Diesel Particulate Filters

Combined with a Fuel-Borne Catalyst

Is the broad market introduction of diesel particulate filters throughout Europe wishful thinking or reality? The challenges facing the introduction of diesel particulate filters with a fuel-borne catalyst for series-production passenger cars are manifold and complex, taking into account different and sometimes conflicting aspects such as technical, economic, environmental and geographical requirements as well as end-user acceptance. This article from the catalyst manufacturer Rhodia presents an overview of the state of the art.

1 Introduction

The requirements to be met by the application of diesel particulate filters (DPF) with a fuel-borne catalyst (additive FBC) in series-production passenger cars are manifold. They are technical (DPF efficiency, reliability, durability and compatibility with the engine performance), economic (cost system compatibility and maintenance), environmental (regulated and non-regulated emissions, such as nitrogen oxides, ozone, furans, dioxins, solid particles), geographical (flexibility regarding different diesel fuel qualities and sulphur contents) and related to customer acceptance (extra cost, vehicle driveability, acoustic performance and maintenance constraints).

Since May 2000, PSA Peugeot Citroën has marketed a DPF system in their passenger cars under the licensed name FAP (Filtre à Particules). The sequential DPF regeneration of this world premiere uses specific engine management. Besides the silicon carbide-based DPF, important components include the pressure and temperature sensors, an adapted DPF canning method, the Eolys cerium-based fuel-borne catalyst from Rhodia and its automatic on-board dosing system [1]. Since its market introduction, more than 600,000 vehicles have been sold throughout Europe, including more than 60,000 vehicles in Germany, without recall or failure.

Today, the FBC-based DPF system is the only technology with demonstrated field experience in everyday operation. Constant system improvements and simplifications were developed over the past two years, resulting in a better vehicle integration and a global cost reduction. In June 2003, PSA Peugeot Citroën announced the third generation of their DPF system, which requires no servicing for 250,000 km [2], based on the following features:

- the second generation of the catalyst Eolys, which is more active and has a lower ash content resulting from the fuel-borne catalyst [3]
- the new asymmetric silicon carbide DPF in Octosquare design developed by Ibiden Co., Figure 1, which offers a larger inlet channel volume for optimised ash management [4].

This dramatic evolution could open up the implementation of the DPF system to a
large number of new applications. In this success story, it is important to emphasise that the DPF system was approached under the partnership of actors involved in the global DPF system design, including maintenance and after-sales departments.

2 Newly Introduced Technologies

Reacting to the leadership of PSA Peugeot Citroën in the DPF field and with the Euro IV deadline approaching on 1 January 2005, European car manufacturers have accelerated their development efforts. DPF systems were the most frequently presented emissions control technologies during the 2003 edition of the prestigious IAA Motor Show in Frankfurt.

The principle of a diesel soot filter was widely announced and appears to have gained the acceptance of the automotive industry as the preferred technology for diesel particulate emission control. This move by the industry is also a response to the current pressure from environmentalist organisations and public opinion in some countries. A summary of the information available on websites and in press releases as well as that showcased on OEMs’ booths at the IAA is shown in the Table.

As the principle of a soot filter is now widely accepted, new technical approaches that are different from PSA Peugeot Citroën’s standard fuel-borne catalyst-based DPF are now being proposed. What is more, different market introduction strategies are being announced, and many car manufacturers are offering their DPF system as an option, based on their local perception of public health concerns and on the maturity level of the different DPF solutions. The main conclusions drawn from the IAA can be summarised as follows:

- The large number of announcements confirms that the DPF is now accepted by the automotive industry
- Some uncertainties remain as to when significant series introduction will really begin
- The maturity of the different technological options varies, and work still remains to be done.

3 Durability and Performance

The key issue at stake is the reliability and durability of the newly introduced coated DPF systems. Durability appears to be linked with complete filter regeneration, which is considered as the key parameter to ensure the robustness, durability and reliability of the DPF system in series applications.

Complete regeneration depends not only on the catalytic process but also on the nature of the soot. According to the basic chemistry of carbon compounds, it is well known that carbonaceous diesel particles are strongly dependent on the physical and chemical conditions of the environment. At present, all of the most advanced research in diesel particulates has shown that fresh soot has more micro-pores and is more reactive than older soot. The physical structure and the chemical composition (especially in hydrocarbon compound contents) is strongly impacted by the oxygen pressure, the local temperature and the time spent under those specific conditions, as illustrated in Figure 2.

It is also important to note that the peak temperature observed during regeneration increases with the changes in the chemistry and structure of the carbon soot. This could potentially cause thermal stress (ageing of the catalyst), leading to a decrease in the catalytic performance of the coated DPF.

Finally, it should be mentioned that the catalytic reaction in a coated DPF is a complex process, due to the limited surface interaction between the catalyst and the soot. These observations in part explain why coated and impregnated systems tend to regenerate at significantly slower speeds than DPF systems with an FBC, Figure 3.

This intrinsic characteristic of long filter regeneration leads to risks of incomplete regeneration and the possible formation of graphitic and pyrolytic carbon. Furthermore, the regeneration cycles are increased, which may result in a high fuel penalty and the risk of injected fuel being dissolved in the lubricant, which can affect the lubricant properties.

4 Areas for Further Development

To ensure smooth and durable operation, it is necessary to be certain that the soot is burned completely during regeneration in order to prevent graphitic and pyrolytic carbon formation and to limit thermal stress. If continuous filter regeneration is not possible due to the fact that the exhaust gas temperature is too low, only sequential systems can be used in series application. These systems are easy to handle and use an FBC (high reactivity of soot). In the case of coated and catalysed DPF, the following requirements have to be met:

- The number of ignition points between the soot, the oxygen and the catalyst (comparable to what is achieved with an FBC) must be increased. A foam-based filter design could be used for that purpose, but the disadvantage is that it lowers the global efficiency of the particulate filtration and may lead to the occurrence of smoke.
- There is a need for new advanced coating materials that can also support the soot combustion by providing more oxygen locally and having a higher thermal stability.
- The platinum loading needs to be optimised in order to successfully achieve regeneration while preventing the release of nitrogen oxides at specific engine operating points.
- The combustion process must be controlled in such a way as to rule out the phe-

### Table: Summary of the providers and the current state of the DPF technology with regeneration

<table>
<thead>
<tr>
<th>Provider</th>
<th>DPF with fuel-borne catalyst</th>
<th>coated DPF</th>
<th>Impregnated catalysed DPF</th>
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</thead>
<tbody>
<tr>
<td>Filter manufacturer</td>
<td>Ibiden, NGK Europe</td>
<td>Ibiden, NGK Europe</td>
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</tr>
<tr>
<td>Catalyst manufacturer</td>
<td>Octel, Rhodia</td>
<td>Engelhard, Umicore</td>
<td>Engelhard, Umicore</td>
</tr>
<tr>
<td>Car manufacturer</td>
<td>Fiat/Lancia/Alfa Romeo, Ford Motor, PSA Peugeot Citroën, Volkswagen</td>
<td>DC/Mercedes</td>
<td>Audi, BMW, GM/Opel, Renault/Nissan, Volkswagen</td>
</tr>
<tr>
<td>Start of production</td>
<td>PSA since 2000, others not before 2003/2004</td>
<td>Announced for the end of 2003</td>
<td>scheduled in 2004</td>
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