Partial-Flow Deep-bed-Filter for Ultra-low Emission Concepts

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Abstract

For "US 2010 / EU 6"-exhaust aftertreatment systems the influences of various parameters on

- reduction of particle mass and numbers,
- the course of events during regeneration,
- the combination and interplay with further parts of the total emission reduction system

will be described.

1. Introduction

To evaluate the efforts necessary to meet future emission standards, one has to know his starting point. An appropriate approach can be to look into the certification data of the relevant year. As an example, the available heavy duty diesel engine data for Germany [1] show that there is majority of test results which fit still to the Euro 3 standards as a carry over. If we state that the development target is to meet US 2010 standards or the scenario for Euro 6 then this means that we have to reduce the PM emission by about 85 % and the NOx emission by 90 to 96 % on the average. If we look to engines that meet Euro 4, then we have to provide a reduction of PM and NOx by up to 24 % and 93 % respectively. If we look to the published Euro 5 engine data, then PM and NOx must be reduced by up to 15 % and 88 %, depending on the set of standards. The techniques applied to today's Euro 4 and Euro 5 engines are the SCR or the PM Metalit™ technique, together with appropriate engine measures. The design of those systems has to take into account the customer's view on low procurement and running costs.

2. System Description

The PM-Metalit™ is characterized as a partial flow deep-bed filter. This is due to the fact that it consists of numerous sections where a small portion of the main flow is diverted through a porous sintered metal fleece layer, where the deep-bed filtration takes place. The diversion of the partial flow is done by shovel-like structures, which are placed inside the standard channel structure in defined distances, with the fleece layer placed beneath these channel building foil layers. There are two main portions of the partial flow: one part is flowing more or less vertically through the fleece in the area of the shovels, another one flows in parallel through and along the fleece, where

filtration of particles mainly takes place due to diffusion effects. A detailed description of the design and the functionality has already been given in [2], [3].
With each section of flow diversion a greater part of the overall flow is filtered by the sintered metal fleece. Therefore a direct correlation between the substrate length and the filtration efficiency exists. This has been shown in emission tests performed on a HDD engine test bench, where the soot reduction in ESC has been measured with the help of two microsoot sensors. In the case of 150 mm length, a filtration efficiency of 50 % was measured, while with a length of 300 mm a reduction of 75% was achieved, which means an additional 50 % reduction of the remaining soot.
This increase in filter length can also partly be achieved by replacing the conventional oxidation catalyst with a coated PM-Metalit™. As an example, replacing an oxidation catalyst of 75mm length and therefore increasing the overall filter length to 225mm results in an increase of PM reduction from 53% to around 66% in a HDD application.
Another important benefit of the PM-Metalit™ is the high efficiency in removing especially small particles in the range of invisible particles (below 400 nm). Compared to a gravimetric efficiency of 45 %, a reduction of particle number of around 70-80 % could be achieved in this particle size range, measured on an EU IV passenger car application according to proposed PMP-standards.
In the meantime, the PM-Metalit™ has shown its efficiency and reliability in numerous applications, for the OEM-market as well as for retrofit applications. Several investigations made on parts returned from long distance durability test vehicles showed a very good condition of the parts even after 600000 km in a HD application. Even without any maintenance, the functionality of the parts is still guaranteed. It was found that the condition regarding soot loading for example is actually more influenced by the driving conditions shortly before the observation of the parts, rather than by the overall driving distance itself.
Based on the reliable and robust product of today, further investigations are ongoing in order to increase the specific efficiency of the PM-Metalit™ to comply with the requests of future emission legislations and customer demands.

3. Regeneration Aspects

To identify the important parameters influencing the regeneration, which means the oxidation of the trapped soot particles, a program was started with a special laboratory balance setup that allows to measure weight changes in the micro-gram range within a gas flow. Theoretical reaction rates were compared with measurement results to develop a tool to predict soot oxidation rates depending on the exhaust condition. Although there is of course a significant difference between the laboratory setup and a real PM Metalit™ system with regards to the conditions of flow and soot loading of the test sample, some general conclusions are possible. NO_2 concentrations of more than 200 ppm, exhaust temperatures above 200 °C and the presence of water vapor support the soot oxidation significantly. In addition to that laboratory program, several other measurements using real systems on engines and vehicles were conducted, which validated the mentioned results. For example, it could be demonstrated that the balance temperature is at about 240 °C which is an attractive level for many engine applications. A different test program run by Toyota [4] gave some information about the soot oxidation rate depending on the total soot mass trapped and the soot mass remained in the PM Metalit™. It can be seen that at about 10 g / dm^3 total trapped soot mass there is a stabilization of the soot oxidation rate at about 55 %. In reference to the remaining soot loading there is a start of stabilization of the soot oxidation from about 3 g/dm³ on to higher values. Another interesting result of the test program was found in the NO_2 consumption. With the given test parameters it could be demonstrated that about 85 % to 65 % of the NO_2 is consumed by the oxidation of the soot. There are further results from other programs which show that sometimes all the NO_2 could be used for the oxidation.

4. Combined Systems for Ultra-low Emissions

Extensive programs on SCR technique using substrates with structured designs optimized for the different process functions have proven to provide the same efficiency compared to standard substrate designs at about 30 % lower reduction volume [5]. The SCR system used was based on a partial-flow hydrolysis approach with an oxidation catalyst in the parallel flow upstream of the module type reduction catalyst in a box-type silencer. The smaller reduction volume offers the possibility to install a PM Metalit™ in the space which was saved. This enables the assembly of a combined system which reduces the NOx and PM emissions simultaneously. Comparing the pressure drop of the silencer with the reduction catalyst, an advantage of about 17 % was found for the version with structured Metalits, compared to standard ceramic reference modules. Adding the PM Metalits increased the pressure drop by about 5 kPa to 13 kPa at maximum flow. For a combined system this is an acceptable value. Within the above mentioned laboratory program on the soot oxidation the influence of NH_3 on soot was observed. It could be shown that NH_3 has a small oxidation effect on the soot. Compared to NO_2 the effect is by an order of magnitude smaller, but it helps for the overall function and is at least not a disadvantage for the soot reduction. The results of ESC and ETC tests show as well as soot and PM reductions of about 50 %. There is no influence on this efficiency caused by the amount of injected urea, as the results of a feed-ratio variation have shown. Using a modified Euro 5 engine (higher NOx emission by disabling the EGR flow), and without having technical achievements like a fuel injection system capable to provide injection pressures of 2500 bar or two-stage turbocharger or turbo-compound systems, it was possible to reach a PM/NOx level which demonstrates that it is possible to meet the engineering targets for US 2010 or Euro 6 standards.

5. Summary and Outlook

Several different programs were carried out by customers and by research institutes. Based on their results it could be demonstrated that:

- permanent regeneration by NO_2 of a PM Metalit™ system provides a safe real world operation, although the temperature is influencing efficiency,
- the PM Metalit™ has been proven to be an adequate solution for EU4 and EU5 applications,
- combined systems can be significantly reduced in volume without any loss of performance by using optimized catalytic systems,
- Combination of the SCR-technology based on structured substrates with a continuously reducing PM Metalit™-System is a most effective approach for EU6/US2010 and beyond.

6. Literature

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