

Two-Stage Electro Thermal Supported HC (Hydro Carbon) Conversion

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Bettina Baier, Klaus Schrewe and Bernd Maurer
HJS Emission Technology GmbH & Co. KG

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ABSTRACT

Many diesel engines have to work at load profiles which, due to the low exhaust gas temperatures, necessitate active regeneration procedures to ensure continued engine operation and the reliability of the particulate filter. An active regeneration may be initiated via inner engine measures such as late injection. However, due to high maintenance interval and run time requirements for non-road applications the combustion of soot accumulated in the diesel particulate filter (DPF) often is realized via downstream processes. Known methods for this purpose are burner systems, systems based on downstream hydrocarbon injection (HCI) and subsequent hydrocarbon (HC) -conversion due to a catalyst or a combination of both.

This paper describes an autarkic system using two-stage electro-thermal supported hydrocarbon conversion. This system is capable to regenerate a DPF within the entire engine operating range and it is less complex than flame burner systems. Compared to the systems that work only with HC-dosing, the described system has the advantage that it is able to regenerate a DPF at low exhaust gas temperatures. It has the additional benefit that it can be used for thermal management of any exhaust aftertreatment system, ensuring early light off even under adverse engine operating conditions such as cold start and prolonged idling. The system is NO₂ - neutral and does not need an additional operating fluid like a fuel borne catalyst.

INTRODUCTION

For the active regeneration of a diesel particulate filter via an exothermic reaction on a diesel oxidation catalyst, hydrocarbons can be used. On the catalyst oxygen and hydrocarbon react into carbon oxides, water and heat [1].

Platinum and palladium are the mostly used catalytic active metals for this reaction. The ratio and amount of both metals and the composition of the washcoat have a determining influence on the light off temperature of the reaction, the aging behaviour and parallel reactions [2, 3]. For the described system the catalyst composition is designed for a high conversion rate of HC even at low temperatures with a outstanding long life stability and NO₂-neutrality [4, 5].

The quite low HC-content of the engine exhaust gas does not lead to a measureable exothermic reaction by means of the DOC. In order to achieve an adequate temperature increase for regeneration HC (diesel) has to be post injected. Spray quality, composition, amount and vaporization of the HC injected play an important role on the efficiency of the conversion [6]. A high spray quality and complete vaporization lead to high conversion efficiency. In order to achieve this, a high quality dosing system is used and the injected fuel is vaporized by hot exhaust gas or an electrical heating element.

The ability of regeneration at low exhaust gas temperatures is realized as well by the electrical heating element. It allows the exhaust gas to be heated up above the light off temperature of the catalyst. Unfortunately, the maximum power is limited by the vehicle's onboard electrical system. Therefore, the exhaust mass flow heated electrically has to be limited. Hence, the heating element should not be placed in the main flow, where the exhaust mass flow rate is high.

The given considerations are incorporated in the described system, which uses consequently a two-stage electro thermal supported HC conversion. Although the processes of fuel evaporation and catalytic two staged heat release controlled via exhaust flap are quite complex, the components and the

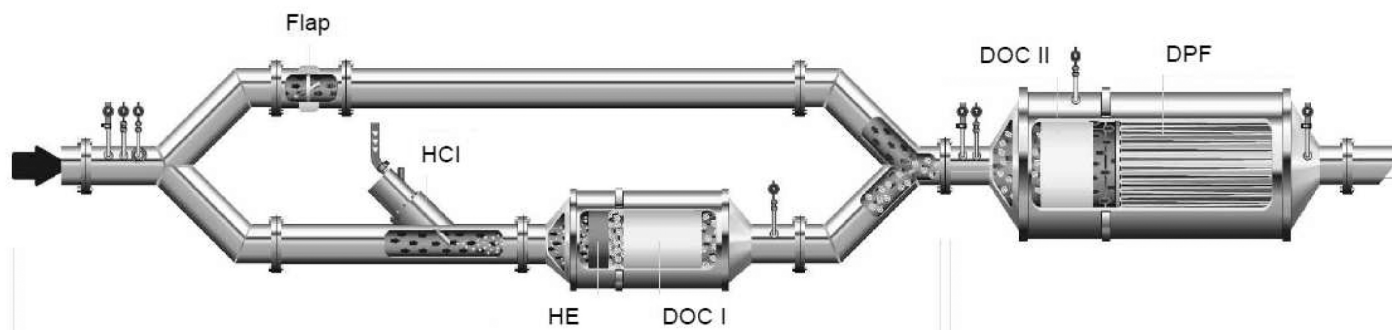


Figure 1. Catalytic Pre Burner.

setup of the System are quite simple and lead to a compact exhaust aftertreatment system.

SYSTEM SETUP AND REGENERATION PROCEDURE

A schematic drawing of the system setup is shown in [figure 1](#). A bypass branch is taken from the main exhaust gas mass flow downstream of the turbo charger for the two-stage, electro thermal supported HC conversion. The bypass line contains the HC injector, an electrical heater (HE) and a diesel oxidation catalyst (DOC I). A part of the injected fuel is converted over the bypass DOC (DOC I). As a result the bypass gas flow temperature is increased and still contains unburned HC. In front of the main DOC/DPF unit this rich gas is mixed with the cooler main exhaust stream. Due to the hot bypass gas it is ensured that the exhaust temperature of the whole exhaust stream in front of the main DOC (DOC II) is always in excess of the light off temperature of the main DOC. The main DOC then oxidizes the remaining hydrocarbons to further increase the temperature of the gas stream entering the DPF. In this way the regeneration of the DPF can be actuated under all engine operating conditions. If the gas temperature in the bypass line is below the light off temperature of the bypass DOC it is possible to increase the temperature of the bypass through a heating unit which is positioned in front of this DOC. Reliable function of the system is thus guaranteed even at very low exhaust temperatures. A throttle is installed in the main gas stream to regulate the flow through the bypass. The boundary conditions for a long term reliability of the bypass DOC are taken into account within the exhaust flap control strategy.

The main objective of the system is to achieve a sufficient exhaust temperature (about 600 °C) for active diesel particulate filter regeneration within the entire operating range of the engine. The software strategy differs for three cases: I.) Cold exhaust: Exhaust temperatures below 300 °C, II.) Warm exhaust: Temperatures between 300 °C and 600 °C and III.) Hot exhaust: Temperatures higher than 600 °C.

For cold exhaust, especially if the temperature is even below 200 °C a three-step system heat up is necessary (see [figure 2](#)). Therefore a certain exhaust gas mass flow rate is given at the bypass, controlled by the exhaust flap. This gas is heated up by the electrical heating element until the light off temperature of the bypass DOC is reached. For this purpose the required electrical power is calculated as a function of the mass flow rate and temperature downstream the bypass DOC. It is limited by the on-board power supply of the vehicle. Due to this limitation the introduced system can be used at 12 volt electrical systems for DPF regeneration at engines up to approx. 130 kW rated power. Then a map based amount of hydrocarbon is injected in front of the heating element and converted at the bypass DOC for a further heat up. The heated exhaust gas of the bypass is mixed with the main flow upstream the main DOC. The temperature at the bypass DOC is raised as less as possible in order to reduce aging [7]. Temperatures at this catalyst are normally below 600 °C, even during filter regeneration. When the light off temperature of the main DOC, which is significantly higher than that of the bypass DOC, is reached, the dosing amount is increased by a second map and the temperature downstream DOC II is controlled until the regeneration temperature is reached via conversion at the main DOC. Only one hydrocarbon injector is used for both catalysts. This is possible due to the high slip of hydrocarbon at DOC I.

The temperature control downstream the main DOC is realized by a PID- controller. This kind of control is not needed at the first dosing phase for the bypass DOC. For this DOC only a maximum temperature limit is implemented. If the temperature is higher than the limit, at first the mass flow rate is increased and in a second step the amount of hydrocarbon is reduced. A further limitation of the dosing amount is given by the actual oxygen content of the exhaust. This is necessary for a successful and short soot burning and consequently regeneration.

If the exhaust gas temperature is above 300 °C the electrical heater and the bypass DOC are not needed at all. For the heat up only the main DOC is used. This can be realized by switching off the electrical heater and an increased bypass

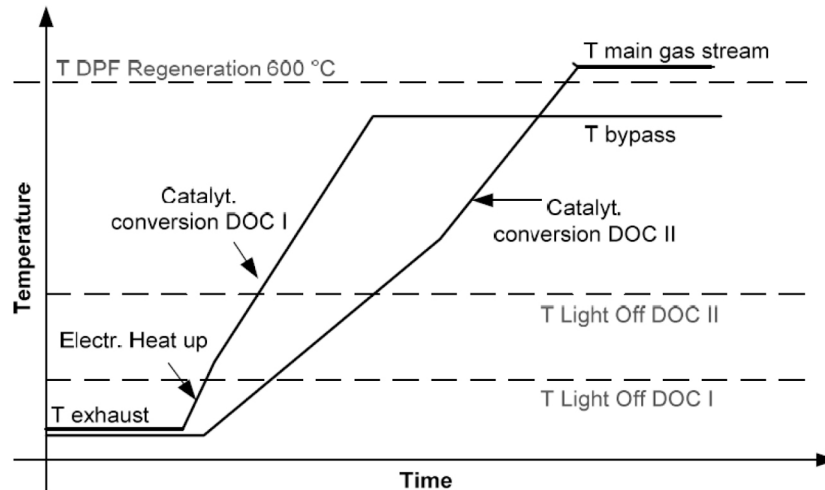


Figure 2. Regeneration procedure for cold exhaust.

mass flow rate in order to prevent a high conversion rate at the bypass DOC and hence overheating. But even in this case a certain conversion at the bypass DOC is helpful for the vaporization of the hydrocarbon. For hot exhaust ($T > 600$ °C) no heat up is needed at all.

As mentioned before the light off temperature of the main DOC is higher than that of the bypass DOC. A conversion of 50 % of all hydrocarbons is reached at a temperature of about 250 °C or higher for the main DOC, while it is about 200 °C for the bypass DOC. This is caused due to the main DOC's higher space velocity

$$SV = \frac{\dot{V}_{exhaust}}{V_{catalyst}}, \quad (1)$$

hence the ratio of the exhaust volume flow and the catalyst volume, and lower PGM loading. The space velocity is reciprocal to the residence time of the hydrocarbons in the DOC. So a high space velocity leads to a low residence time and hence a lower feasibility of reaction. A higher coating leads to a higher content of active materials leading to a higher feasibility. As an alternative to the actual system the coating thickness and catalyst volume of the main DOC could be increased, but this would result in higher packaging space and higher costs. Over that the system would not work at exhaust temperatures below 200 °C due to a limited electrical power. The volume ratio of main and bypass DOC is about 7:1, which depends on the application.

RESULTS

All tests were carried out at an engine test bench with a VW AJM 1.9 L engine which has a rated power of 85 kW. The positioning of the most important temperature sensors is shown in figure 3. The arrow 1 indicates a temperature sensor placed downstream the heating element (Tr_{ds_HE}). Here the

temperature lift due to electrical heating is measured and, if the heating element is switched off, the inlet bypass temperature is given. This temperature sensor is for testing purposes only. The second sensor (arrow 2) is mounted downstream the bypass DOC (Tr_{ds_DOCI}). It is used for the calculation of HC- dosing and temperature control. The temperature sensor at arrow 3 gives the mixture temperature upstream the main DOC (Tr_{us_DOCII}). The light off of the main DOC is checked at this position.

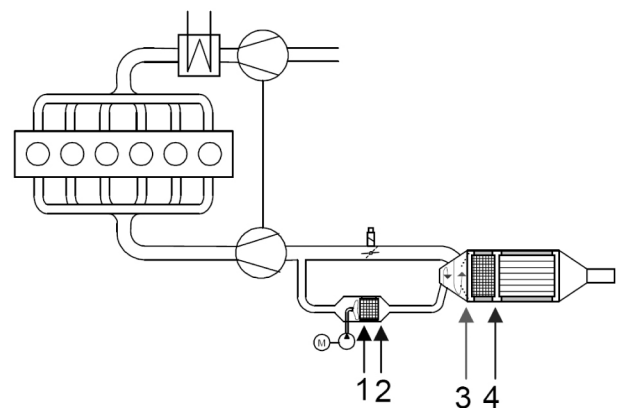


Figure 3. Temperature sensor positioning.

Downstream the main DOC (arrow 4) another temperature probe is placed in order to control the regeneration temperature upstream DPF (Tr_{ds_DOCII}). Additional sensors have been used for testing purposes in order to measure temperature, pressure and exhaust composition at different positions.

STATIONARY TESTS

The system behaviour for regeneration in a stationary engine operating point is shown in figure 4. The exhaust mass flow