Electrically Heated Catalyst System Application and Durability

W. Maus, R. Brück, P. Hirth
EMITEC GmbH

1994
Aachen, Germany
31th October – 4th November

Dedicated conference on the motor vehicle and the environment-demands of the nineties and beyond
1. Introduction

Stringent future emission values such as will be required for the European Stage 3 and the Californian Low Emission Vehicles, will necessitate modifications of existing exhaust systems (fig. 1). Similar as with the LEV values, the cold start is also for the European legislation a critical factor for overall effectiveness. That the electrically heated catalytic converter presents a possible solution has been frequently proven in the past [1, 2, 3]. During the course of development, modifications to the heated catalytic converter, the exhaust system and engine management have reduced energy consumption to 1 to 2 kW when post-heating is implemented [4, 5]. The Emetec Series 6 heated catalytic converter represents a durable, long term, stable system with a low heating energy requirement. This has been achieved with standard metal foils manufactured under existing production techniques. The objective of this study is to examine mechanical and chemical durability in relationship to the size of the heated catalytic converter and the heating energy. The stability of emission levels will be examined on heated catalytic converter systems aged on an engine test bench in conformance with the requirements of the Federal Test Procedure (FTP test) as well as the projected MVEG Stage 3 Test.

Fig. 1: Future Emission Standards for Europe/USA
4. Mode of experimental procedure

After the standard mechanical durability tests can be considered finalized, it will remain to be proven whether future emission standards can also be satisfied with aged heated catalytic converters.

A critical factor in this respect is the required energy consumption. The essential objective is to achieve catalytic converter light-off within 15-20 s following engine cranking using the lowest possible energy consumption. Tests were carried out, therefore, on 5 catalytic converter systems in order to evaluate the following factors and their influence on emissions:

a) Electrical Heating Energy

The electrical heating energy directly determines the heating-up time of the catalytic converter. Tests were carried out on converters with a heating energy between 1000 and 1500 watts (100 A-150 A / 10 V). The following diagram represents the influence of the heating energy using as an example a $\varnothing$ 90 x 10 mm heated catalytic converter with a cell density of 160 cpsi.

The uncoated EHC Series 6 $\varnothing$ 90 is able to reach a temperature of more than 500 °C in 10 s with an heating energy of 1 kW which indicates light-off very quick after engine cranking.

b) Catalyst diameter

The diameter of the catalytic converter, and thus the converter volume at a constant converter length, influences the mass to be heated. A constant cell density and thickness of the foil was maintained in all catalytic converters; the heating-up time is therefore approximately proportionate to the diameter. Catalytic converters of $\varnothing$ 70, 90 and 118 mm were tested. The following diagram shows the heating-up behaviour of the individual catalysts under static air conditions.

Fig. 5: Heating-up behaviour of Series 6 heated catalytic converters relative to heating energy

Fig. 6: Heating-up curve EHC Series 6 $\varnothing$ 70/90/118/100 A and $\varnothing$ 118/150 A at 10 V
Since the heating-up time of the Ø 118 heated catalytic converter with a heating energy of 1000 watts is too brief even under static air conditions, to attain the light-off temperature within the preferred 10-15 s after engine cranking the catalytic converter in this size was tested with 150 A.

c) Coating

The coating influences both the heating-up behaviour of the catalyst by increasing the heat capacity, as well as the light-off behaviour through the light-off temperature specific to the coating.

Heat capacity:

A Pt/Rh coating (coating A) and a Pt/Pd/Rh coating (coating B) was tested on an EHC Series 6. The specific washcoat mass data are given in table 2. The main catalysts were coated with production Pt/Rh coating/ (Coating C). The only exception was catalyst system 4 (table 3) because the supporting brick of this EHC is in the same time the main catalyst, so that it is totally coated with Coating A.

Specific washcoat mass data of the EHC Series 6 including supporting brick.

Table 2:

<table>
<thead>
<tr>
<th>Specific washcoat mass [g/l]</th>
</tr>
</thead>
</table>
| **Coating A** | 168  
| **Coating B** | 185  

It can be determined that the specific mass of coating B is about 10 % higher than that of coating A. This influences the heat capacity of the EHC and increases the heating time.

Light-off behaviour:

Efforts to achieve lower light-off temperatures are being facilitated by using Palladium and new developments in coating techniques.

This lowered light-off temperature should allow reduction in the required heat energy at a constant exhaust gas intake temperature in the converter.

4.1 Test Catalytic Converters

The influence of the variables described above shall be determined during testing of the following 5 catalytic converter systems.

| 1 : EHC | Ø 90 x 11 mm, 160 cpsi, 150 A, Coating A |
| 2 : EHC | Ø 90 x 11 mm, 160 cpsi, 100 A, Coating A |
| 3 : EHC | Ø 118 x 11 mm, 160 cpsi, 160 TS cpsi, Coating C |
| 4 : EHC | Ø 118 x 11 mm, 160 cpsi, 150 A, Coating A |
| 5 : EHC | Ø 118 x 11 mm, 160 cpsi, 150 A, Coating B |

Table 3: EHC Systems tested

5. Test Set-up

These catalytic converters were examined in both the FTP and the projected MVEG Test, Stage 3. A Porsche 968 with a 3-liter, 4-cylinder, 4-valve engine served as the test vehicle. With the aid of the following parameters the gas temperature was increased, in order to allow the possibility of achieving future emission legislation with low electrical heating energy.

a) Modification of engine management parameters

The following modifications to the warmup parameters were carried out:

- increased idle speed
- increased air-mass flow during idling
- retarded spark timing
- reduced enrichment during warmup
- reduced enrichment during acceleration

b) Reduction in heat losses from exhaust gas flowing to the catalyst

To reduce heat losses from exhaust gas flowing to the catalyst, the thermal mass in front of the catalyst was reduced. With the implementation of a 4-in-1 exhaust manifold with a wall thickness of 1.5 mm and a single pipe in front of the catalyst, a weight reduction of 30 % could be achieved.

c) Optimization of secondary air injection

For optimal secondary air injection, a 10 mm pipe was inserted into each exhaust canal and positioned centrally versus the exhaust flow. The transverse section of these
Influence of amperage:

Taking the example of a catalyst 90 mm in diameter, the influence of heating energy between 0 - 1500 Watts is emphasized.

The heating improves the cold start emissions by 23 % with 1000 Watts and 30 % with 1500 Watts. The slightly better results of the 150 A catalyst can be explained by more active catalyst volume during hill 1 in Bag 1 which gives a higher conversion rate in the acceleration phase.

Influence of coating

Taking the example of the catalysts Ø 90 mm with a heating energy of 100 A the influence of the coating is emphasized.

Coating B shows for the not heated test 3 % better emission results and for the heated test 9 % worse HC emission results. No clear indication for an advantage of the Pd content in coating B could be found. The reason might be the air/fuel ratio in the exhaust gas, which was controlled close to lambda = 1 even during cold start.

9.1.2 MVEG test

Influence of ageing:

Using the catalyst Ø 90 x 150 A the influence of ageing on the MVEG test was maintained. Figure 13 shows the accumulated cold start emissions of this catalyst under heated conditions.

The ageing reduces the efficiency of the catalyst during the cold start HC emission compared to the EHC-system with activated heating by 110 %.
9.1.3 Comparison FTP/MVEG Test

The catalyst Ø 90 mm with a heating energy of 150 A was used to compare the FTP and the projected MVEG Test for 1999.

![Graph showing accumulated THC emissions during cold start of the FTP and the MVEG Test](Image)

Fig. 14: Accumulated HC emissions during cold start of the FTP and the MVEG Test

The results indicate that the HC cold start emissions for FTP and MVEG under aged conditions show a similar behaviour. The FTP Test shows due to the higher engine out emission about 0.1 g more HC during the first 125 s. It has to be mentioned that the ageing for this comparison was the same for all catalysts. But different ageing behaviour in real life in the US and Europe due to different gas inlet temperatures (fig. 15) leads us to expect a higher thermal loads for Europe for close coupled applications. Nevertheless the EHC is a tool which lights-off aged catalyst systems within the first 30 s after cold start, which should guarantee emission values within the limits.

![Graph showing remaining time](Image)

Fig. 15: Comparison between German and American gas temperatures in front of the catalyst due to the driving conditions

9.2 Total Test result:

9.2.1 FTP-Test:

The heating was only activated during bag 1. In spite of that the catalyst diameter influences the warm start emissions. Figure 16 shows the accumulated HC emissions during first 125 s of bag 3.

![Graph showing accumulated THC emissions during the first 125 s of Bag 3 in FTP](Image)

Fig. 16: Accumulated GC emissions during the first 125 s of Bag 3 in FTP.

The smaller diameters restart quicker, which means it works like a heat cascade with a smaller heat capacity in the first brick.

The total catalyst volumes are between 1.87 l and 2.03 l, which is 62 % - 68 % of engine displacement. This small catalyst size was chosen to find the critical points in conversion during the total FTP cycle. The following table shows the bag and total FTP results of the catalyst Ø 90 x 50,8 mm 150 A under fresh and aged conditions. The total emission results miss the ULEV level by more than 100 %. Examinations showed that this is due to break throughs in the high speed phase of the total test. For example typical bag 2 results were in the range of 0.04 to 0.05 g/m.

In order to improve the conversion rate an increased main catalyst Ø 127 x 120/74,5 mm which was aged in the same way was tested. With the bigger catalyst volume the total conversion rate could be improved by 100 %. The bag 2 HC emissions were lowered to 0.01 g/m, which gave a total test result of THC 0.046 g/m. Assuming that the EHC influences only the first 125 s of bag 1 and bag 3 it is possible to calculate emission results for the other catalysts which was tested with the small main catalyst only. The best results showed the EHC Ø 70 x 50,8 100 A. The calculated THC result is 0.036 g/m.