Neue Dieselkatalysatorsysteme zur Erreichung der europäischen Grenzwerte 2005 – getestet an einem Volvo S60 Personenkraftwagen

New Diesel Catalyst Systems to Achieve European 2005 Legislation – Tested on a Volvo S60 Passenger Car

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Abstrakt:

Zur Einhaltung der europäische Stufe IV (2005) Gesetzgebung für Dieselfahrzeuge werden hinsichtlich aller Schadstoffe verbesserte Katalysatoreffektivitäten benötigt. Neben einer Optimierung des Motors und des Motorsteuerungssystems, müssen die für die HC und CO Umsetzung erforderlichen Oxidationskatalysatoren an die spezifischen Anforderungen von modernen direkteinspritzenden Dieselmotoren angepasst werden. Aufgrund der Wechselwirkung zwischen Stickoxid und Partikelemissionen, werden speziell Fahrzeuge mit höherer Fahrzeugmasse eine Partikelreduktionsmaßnahme benötigen.

An einem Volvo S60 wurde das Potential verschiedener Dieselkatalysatorsysteme wie Hybrid Katalysatoren, PM-Filterkatalysatoren und Vorturboladerkatalysatoren im neuen und gealterten Zustand dargestellt.

Abstract*:*

In order to comply with the European 2005 legislation for diesel cars improved catalyst efficiencies for all emission components are needed. Apart from optimizing engines and engine management systems, the oxidation catalyst for converting HC and CO has to be designed for the specific demands of direct injected turbo-charged diesel engines. Because of the trade off between NO_x *and particulates (PM) engine out emissions, cars with higher mass in particular might require increased PM efficiency.*

Tests were conducted using a Volvo S60 in order to investigate the emission potential of various new diesel catalyst systems, such as PM Catalysts, Hybrid Catalysts and Pre-Turbo-charger Catalysts.

1. Introduction

As part of the political debates regarding emissions from motor vehicles in general and also whether Hydrocarbon (HC), Carbon monoxide (CO), Nitrogen oxide (NO_X) and Particulates (PM) as pollutants or Carbon dioxide (CO_2) as a climate gas are more harmful to the environment, customers have decided to increasingly use the fuel consumption advantages of the diesel engine as an argument in favor of purchase. This decision is made all the more easy by the fact that today's modern turbo-charged, direct injection diesel engines are barely at a disadvantage compared with spark ignition engines with regard to torque and performance and above all even tend to show advantages in everyday use. This is clearly illustrated through the strongly increasing percentage of diesel vehicles on the road in recent years in all European countries. Through lower specific fuel consumption of diesel vehicles the average fleet consumption has been positively influenced and therefore so have CO_2 emissions.

The emission characteristics of the various engine concepts differ greatly. Where a Lambda 1 spark ignition engine emits HC, CO and Nitrogen oxide and only small amounts of particulates, it is specifically the particulates and Nitrogen oxide that are the main emissions from diesel engines.

The catalytic conversion of the emissions in the various engines is also different since a diesel engine always runs lean, i. e. with excess air. In contrast the spark ignition engine today usually works with stoichiometric mixture. One exception here is the lean-running direct injection spark ignition engine, which is very similar to the diesel engine with regard to the problems pertaining to NO_X exhaust gas after-treatment.

If the untreated emissions of the Volvo S60, Model year 2002 with a 2.4 liter engine are compared with the values in Exhaust Emission Legislation, the following conversion rates are to be found for HC, CO, PM and NO_X dependant on legislation status (Table 1).

	HC	CO	PM	NO_X
EU III	89 %	65 %	–	–
EU IV	91 %	72 %	21 %	36 %

Table 1: Required Conversion Rates to meet with EU IV, EU III Limit values

2. Exhaust gas aftertreatment of the Volvo S60 MJ 2002

The Volvo S60 with the 2.4-l diesel engine is fitted today with an oxidation catalyst close-coupled and an underfloor catalyst. The close-coupled catalyst has the dimensions 135.8 x 78.4 x 124 mm/400 cpsi/4 mil (Coating 100 g/ft^3 Pt only) it is located, 175 mm behind the turbo-charger. The underfloor-oxydation catalyst, with the dimensions 152.4 x 101.6 x 152.4 mm/ 400 cpsi/6.5 mil (Coating 50 g/ft^3 Pt only) is positioned approximately 705 mm behind the turbo-charger.

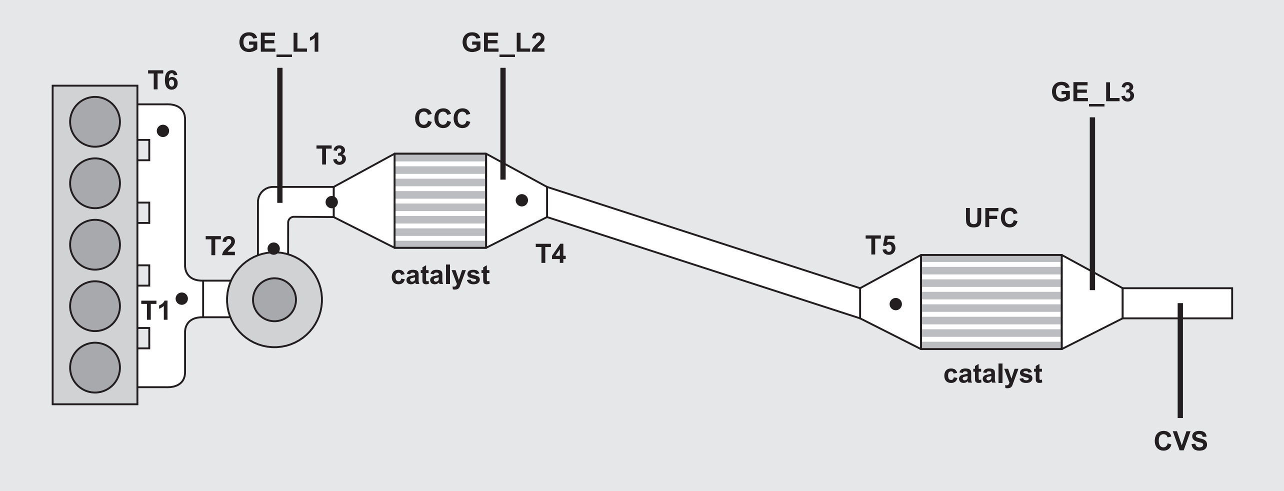

Figure 1: Standard Production Exhaust System of the Volvo S60 with Measurement Point Map

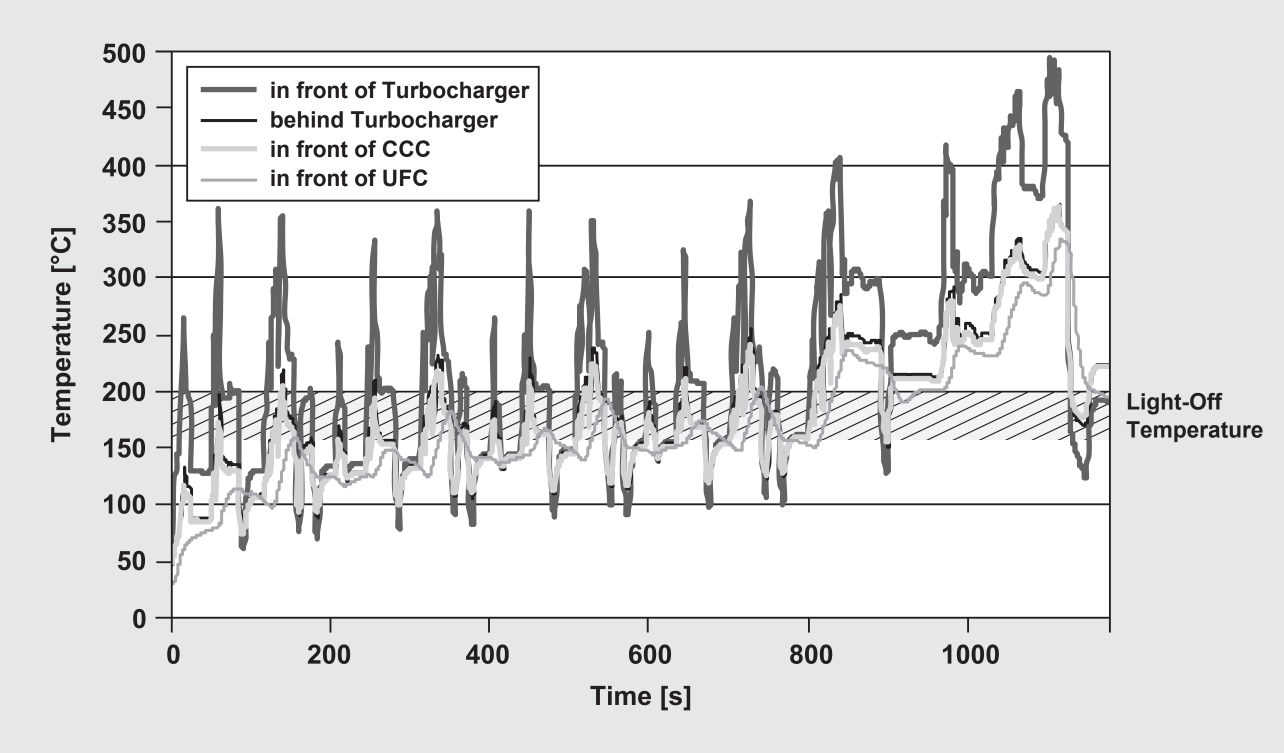

Figure 2: Exhaust gas temperatures before and, behind the turbo-charger, before the pre-catalyst and before the underfloor catalyst of a Volvo S60 in the EU III cycle

The efficiency of oxidation catalysts is determined above all by the exhaust gas temperatures [1, 2]. Since the gas temperatures in front of the catalyst in the European test cycle are in the range of catalyst Light–Off temperature, even if the catalyst position is directly behind the turbo-charger.

The oxidation catalysts also convert in part the hydrocarbons attached to the particulate, thus reducing the total mass of particulates. Figure 1 shows the standard production exhaust gas system with the built-in measurement points.

Figure 2 shows the developments of temperature over time at various catalyst positions in the European exhaust gas test.

The catalytic light-off range was shown to be between 160 and 200 °C. It became clear that above all the underfloor catalyst but also the close-coupled production catalyst were being operated within the light-off temperature range during the entire city cycle. With this catalyst system, the vehicle is certified in accordance with the EU III limit values.

The aim of this investigation is the optimization of the existing catalyst system with regard to costs and achieving an improvement in emission levels for future emission legislation.

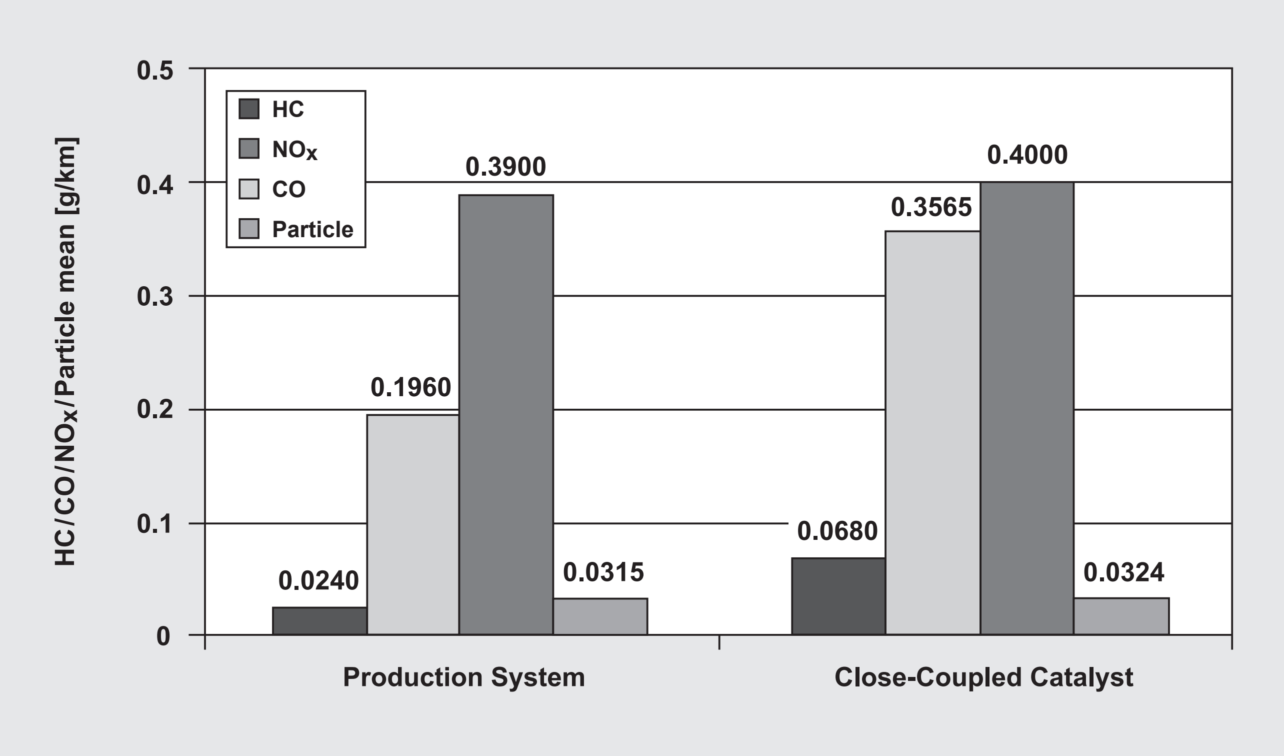

Figure 3: HC, CO, NO_X, and PM emissions results for the total production exhaust system in comparison with only the close-coupled production catalyst

Firstly, the underfloor catalyst was removed in order to conduct optimization of the close-coupled catalyst. Figure 3 shows the emission results for the standard equipment and for the variant with only the close-coupled production catalyst. It became clear that the underfloor catalyst performed a considerable share of the total HC and CO conversion due to its large catalytic volume.

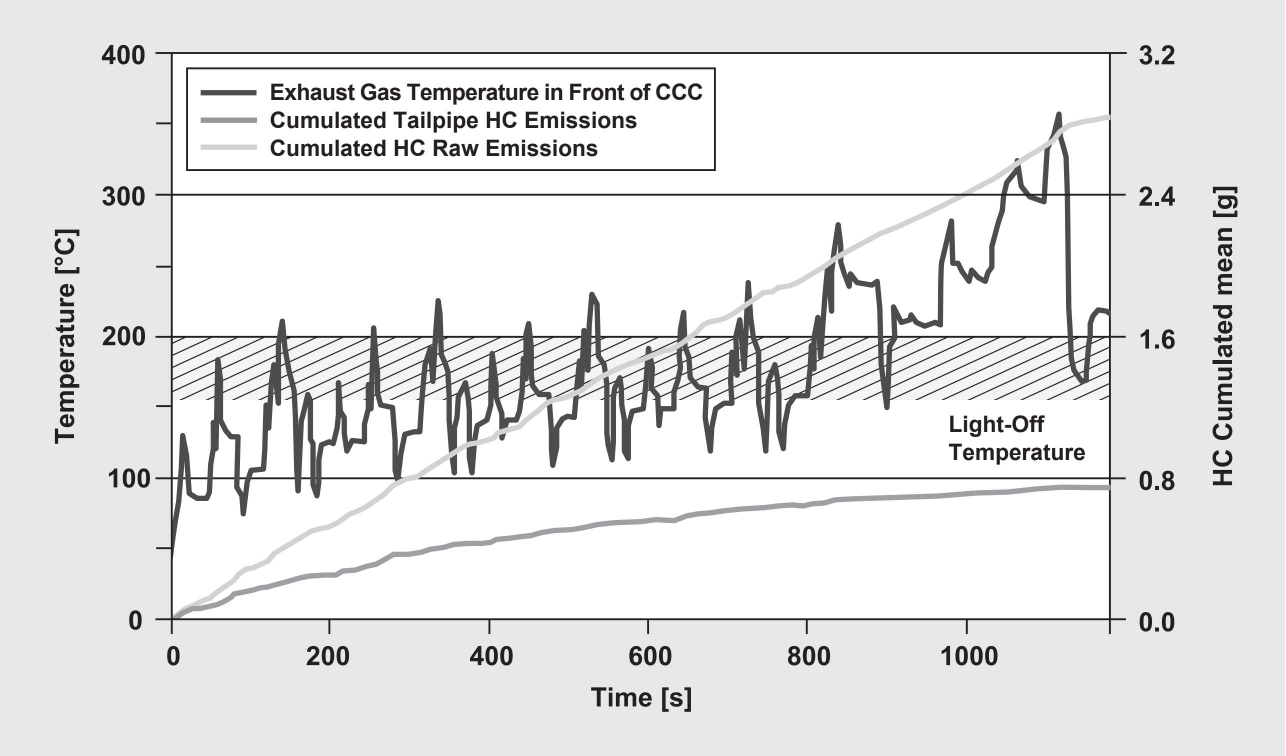

Figure 4a: Cumulated tailpipe HC emissions in the European Exhaust Gas Test and exhaust gas temperature before the close-coupled catalyst

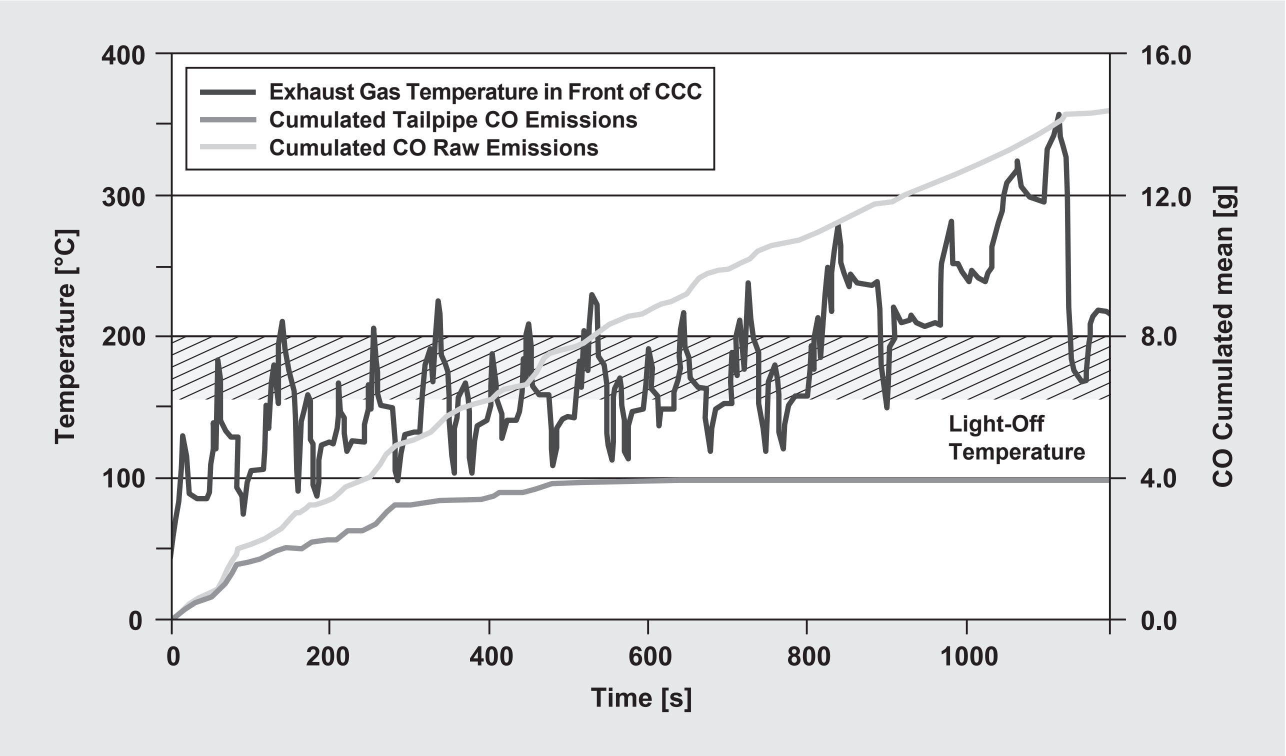

Figure 4b: Cumulated tailpipe CO emissions in the European Exhaust Gas Test and exhaust gas temperature before the close-coupled catalyst

Since this investigation is only dealing with an optimization of the oxidation catalyst, the following will primarily deal with the HC, CO and particulate emissions.

For the remaining examinations the close-coupled production catalyst was used as a basis.

For a better understanding in which test phases improvements to catalytic efficiency are needed and achievable, second by second analyses of the exhaust gas emissions were conducted. Figure 4a, b shows the cumulated HC and CO emissions in the European exhaust gas test using a 100,000 km aged, close-coupled, standard catalyst of the dimensions 135.8 x 78.4 x 124 mm / 400 cpsi / 4 mil and a volume of 1.04 l.

Comparing the exhaust gas temperatures and the HC and CO tailpipe emissions, the influence of temperature on catalyst efficiency becomes clear.

3. Development of an Improved Close-Coupled Oxydation Catalyst

In principle, at low temperatures an increase in catalyst efficiency can only be achieved via an increase in the dwell time and therefore of the catalytic volume. Admittedly, larger catalysts achieve higher efficiency rates but they do incur significantly higher costs, particularly due to their increased load of precious metals. An engine-technical increase in exhaust gas temperature also leads to an improvement in catalyst efficiency, but is not desirable due to a reduction in engine efficiency and worsening of fuel consumption.

For this reason, the main aim of the developments conducted here was to utilize the existing marginal conditions via optimum heat management within the catalyst. All catalysts used were aged in Volvo bench aging cycle.

The Volvo aging cycle is done in 10 steps with a total aging time of 53.3 h. It includes both exposure to high temperatures as well as contamination by using a 350 ppm sulfur fuel.

The aging corresponds to a running performance of 100,000 km on European roads.

3.1 Pre-Turbo-Charger Catalyst

The use of pre-turbo-charger catalyst [1, 3] and of hybrid catalysts [1, 4] takes optimum advantage of the given energy within the exhaust gas and leads to an increase in catalyst efficiency. The very small pre-turbo-charger catalysts show high specific efficiency with regard to the oxidation of HC and CO [1] due to the higher temperature levels and the increased mass transfer due to turbulent flow in the channels.

In order to first test the influence of the pre-turbo-charger catalysts overall efficiency, a catalyst was inserted in the manifold / turbo-charger flange. Its dimensions Ø 39 x 19 mm / 200 cpsi / 80 µm Coating: 150 g/ft^3 Pt only). The results are shown in Table 2 with the aged pre-turbo-charger catalyst in comparison with the production system.

With an additional catalyst volume of 0.02 l it was possible to achieve an improvement of 19 % in HC emissions, 25 % in CO emissions and neutral PM and NO_X emissions. No increase in fuel consumption due to the pre-turbo-charger catalyst could be found. In a previous Volvo test program it was established that the pre-turbo-charger catalysts produced the same results before and after aging.

	HC [g/km]	CO [g/km]	PM [g/km]	NO_x [g/km]
Production System	0.0240	0.1960	0.0315	0.390
Production System + aged Pre-turbo Catalyst	0.0195	0.1475	0.032	0.410

Table 2: Exhaust gas results with an aged, pre-turbo-charger catalyst compared with the production catalyst system

In order to show the influence of the pre-turbo-charger catalyst more clearly, additional measurements were made with the close-coupled, standard catalyst only. Figure 5 shows the cumulated HC and CO Emissions from the close-coupled, standard catalyst with and without an added pre-turbo-charger catalyst.

It is clear that because of the more favorable temperature conditions in front of the turbo charger, a significantly higher specific efficiency of the given catalytic volume can be achieved. Because of the given manifold and turbo-charger configuration, it was not possible to install a larger catalytic volume in the first stage. Consequently attention was directed to an optimization of the close-coupled catalyst.

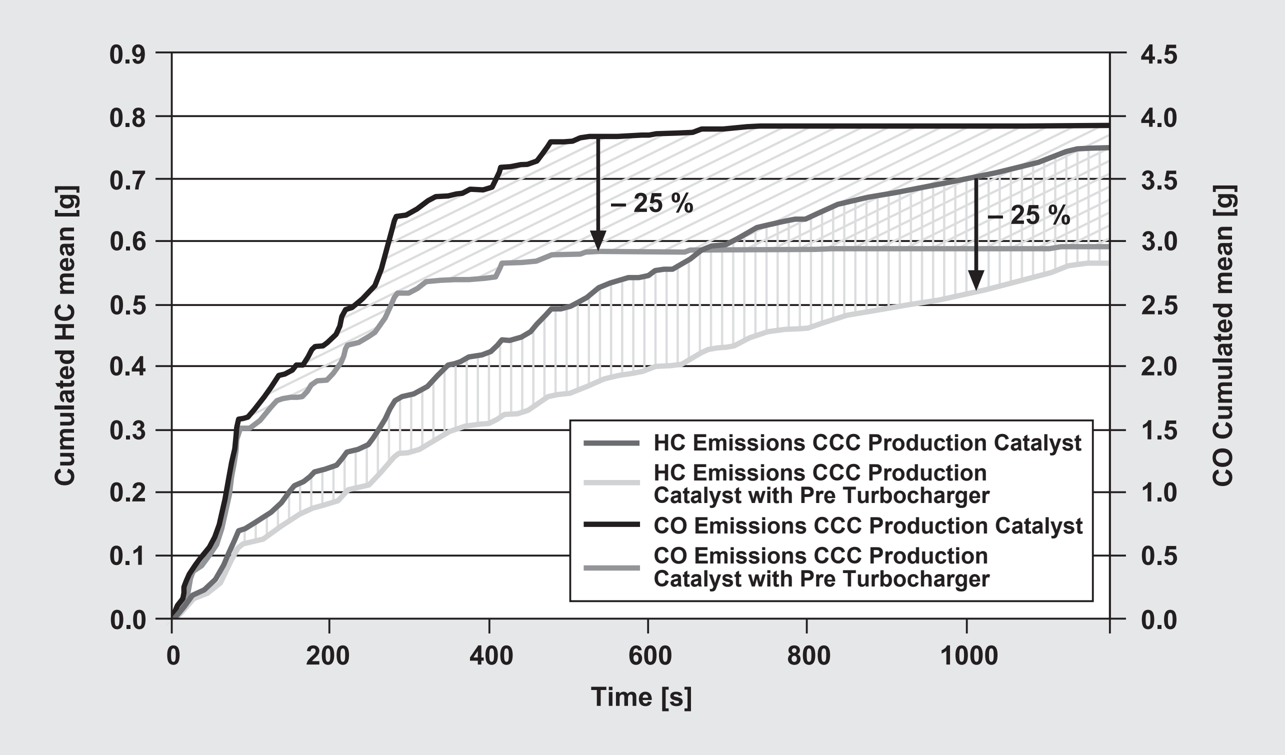

Figure 5: Cumulated HC and CO emissions from the close-coupled, standard catalysts with and without added pre-turbo-charger catalyst

3.2 Hybrid Catalyst

A further improvement of the volume-specific catalytic efficiency is possible with the help of the hybrid catalysts (figure 6). The hybrid catalyst is composed of an upstream part with low heat capacity, i. e. favorable heating-up behavior and a downstream part with higher heat capacity and therefore heat storing capacity. Using these special catalyst substrates, the operation point-dependent variations in exhaust gas temperatures are used to beneficial advantage via the specific use of thermal masses in the catalyst.

In the exhaust gas test, the production exhaust gas system was replaced by a close-coupled, hybrid catalyst with the dimensions Ø 110 x 50.8 mm/400 cpsi/30 µm + 101.5 mm/400 cpsi/80 µm and with a cell density of 400 cpsi (catalyst volume 1.45 l). In order to show a cheaper alternative, the precious metal loading was reduced by a factor of 2 to 50 g/ft^3 in comparison with the close-coupled, standard catalyst (100 g/ft^3). The exhaust gas measurements were made with an in-built pre-turbo-charger catalyst and were conducted using aged catalysts. Figure 6 shows the exhaust gas results for the production pre-catalyst compared with the hybrid system and pre-turbo catalyst with a reduced Pt loading (– 28 %) the HC emissions were reduced by 35 % and CO by 29 %.

In addition to HC and CO, NO was oxidized to NO_2 within the hybrid catalyst. Given sufficient dwell time, NO_2 already reacts with soot particles at temperatures upwards of 200 °C [JM]. In order to make beneficial use of this effect an uncoated PM filter-catalyst was inserted immediately behind the hybrid catalyst.

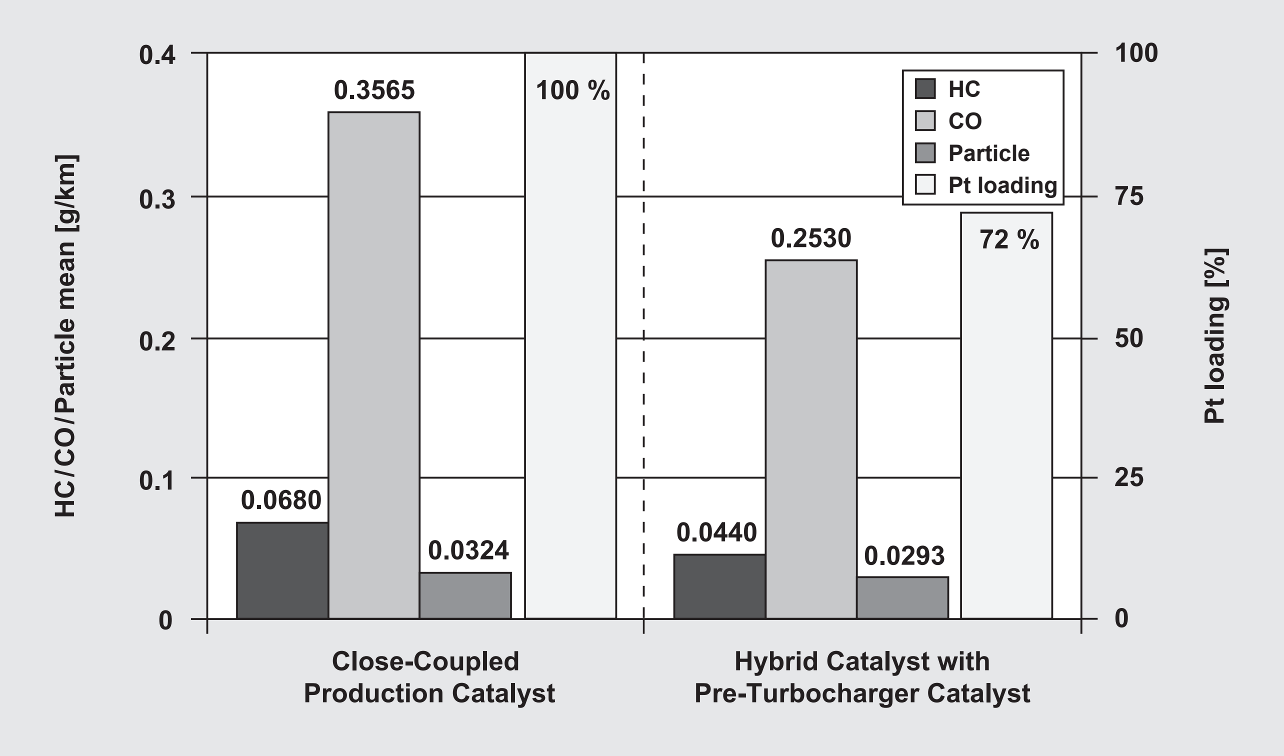

Figure 6: HC, CO and PM emissions for the close-coupled standard catalyst (Coating 100 g/ft^3) compared with the hybrid catalyst (Coating 50 g/ft^3) with aged, pre-turbo catalyst and relative platinum (Pt) loading

3.3 PM Filter-Catalyst

The PM filter-catalyst [5, 6, 7] is a separating system which cannot block due to the nature of its open construction. The aim of the PM filter-catalyst is to increase the particulate dwell time via intermediate storage in a sintered metal layer. In order to limit the maximum amount of soot storage, thus enabling the risk of an uncontrolled temperature increase during sudden thermal regeneration to be ruled out, the catalyst cross section was kept small. At a diameter of 110 mm the aerodynamic forces in the S60 are so high that separation of the particulates only occurs in the sintered metal layer and not in the channels at the edge of the guide blades. Figure 7 shows the principle of the PM filter-catalyst. The depositing of soot in the sintered metal layer is shown in figure 8.

For the purpose of the exhaust gas test, an uncoated PM filter-catalyst with the dimensions Ø 110 x 150 mm / 200 cpsi / 65 µm was positioned immediately behind the close-coupled hybrid catalyst. The underfloor catalyst was not installed. Figure 9 shows the PM emissions with and without inserted PM filter-catalyst in the catalyst system with pre-turbo catalyst and hybrid catalyst – compared with the standard catalyst system. The exhaust gas results are the mean values for at least 3 exhaust gas tests.

The PM filter catalyst achieved a reproducible 40 % reduction in particulate emissions.

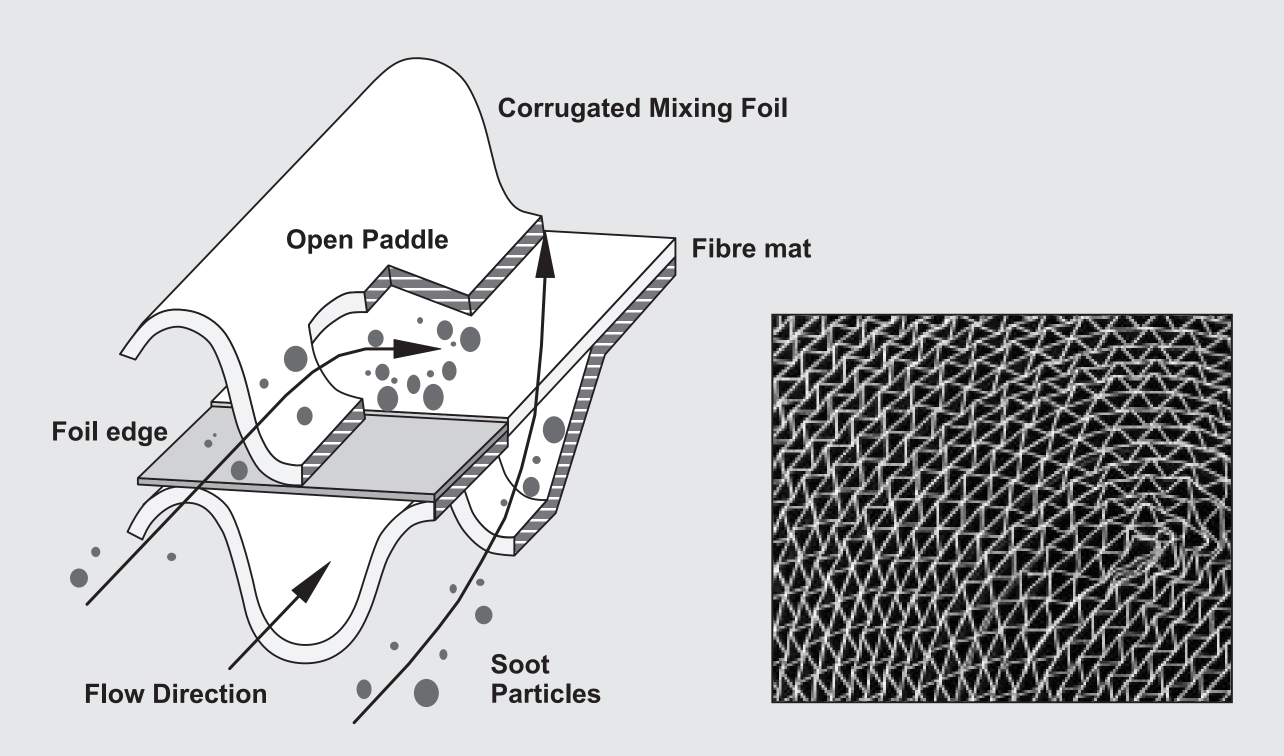

Figure 7: Principle of the PM Filter Catalyst

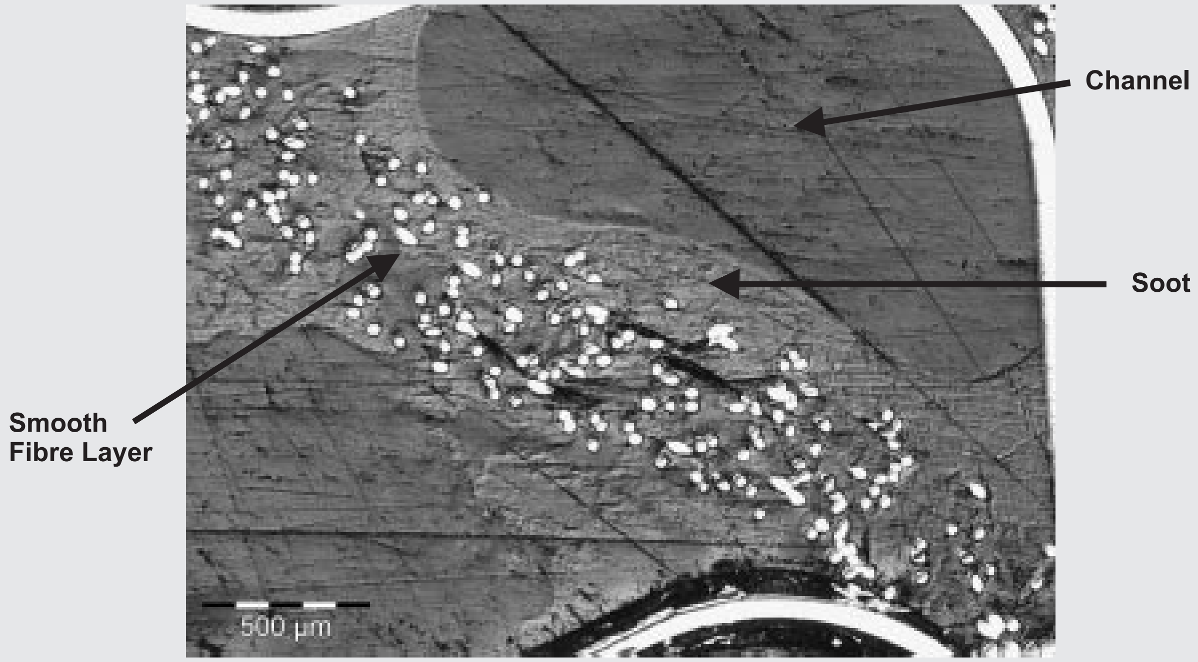

Figure 8: PM Filter Catalyst – Depositing of Soot in the Sintered Metal Layer

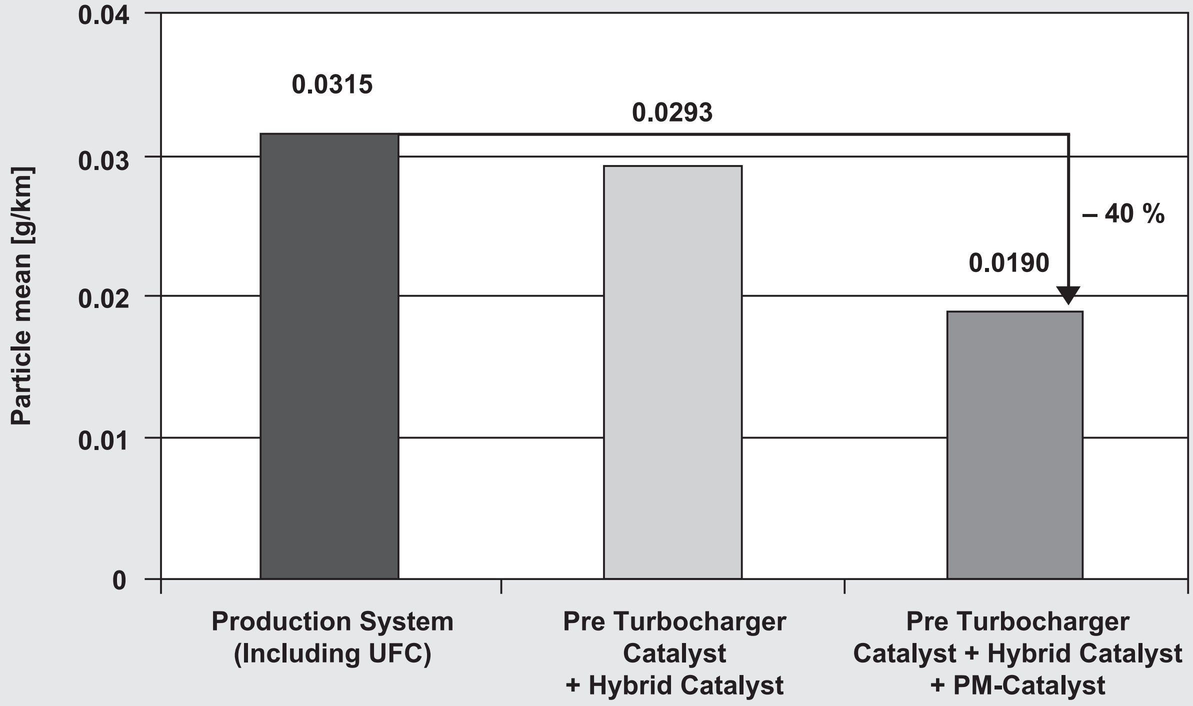

Figure 9: Comparison of the PM Emissions for the Standard Catalyst (including Underfloor Catalyst), for the System: Pre-Turbo-Catalyst + Hybrid Catalyst; and for the System: Pre-Turbo-Catalyst + Hybrid Catalyst + PM Filter Catalyst

4. New canning Variant for Close-Coupled Catalysts

In comparison with the production catalyst system with underfloor catalyst it has not been possible to achieve the HC and CO values with the pre-catalyst variant. Since temperature has a fundamental influence on the conversion quality, an alternative catalyst position immediately behind the turbo-charger was thought of. Due to the amounts of space available it was necessary to position the gas inlet and gas outlet on one side of the catalyst. The following canning solutions are available [8] (figure 10).

In the continuing course of the investigations an alternative catalyst system was tested. The catalyst size was Ø 98,4 x 40 mm; 400 cpsi / 30 μm + 95 mm / 400 cpsi / 80 μm (volume: 1.02 l) in hybrid construction. The coating corresponded to the production coating of the close-coupled catalysts. The exhaust gas tests were conducted with an in-built pre-turbo catalyst. Figure 11 shows the gas inlet and the gas outlet temperature in the close-coupled standard catalysts compared with the new canning variant.

Since it was possible to realize the new canning variant without pre-catalyst deviation of gas, the resultant gas inflow temperatures are 10 - 20 Kelvin higher. The post-catalyst temperature clearly shows that the hybrid system has a heat-storing effect and that consequently the temperatures in the rear parts of the catalyst are higher in the deceleration phases than they are in the standard catalyst. The corresponding exhaust gas results are shown in figure 12.

The close-coupled position in conjunction with the new canning again shows an improvement in HC and CO Emissions in 16 % and 44 % compared to the hybrid system at the original catalyst position. Therefore the CO emission results for the standard pre-catalysts were bettered by 60 %. With regard to HC emissions, an improvement of 46 % was achieved.

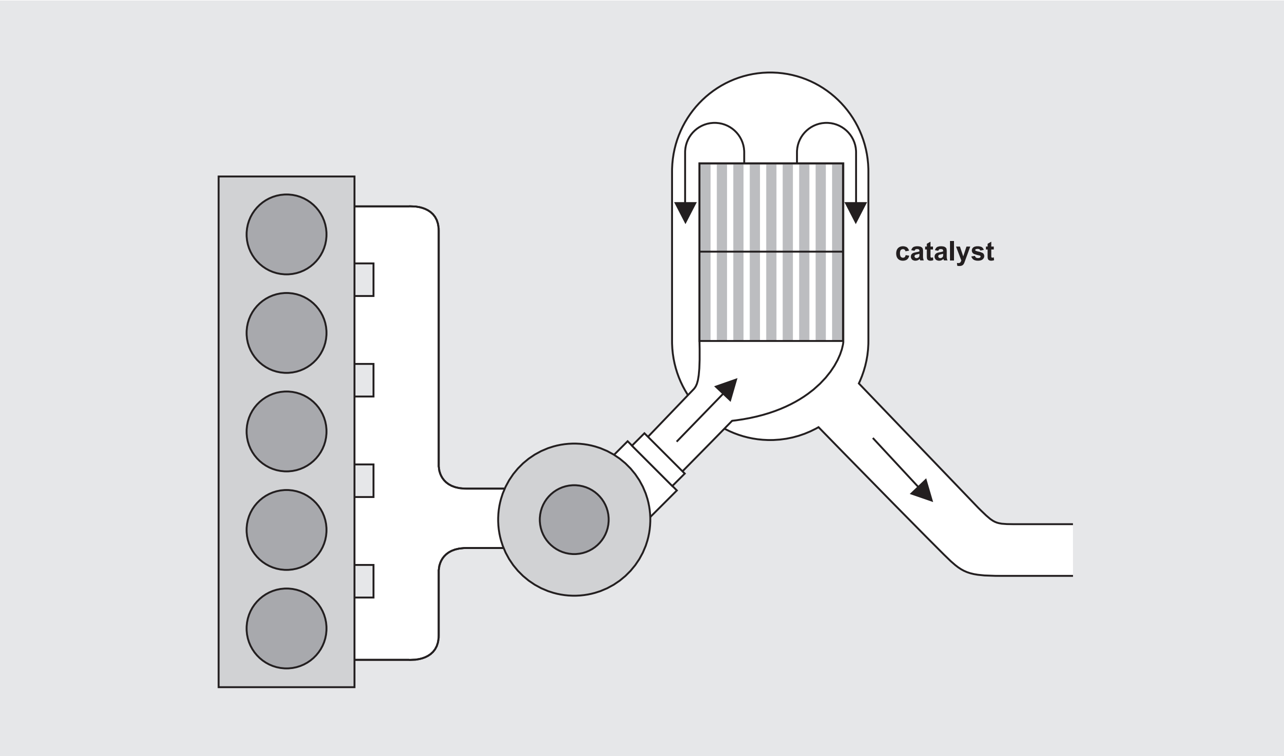

Figure 10: Alternative Catalyst System with Exhaust Gas Feed in Counterflow

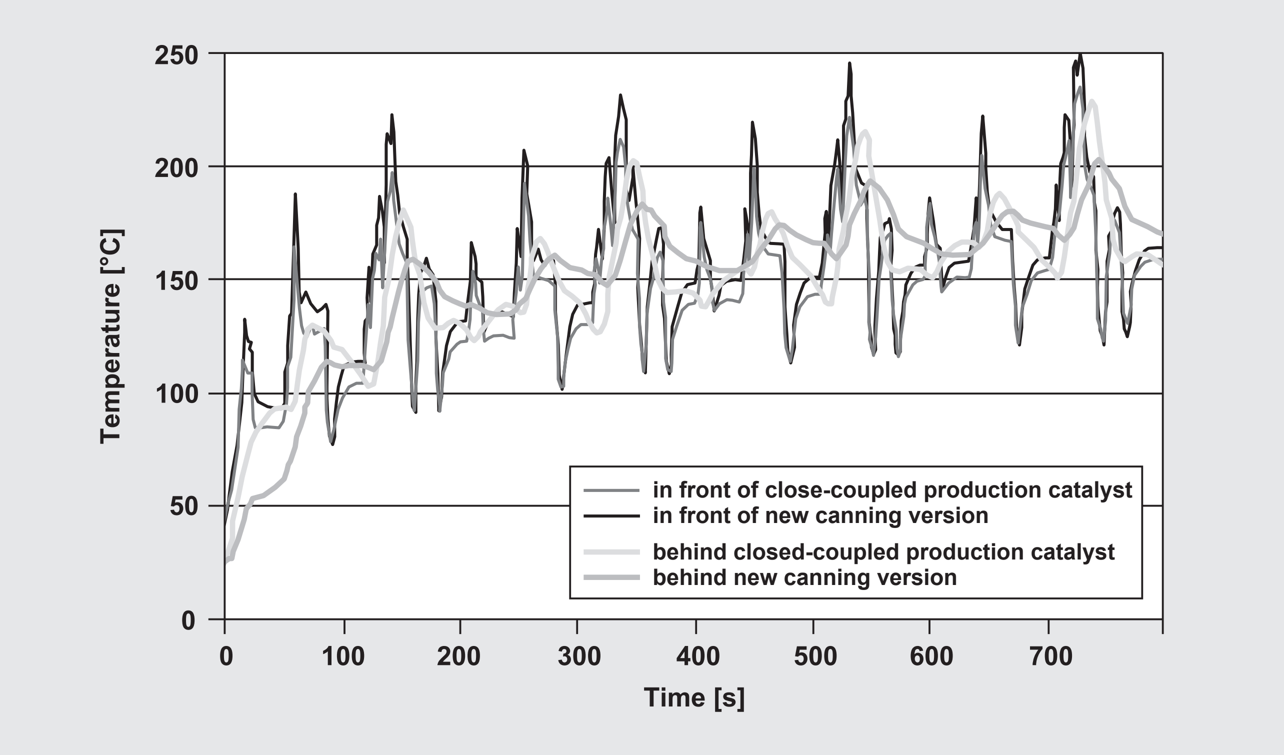

Figure 11: Pre- and Post-Catalyst Gas Temperatures for the Production Substrate Compared with the New Canning

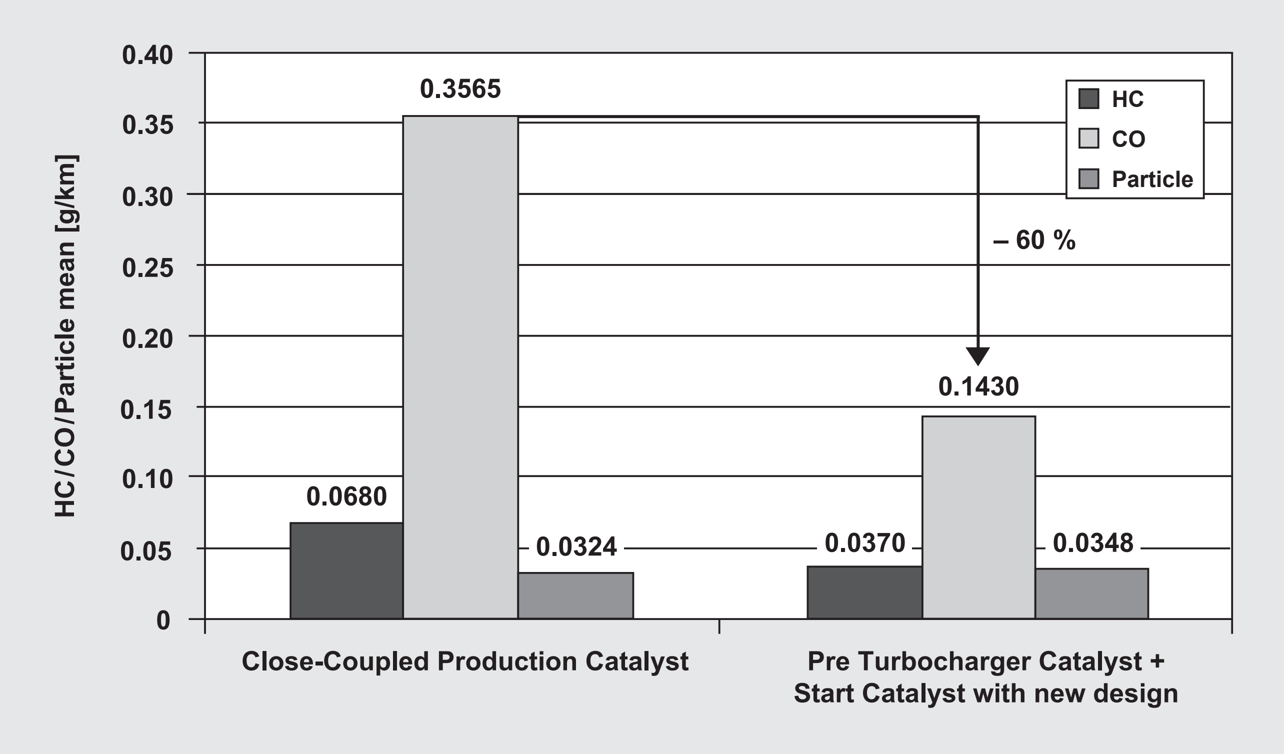

Figure 12: HC, CO and PM Emission Results for the Pre-Turbo Catalyst + Close-Coupled Catalyst in the Optimized Position Compared to the Production Pre-Catalyst

In comparisen to the total production catalyst (volume: 2,89 l) the CO values were 17 % lower with the modified close-coupled system with a pre-turbo catalyst (volume: 1,04 l) while the HC results are 50 % higher.

5. Summary

The investigations have shown that it is possible to achieve a significant increase in the efficiency of a close-coupled oxidation catalyst via the optimization of the substrate combined with a new canning method and the use of a pre-turbo catalyst. By doing so it is possible to significantly reduce the size of the main catalytic converter or even to remove it completely, thus saving costs.

Above all, the advantage of the new canning is that because of its construction, spaces that were not usable before in the engine compartment can now be used for the oxidation catalyst. Consequently the conventional catalyst positions are free and may be used, for example, for additional particulate filters or NO_X absorbers.

The use of catalyst substrates with hybrid design leads to a more balanced heat management through which catalyst efficiency can be further improved.

Through the insertion of an uncoated PM filter catalyst behind the oxidation catalyst, particulate emissions were reduced by 40 % compared with the production system.

In order to fully utilize the potential of the catalyst variants shown, it is necessary to increase the volume of the pre-turbo catalyst and to insert a coated PM filter catalyst in the position directly behind the turbo-charger.

6. Reference

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