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Pre-Turbocharger Catalyst – Fast catalyst light-off evaluation

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ABSTRACT

Further tightened emission legislation and new engine technologies increase the requirements for the exhaust after-treatment system of modern diesel passenger cars. Especially the increasing raw emissions of HC and CO as well as the low temperature of the exhaust gas for a long period during cold start of the New European Driving Cycle (NEDC) require additional efforts in the design of the oxidation catalyst system [1].
A highly efficient micro catalyst, which is mounted in front of a turbocharger, can help to treat efficiently these high HC and CO emissions. Due to the higher temperature level in front of the turbine and the significantly increased mass and heat transfer by turbulent flow, efficiency especially during cold start is highly increased. However the packaging constraints are more critical in this area due to heat considerations and also to maintain engine performance. The Pre-Turbocharger Catalyst (PTC) is able to balance the total functionality and has a high potential to make the Diesel Oxidation Catalyst (DOC)more efficient.

INTRODUCTION

The turbocharged, direct injection diesel engine still offers one of the most promising approaches to the reduction of CO_2 emissions and the economic use of remaining resources. However, it is coming under increasing pressure because of its high HC and CO emission levels.
This affects the design of the oxidation catalytic converter. The demands for effectiveness and performance are growing because modern diesel engines are becoming increasingly efficient and produce ever-lower exhaust gas temperatures.
An obvious solution to this problem is placing catalytic converter volumes in front of the exhaust gas turbine to take advantage of the higher temperature levels there for the fast light-off of the catalytic converter [2]. This can ease the cold start problem considerably allowing the main catalytic converter fitted downstream behind the turbine to be more efficient as shown in [3] where its size could be reduced.
It has been shown that such solution has just a very small influence on fuel consumption [2], engine power [3] and Torque [4].

PTC-FUNCTION

INFLUENCE OF TEMPERATURE IN PTC POSITION

Because of the great efficiency of the diesel engine and the high volume of excess air, particularly under part-load operation, its exhaust gas temperatures are very low during driving conditions and certainly also in the typical NEDC test cycle when compared to those of gasoline engines. This has a significant effect on the light-off behaviour of the oxidation catalytic converter. Although the light-off temperature of modern diesel coatings is considerably lower than that of three-way catalytic converters due to the high oxygen content in the exhaust gas, the exhaust gas temperature still keeps dropping below this light-off range even during advanced stages of the test cycle so that the effectiveness of the catalytic converter is limited during the first 600 seconds. Figure 1 shows the typical variations of the exhaust gas temperature behind the turbocharger of a modern diesel engine (blue trace) and the light-off temperature range (pink surface area) of current DOC. Also shown for comparison is the temperature in front of the turbocharger (red trace).

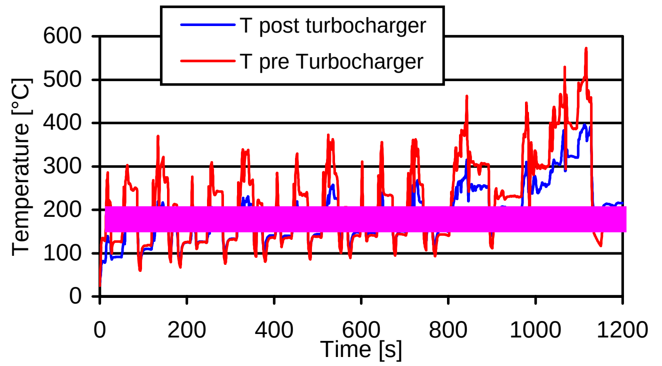

Figure 1: Temperature in front of and behind exhaust gas turbine in NEDC

Figure 2 shows the energy flow in the exhaust gas stream from the cylinder outlet to the outlet of the exhaust system. This clearly illustrates that up to 30 % of the available exhaust gas energy has already been converted in the turbocharger before it reaches the catalytic converter. On the basis of these considerations it makes good sense to install catalytic converter volumes in front of the exhaust gas turbine.

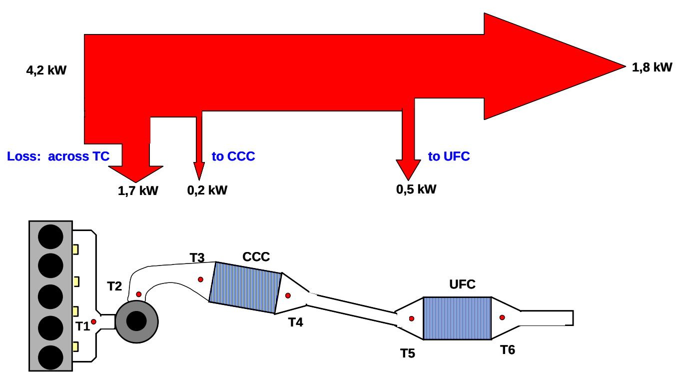

Figure 2: Energy flow through an exhaust system

There are a number of different installation options [2], which among other factors also depend on the configuration of the exhaust system:

1) Installation directly in the exhaust port

Catalytic converters can be fitted in each exhaust port in the junction between cylinder head and exhaust manifold. Its volume is limited due to the available space, and several single partial volumes are required to capture the entire exhaust gas stream.

2) Installation in the pipe connecting the exhaust manifold and turbocharger

In engines with two cylinder banks but only one turbocharger catalytic converters can be fitted in the connecting pipes. In this case the local geometry allows for a larger catalytic converter volume than in the previous option.

3) Installation in the connection between exhaust manifold and turbocharger

This is the preferred solution for the vast majority of applications. However, even in this case space is limited at least in existing structures. With minor modifications to the turbine and/or exhaust manifold the possible catalytic converter volume can be greatly increased.

INFLUENCE OF FLOW CONDITIONS IN PTC

In addition to higher temperature levels, it is above all the particular flow conditions in the PTC that lead to very high volume-specific effectiveness. Due to the small diameters inherent in its construction very high flow speeds are reached in the PTC. This results in a largely turbulent flow pattern in the catalytic converter channel, which leads to a significantly increased mass transfer between exhaust gas and channel wall (figure 3).

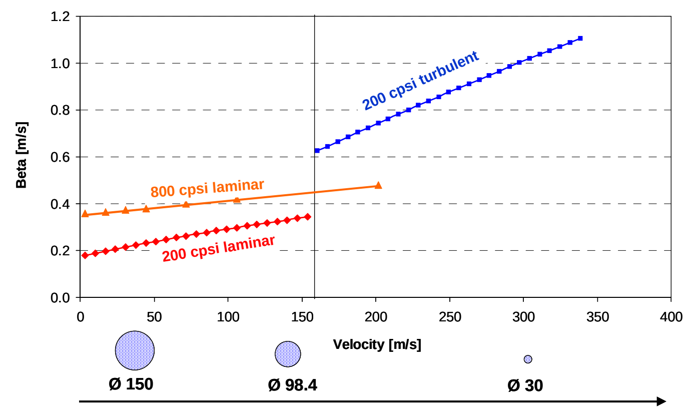

Figure 3: Calculated mass transfer in the channel of a standard catalytic converter and a PTC

FUNDAMENTAL ANALYSES

OXIDATION EFFICIENCY OF PTC

Basic investigations were performed with different types of PTC in several constant load points on a 1.9 l TDI test engine. During the test HC- and CO-concentrations in front of and behind PTC were measured and efficiency of PTC was determined.
There were two characteristic types of PTC used. The first one has a very small volume of 0.02 l, which represents a size that can be easily fitted into most existing Diesel exhaust systems without any modifications. The second one has a volume of 0.2 l. To be able to use both sizes in the same setup, a special manifold was used for the testing.
Two characteristic load points were chosen:

- 1500 1/min, 3 bar bmep
- 2500 1/min, 8 bar bmep

Figure 4 shows conversion rates at the different load points for the two PTC volumes. Already with the very small volume of 0.02 l conversion rates up to 25 % for HC and up to 30 % for CO could be shown. The PTC with higher volume showed even significantly higher conversion rates of 53 % for HC and up to 80 % for CO.

INFLUENCE OF PTC ON OXIDATION BEHAVIOUR OF MAIN CATALYST

In addition to the high activity of the PTC itself, this has also an effect on the main catalyst which is located downstream of the turbine. Due to the significant reduction of inlet concentration for the main catalyst, the light-off temperature is significantly decreased.

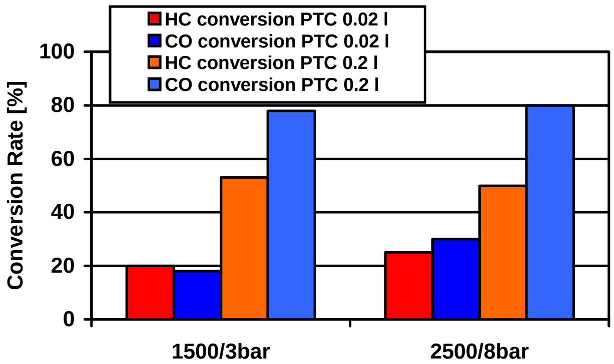

Figure 4 : Conversion rates at different load points

To evaluate this effect under realistic driving conditions, a catalyst system consisting of PTC (volume 0.05 l) and standard oxidation catalyst was fitted to an existing 2.2 l engine and was then aged on the engine test bench. Figure 5 shows the CO conversion rate of the PTC itself as function of PTC inlet temperatures. Measurement was made first by decreasing the temperature and then by increasing it. A maximum conversion rate of 35 % can be seen. Figure 6 then shows the light-off curves measured with the main catalyst downstream of the PTC. These curves show the conversion only of the DOC by measuring inlet and outlet concentration. It can be seen that light-off temperature is decreased by approximately 20°C. In addition, maximum efficiency at higher temperatures is increased.

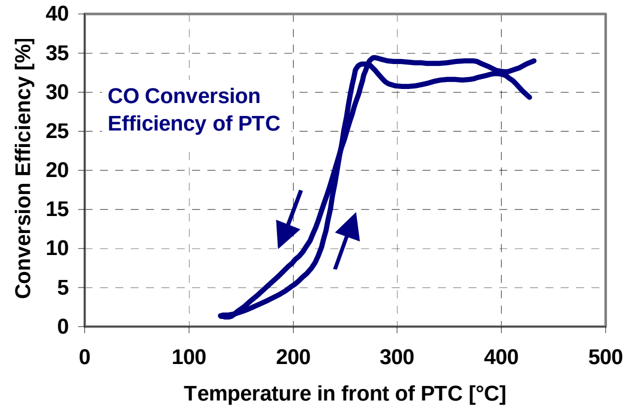

Figure 5 : Conversion rate of aged PTC

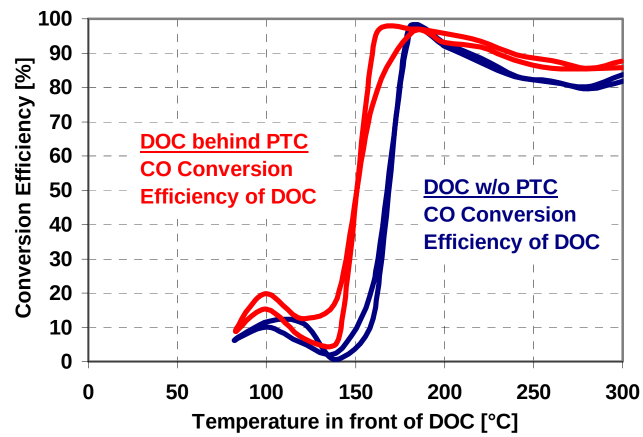

Figure 6 : Conversion rate main catalyst with and without PTC

VEHICLE APPLICATION OF PTC

PTC EFFECT ON THE EMISSION LEVEL OF A EURO 3 VEHICLE

In order to confirm the test bench results under actual driving conditions a Euro 3 vehicle with a different engine and a different original DOC (Focus C-Max 2.0 l TDCI) was fitted with different PTC versions.

This was based on two fundamental scenarios:

1) No modifications to exhaust system and mountings

This leads to a limited possible catalytic converter volume of the PTC of approx. 0.02 l. Its diameter is 36mm at a length of 20mm.

2) Minimal modification within the scope of the existing structure

Through the use of a small spacer and minor modification to the turbocharger inlet the length of the

PTC could be increased to 40mm thus doubling the volume.

In addition to the bag sampling results, the modal values of different positions were also established during measurements on the chassis dynamometer. Test points were placed in the exhaust manifold in front of the PTC and directly behind the exhaust gas turbine in front of the main catalytic converter in order to measure the effectiveness of the PTC directly. Another test point was placed behind the main catalytic converter. The measurements with a PTC were carried out with an aged main catalytic converter. Figure 7 shows the comparison of the base measurements with a fresh and an aged main catalytic converter.

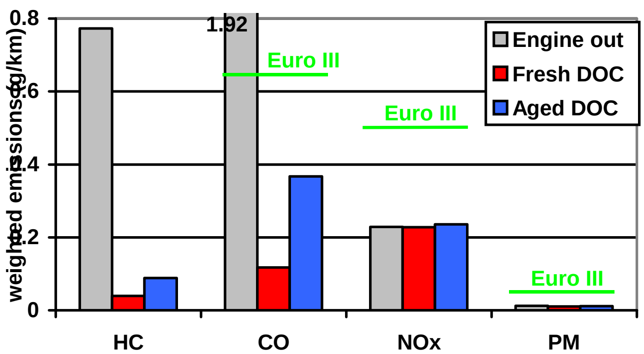

Figure 7: Comparison of the base measurement with fresh and aged catalytic converter

To begin with measurements were carried out with fresh PTCs to establish the maximum potential. An examination of the conversion rates of PTCs shows similar conditions between the different versions and also between HC and CO conversions as measured on the engine test bench under constant load . Figure 8 shows the HC and CO conversion rates of the long PTC version established on the basis of the cumulative emissions in front of and behind the PTC. This illustration was chosen to eliminate any strong deflections, which are inevitably caused by minimum variation of the two measurement lines in the direct calculation of the conversion rate from the modal data.

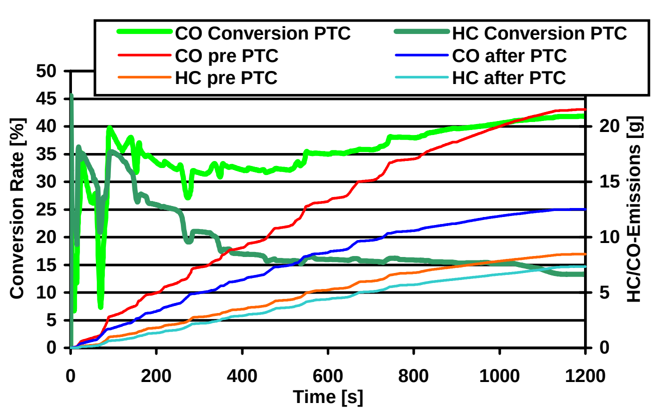

Figure 8: Conversion rates from cumulative HC and CO emissions of the long PTC versions

However, the most noticeable feature is that the positive effect does not stem from additional conversion activity in the PTC alone but that the main catalytic converter also lights off much more quickly and also achieves much higher maximum conversion rates. Figure 9 illustrates the effect of the long PTC version on the conversion behaviour of the main catalytic converter. The blue curve shows the conversion rate of the main catalytic converter without upstream PTC calculated on the basis of cumulative CO emissions; the red curve with PTC. The much steeper rise in conversion rates and the considerably higher maximum level are clearly evident. Same behaviour is observed with conversion of hydrocarbons.

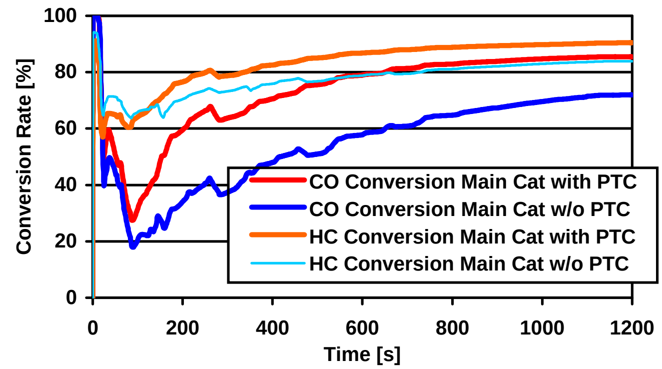

Figure 9: Conversion rate of the main catalytic converter with and without upstream PTC

Together these two effects produce the much better emission levels of the combined system. The version 1 PTCs (20mm long, volume 0.02 l) already showed a significant improvement in HC and CO values (HC –33%, CO –43%). The long version 2 (40mm, volume 0.04l) even reduced HC emissions by 45% and CO emissions by 65% compared to OEM catalyst system (figure 10).

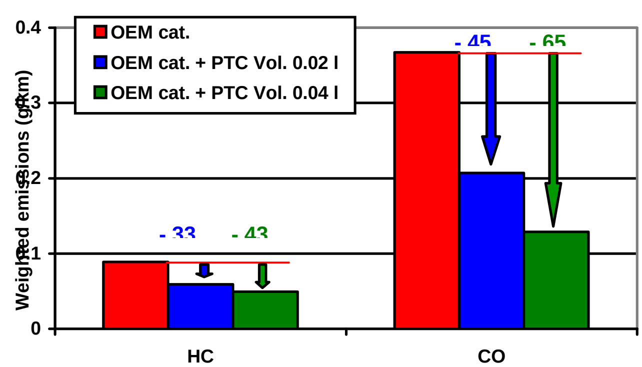

Figure 10 : Influence of PTC lengths (volumes) on emissions after fresh PTC + OEM catalyst system.

In addition to measurements with a fresh PTC, tests were carried out with oven aged parts in order to estimate the behaviour over the lifetime of the vehicle. As a result, the system with the larger PTC still offers significant advantages over the production system at 20% for HC and 31% for CO (figure 11).

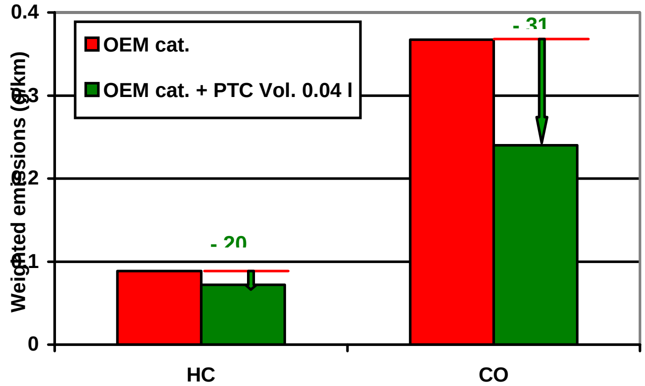

Figure 11: Emissions after aged PTC + OEM catalyst system.

USE OF PTC FOR AN EFFECTIVE EURO 4 SOLUTION

To demonstrate once again the improved light-off and conversion behaviour of the main catalytic converter with upstream PTC; further measurements were carried out on a Euro 4 vehicle. The production exhaust system was replaced with an Euro 3 DOC and an upstream PTC. The measurements were carried out with oven aged systems. Figure 12 shows the results of the measurements from the Euro 4 vehicle with aged Euro 3 DOC with and without upstream aged PTC and with the aged Euro 4 counterpart. The red bars show the emissions of the Euro 3 system with PTC. It can be seen that the effect of the PTC is the same as for the Euro 3 vehicle, which results in a similar emission level as with the Euro 4 system.

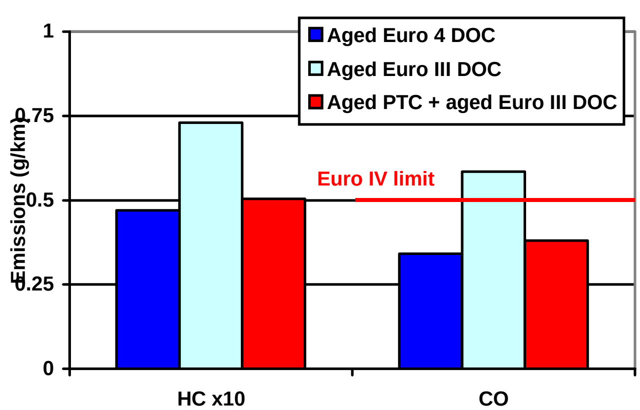

Figure 12 : Results on Euro 4 vehicle with different systems

CONCLUSION

The investigations with pre-turbocharger catalysts described above show the possibility to reach high conversion efficiency even with small catalyst volume by placing it in front of the turbocharger and thereby profit from the higher temperature level and exhaust gas energy. This means a strong relief for the main catalyst, which can therefore show a higher efficiency : earlier light-off and improved conversion behaviour. In this specific case it was shown that by the use of a PTC in connection with a main Euro III catalyst the same tailpipe emission was obtained as with a single main Euro IV catalyst.

These measurements were performed with aged catalyst systems, with fresh PTCs even much higher efficiencies were measured. As the temperature level and other boundary conditions in the pre-turbo position are quite different from those of standard oxidation catalyst location, a further adaptation or even new formulation compared to the standard diesel oxidation catalytic coating is supposed to reveal even a greater part of the potential of the PTC technology.

ACKNOWLEDGMENTS

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