the specific efficiency with respect to CO and HC but they have no impact on the solid PM.

The so-called PM filter catalyst is a flow-through system in which a part of the gas stream is diverted by deflection shovels and therefore the particulate is forced to flow-through metal-fiber fleece and to be filtered [6, 7]. The particulate deposited in the fleece can be oxidized in a pseudo-continuous process with the help of NO_2 and O_2 [8].

HYBRID CATALYSTS: EMISSION RESULTS – The above described technologies have been coated with innovative technologies by UMICORE.

The serial system (SERIE1) consists of a close coupled metallic support Ø98,4x95mm; 400 cpsi, 90g/ft³ with two underfloor converters, the first Ø110x100mm; 400 cpsi, 90g/ft³, the second Ø110x130mm; 400 cpsi, 54g/ft³.

The first Hybrid CATALYST (HYBRID1) is a Ø98,4x95mm; 400 cpsi, 70g/ft³. The first and second UFC remain unchanged in this test.

The second Hybrid CATALYST (HYBRID2) is a Ø98,4x95mm; 400 cpsi, 70g/ft³ with the first UFC modified (Ø110x130, 400 cpsi, 90g/ft³) and the second one is taken off the system.

The results in fresh conditions show that the system HYBRID1 is almost equivalent to the SERIE1 system, even if the PGM-content is 7% lower. The performance of the HYBRID2 system shows only a slight reduction in efficiency even if the total PGM-content content is 25% lower (Fig. 5). For HC an expected reduction in efficiency is visible. This is especially based on the substitution of the two underfloor DOC's by only a single part.

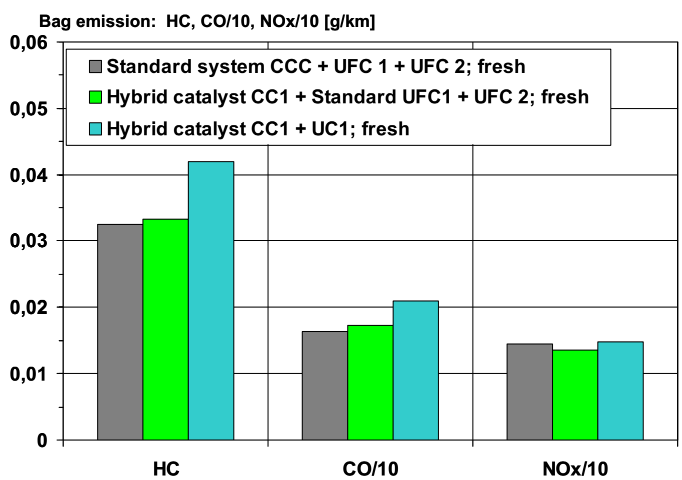

Fig. 5: Emission results with SERIE1, HBRYD1 and HYBRID2 systems, fresh condition

This good results show the importance of a well balanced thermal management for the DOC.

PRE TURBO CATALYST: EMISSION RESULTS– The system HYBRID2 has been tested once more adding a PTC Ø36x42, 200 cpsi (volume 0.042l) with a with a PGM loading of 100 g/ft³ (PTC1).

A first interesting result is focused to the light off behavior of the PTC1 system.

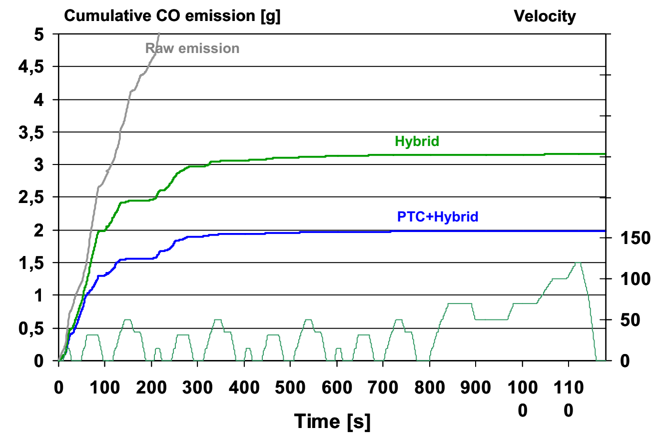

Fig. 6: Cumulated CO emission of HYBRID2 and PTC1 systems upstream UFC substrate.

The effect of the PTC is very clear: the light off is reached earlier and the accumulated advantage is almost 35% in the first part of the cycle as can be seen in the cumulated CO emission in figure 6. The CO tailpipe emission is significantly reduced (45 %) compared to the serial application (Fig. 7). On the other hand the HC efficiency is lower compared to the HIBRYD2 system probably due to the different light off behavior of the DOC (see also Fig. 5).

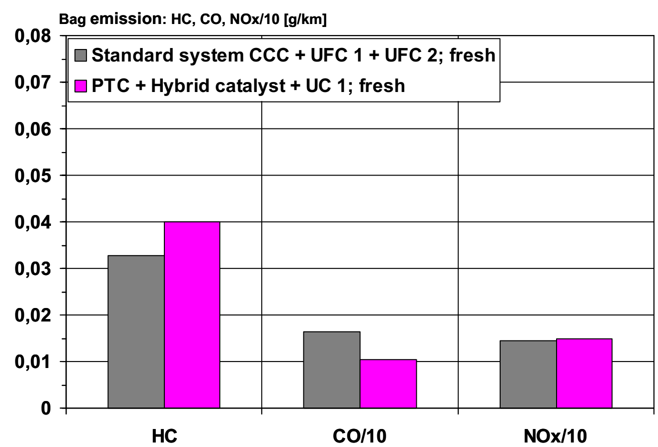

Fig. 7: Tailpipe emission of HYBRID2 and PTC1 systems, fresh condition.

The system PTC1 shows that a reduction of Pt content of about 25% leads to the same overall efficiency making possible a very interesting cost saving.

RESULTS WITH PM FILTER CATALYST – Even though the PM emission level of this engine is already very low, a test has been carried out to verify the efficiency of a coated underfloor PM Filter Catalyst. A PM Filter Catalyst (Ø110x130 90g/ft³) replaces the UFC catalyst in the system PTC1. This system, called PM1, has been tested and the results are shown in Fig. 8, compared to the production system.

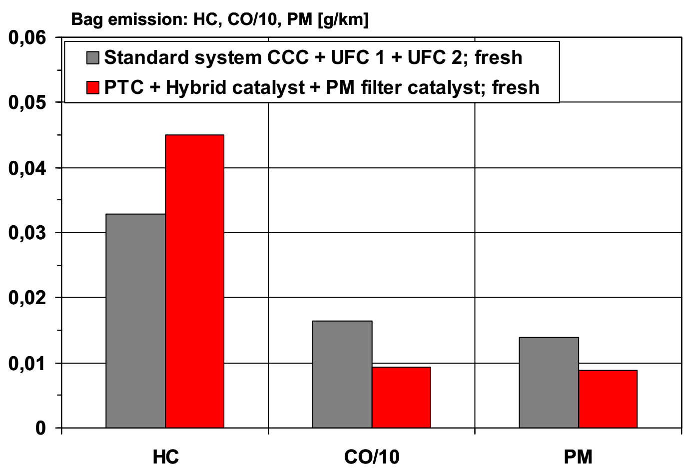

Fig. 8: Emission results for system PM1.

The reduced oxidation surface of the PM filter catalyst compared to the underfloor catalyst used in the PTC1 system leads to a slight increase of HC tailpipe emission, while the presence of the PTC still has a positive impact on CO reduction as shown in figure 7. Besides the results for the gaseous emissions the PM results are remarkable: with this system a PM emission level of 0.009g/km is achieved with an average efficiency of 38%.

RESULTS WITH AGED COMPONENTS – The systems were aged according to a procedure 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 70 h at a temperature of 550 °C.

Accordingly, the HC emissions of System HYBRID2 (hybrid catalyst CC1 with downstream catalyst UC1) increased to 0.072 g/km. However, this is still well below the EU IV threshold value for HC+NOx (0.30 g/km).

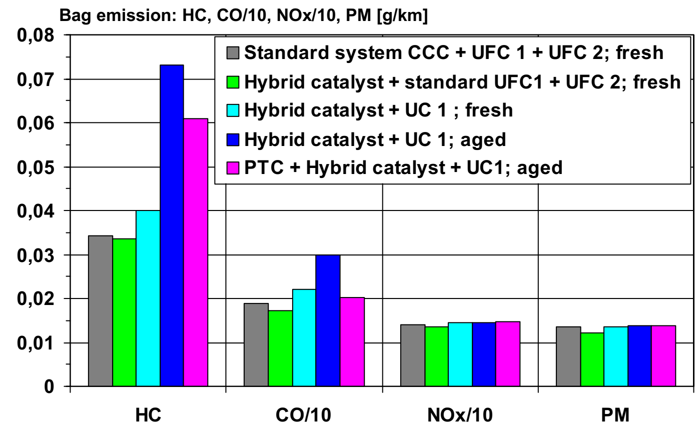

Fig. 9 HC and CO tailpipe emission.

The use of the PTC1 showed a positive effect after aging as well, for both the HC and the CO emissions. Compared to the fresh HYBRID2 system, for example, the aged PTC1 system achieves the same CO emissions.

EXPERIMENTAL MEASUREMENTS ON THE 1.3 LITER ENGINE

MASS PRODUCTION SYSTEM – The EU III Fiat Doblo' 1.3l M-Jet is a modern 4 Cylinder 16 Valves Common Rail Diesel Engine with cooled EGR and Turbocharger. In this application it has a power of 51Kw and uses a ~1.4 Liter ceramic close coupled DOC with 350cpsi and 70g/ft³ Pt only coating.

In order to point out how a metallic support can achieve similar or even lower emission levels with a lower volume, a Ø127x50.8/300-600LS/40µm support has been tested, using an innovative UMICORE coating technology with 140g/ft³ Pt only.

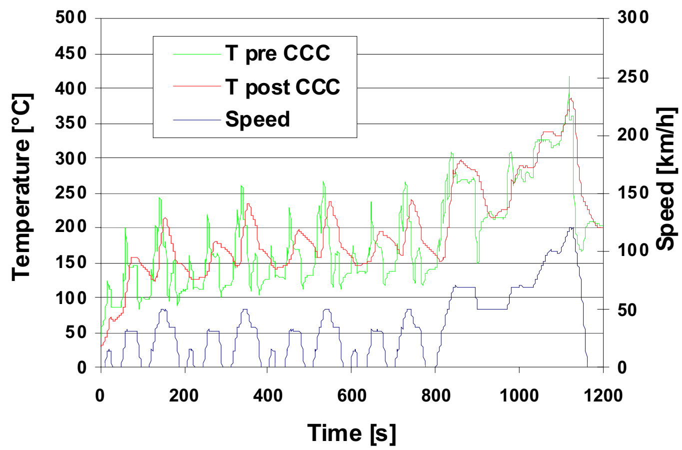

Fig. 10: Temperature pre and post DOC for the 1.3l M-Jet.

The first measurement was the temperature pre and post CCC. Even if the load factor for this type of car is greater compared to the Honda 2.2 I-CDTi, the exhaust gas temperature is very low (Fig. 10). Even for this car an optimized metallic substrate leads to lower tailpipe emissions.

THE STRUCTURED FOILS – The metallic structured foils technology has been already extensively described and implemented in mass production [9]. For this test, an LS-Design substrate has been chosen. The LS technology consists of a secondary corrugation applied on the sinoidal part of the single channel in order to create some turbulent like areas.

Behind the inlet zone, where the flow is not completely developed, the flow condition in a standard channel is usually laminar. In this case the driving parameter for the mass transfer is diffusion of the exhaust gas from the bulk phase to the reacting wall.

In an LS channel (Fig. 11) in correspondence of the secondary corrugation, i.e. a shovel, the laminar flow is broken and a new “turbulent like” zone is created: thereby the efficiency of the catalytic support is enhanced.

It is already been demonstrated, how a metallic substrate with lower cell density but using LS technology can achieve the same conversion efficiency of a standard converter with higher cell density [10].

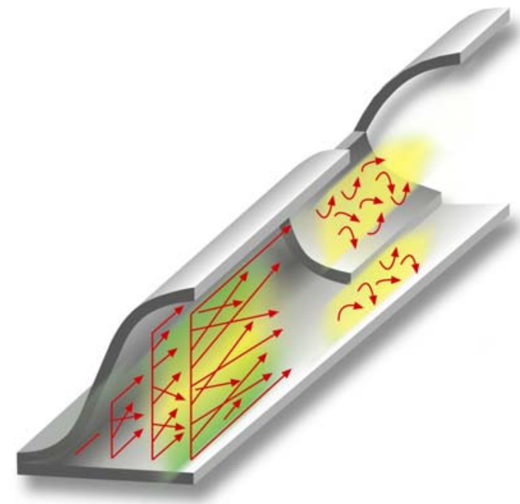

Fig. 11: LS channel

The support tested has a volume 53% lower than the serial system.

EMISSION RESULTS ON THE LS CATALYST – The dimension of the tested support (Ø127x50.8/300-600LS/40µm) fits in the production canning. The baseline is a ceramic converter, which has been conditioned during a total of ~ 4.000km of on-road usage. Every test is repeated three times to ensure a good repeatability. Before each tests the catalyst system have been preconditioned. The results are summarized in fig.12.

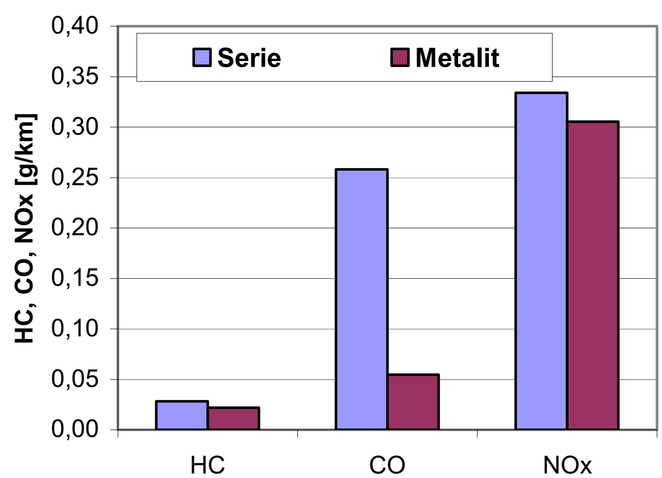

Fig. 12: Emission results with series and LS catalyst for the 1.3l M-Jet engine

The CO and HC results clearly show the remarkable advantage of the LS catalyst. NOx values are almost unchanged being as expected (oxidation catalyst). This test shows a great potential for the LS-Structured catalyst.

CONCLUSION

The described results demonstrate that through the use of optimized catalytical coatings and advanced substrate structures, additional potential exists with respect to cost savings and lower emissions.

Due to the improved thermal management with the hybrid structure used, as well as an appropriately adjusted catalyst formulation, the results that were obtained were comparable to those of the serial system despite a reduction in the precious metal content (by about 30%).

Even after aging, the use of the pre-turbo catalyst showed a positive tendency towards reduction, primarily of CO emissions. No negative influence on the emission of CO2 could be determined during the NEDC test cycle with the vehicle tested here.

New advanced catalyst formulations and adjusted processes allow the catalytic activation of PM filter catalysts without decreasing filtration efficiency.

The coated PM filter catalyst used in this test series reduced the already very low particulate emissions by further 38% (see the results with the Honda vehicle).

Further potential is demonstrated from the use of substrates with improved mass transport (LS design) and more advanced coatings.

The results demonstrate that the key factors in the development of an highly effective emission control system is on one hand the thermal management of the components which are influenced by the thermal mass and position of the substrates and one the other hand by the efficiency of the catalytical coating.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

DOC: Diesel Oxydation Catalyst

PTC: Pre Turbo Catalyst

UFC: Under Floor Catalyst

CCC: Close Coupled catalyst

LS: Longitudinal Structure

NEDC: New European Driving Cycle

PM: Particulate Matter