The Emitec Approach to the Low NO_X frontier; Solutions for LCVs and HCVs

Dr. Manuel Presti, Jan Kramer, Bin Hu

Emitec Technologies GmbH, Lohmar, Germany

Abstract. Lowest greenhouse gas emissions along with new regulation worldwide such as US Omnibus, European VII/7 and Bharat Stage CEV/Trem V point the way forward for all future combustion engines applications to emit lowest NO_X levels at all working conditions.
Historically, in addition to specific heat modes and change of combustion process to address robust emission control, lowest CO^2 target has been "decoupled" from exhaust aftertreatment emission control.
Meanwhile, advanced powertrain architectures such as hybrid technology and applications with electrical storage / energy recovery capabilities-are opening up new system innovations for lowering CO^2 emissions combined with close coupled system architectures.
Thermal management technologies such as the proven Electrically Heated Catalyst (EHC) and the newly developed Electrically Heated Disc (EHD), which enable Exhaust Gas Aftertreatment System (EATS) to be heated with highly dynamic profiles, allow emissions regulation compliance with minimum CO^2 penalty over a wide working range.
This paper shows real-life examples of EHC-EHD systems with modular building blocks both for on-road and off-road applications, demonstrating the high level of integration with reduced impact on existing EATS architectures for global applications.

Keywords: Exhaust Gas After-Treatment, Thermal Management, CO^2 Emissions.

1 Introduction

While market studies about electric powertrain penetration continuously change at quite a dynamic pace, one point remains fairly constant: ICE powertrains will continue to serve commercial mobility for decades. Similarly, while the phase-in date for EUVII Standard as well as some details of the limit values are still under discussion, one point remains fairly constant here too: thermal management in the EATS (Exhaust After-Treatment System) will be of utmost importance in order to securely comply with the emission limits under various operating conditions.
Additionally, CO^2 targets represent a crucial part of the entire Powertrain-EATS chain, as engines with improved fuel efficiency tend to have lower exhaust temperatures, which further complicates catalyst operation in low load condition.

In many cases EU-VI HD-Engines have the highest tailpipe nitrogen oxides (NO_X) emissions in the first 10% of the engine-work [g/kWh], while Stage V non-road mobile machinery (NRMM) operate in some cases within extended idle mode. The tailpipe NO_X -concentration peaks at power levels below 10% or above 75% of rated power.
Several studies have been conducted on thermal management of heavy-duty exhaust systems to bring the catalyst temperature into the window of best performance.

This paper discusses with various application examples of Emitec Technologies products from the well-known Electrically Heated Catalyst (EHC) to the newly introduced Electrically Heated Disc (EHD) featuring an optimized integration into HD EAT architectures.

2 Requirements for Next Generation Emissions Control Systems

To meet future emissions legislations such as the CARB Omnibus regulation or the U.S. EPA 2027 legislation, Commercial Vehicles require more refined thermal management strategies to move the selective catalytic reduction catalyst into the most efficient temperature range while minimizing CO^2 impact under cold start conditions as well as in low load operation. Previous studies have investigated possible solutions for heavy-duty engine and aftertreatment systems, and one likely scenario is a Light-Off SCR (LO-SCR) system followed by a primary Aftertreatment System (ATS) which includes a diesel particulate filter (DPF) and main SCR catalysts.
The primary ATS ideally uses current and proven technologies to take advantage of the extensive experience of engine manufacturers with respect to aging, diagnostics, calibration, and application and to minimize the risks that are normally associated with the addition of new technology. The LO-SCR is placed as close as possible to the turbo outlet to minimize temperature losses. To introduce auxiliary heat into the ATS, an electrically heated catalyst or small electrical heater could be placed upstream of the LO-SCR. Alternatively, a large diameter electrically heated catalyst or exhaust heater could be placed upstream of the main SCR catalysts, see Figure 1.

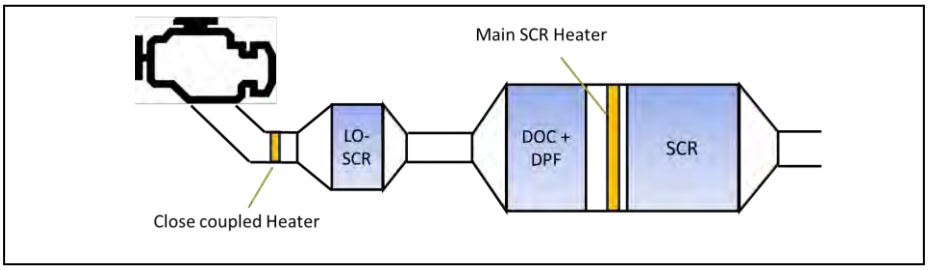

Fig. 1. Possible locations for an electrical heater in a future HD engine ATS

3 The EHC – History and future outlook

3.1 Design

The Electrically Heated Catalyst (EHC) is a well-known and field-proven component and has been in serial production for several decades in different applications from gasoline engines for passenger cars to diesel heavy duty engines for city busses. The flexible design of the EHC allows a wide range of dimensions in diameter and length as well as different voltage applications from 12 to 48V. The EHC is available for an electrical power heating power range from 1 to >10 kW.

The main EHC components are the heated disc, electrically isolated support pins to secure the heating disc to its surrounding components, the support catalyst matrix and electrical pins to connect the EHC to the power supply (Fig. 2).

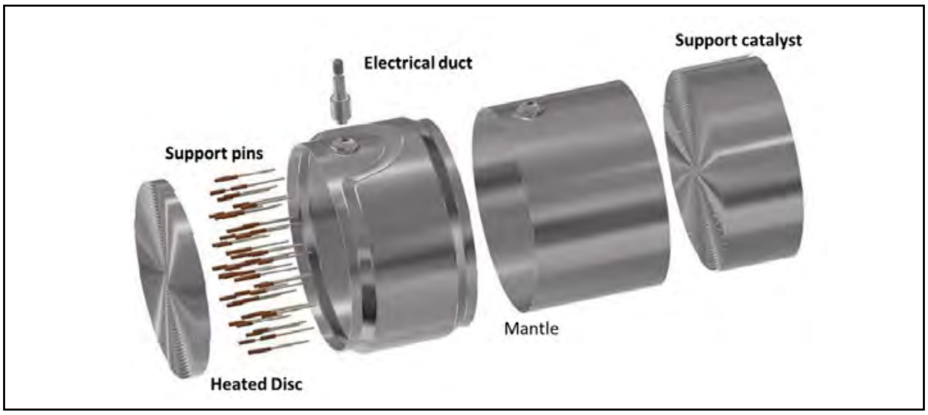

Fig. 2. Design of the electrical heated catalyst EMICAT®

Commercial Vehicles and probably NRMM are going to implement 48V net on board partly replacing the well-established 24V landscape. The higher voltage enables the adoption of high-power auxiliaries with viable cable diameters. The development of advanced EATS is becoming increasingly important as future emission limits are further reduced in certification cycles.

Especially during cold start and low load cycles (Commercial Vehicles), due to the limited conversion efficiency of catalytic converters at low temperatures, high tailpipe emissions would be expected.

In order to achieve the required high conversion rates for nitric oxides in the SCR system it is essential to operate the exhaust aftertreatment in the optimal temperature window. Load points with low exhaust gas temperatures and especially cold starts will require (active) heating, which can be realized by means of the Electrically Heated Catalyst (EHC). The beneficial result of the EHC, a quicker catalyst light-off, can be further enhanced by combining it, in some cases, with the additional fuel injection for advanced heat management.

With active exhaust heating it is realistic to operate the engine for a longer period of time in more fuel-efficient load points. Pure electrical heating might be sufficient for many low load points.

The Electrically Heated Catalyst (EHC) introduces "actively" heat energy at the "heating disc" into the exhaust system with high uniformity over the complete cross-section. The heating disc is attached to the insulated support pins and thus fixed to the support catalyst. The support catalyst itself is brazed to the outer mantle. This "assembly" (including the electrical connection of the heated disc) can be coated similarly to a conventional catalyst substrate with the appropriate washcoat formulation (such as for Gas Engine powered Commercial Vehicles) and provide the potential lowering precious metal content.

The possibility to have a very tight angle between the two electrical connectors allows the use of the EHC also in the very crowded engine compartments, typical of modern vehicles. Moreover, the recently introduced two-pieces electrical connector (Fig. 3) improves further the possibility to mount the EHC without or with minimal impact on the existing canning.

Fig. 3. Two-Pieces Electrical Connector

It is well known that in the Heavy Duty Vehicle market, there is a tendency to keep design changes to the EATS to a minimum, given the significant investment costs. The EHC can be seen as an extremely valid tool to optimize the thermal management of the entire EATS, by offering different installation positions as described in [1].

Fig. 4. Example of a possible integration of the EHC into an existing HD muffler (source Boysen, [2])

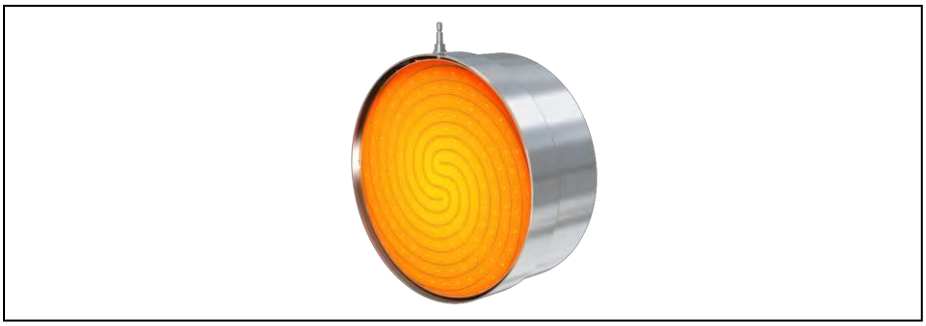

Fig. 5. Big scale EHC for HD applications with diameter of up to 13"

In most cases, the integration of an electrically heated catalyst into an existing exhaust system is relatively easy for exhaust system manufacturers. The EHC replaces an existing catalyst volume with almost identical installation space. Only the electrical feed and cable routing needs to be adapted.

Alternatively, it is possible to position an EHC as an additional component in front of the existing exhaust system (Fig. 6). This makes it easier to optimize fuel dosing directly on the EHC – especially for heat management during cold start.
Thus, already proven exhaust systems or components can be partially reused. This reduces development and testing effort as well as tool costs for new configurations.

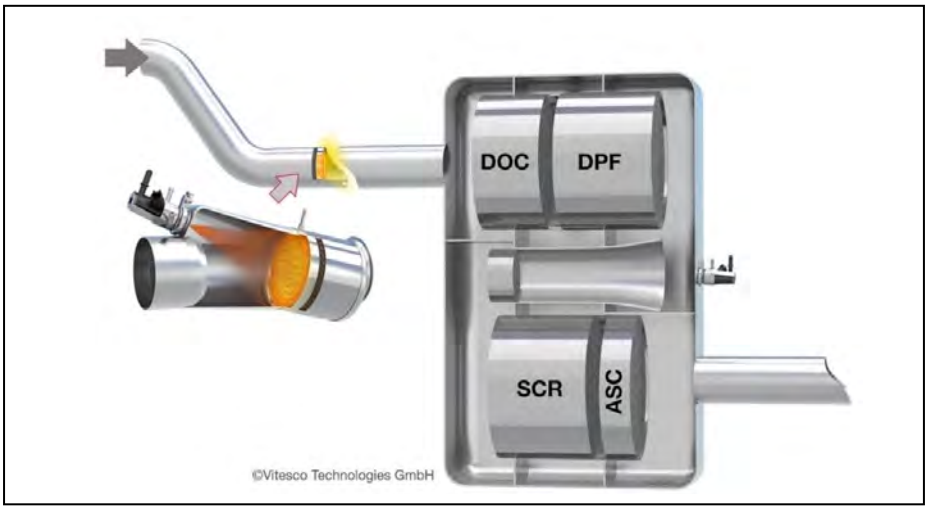

Fig. 6. Integration EHC in front of an existing muffler

3.2 Application examples and results

Multiple studies have investigated possible implementations of an EHC for HD engine aftertreatment systems in an attempt to find the best system configuration to meet future NO_X limits.

For instance, one study focussed on the implementation of a modular close coupled SCR system upstream of the proven main ATS. A 7kW heater was used to support quick warmup of the close coupled SCR catalyst. First engine dynamometer tests showed that this system was capable of achieving CARB 2027 limits even after exposure to sulfation and desulfation events (see Fig. 7). [4]

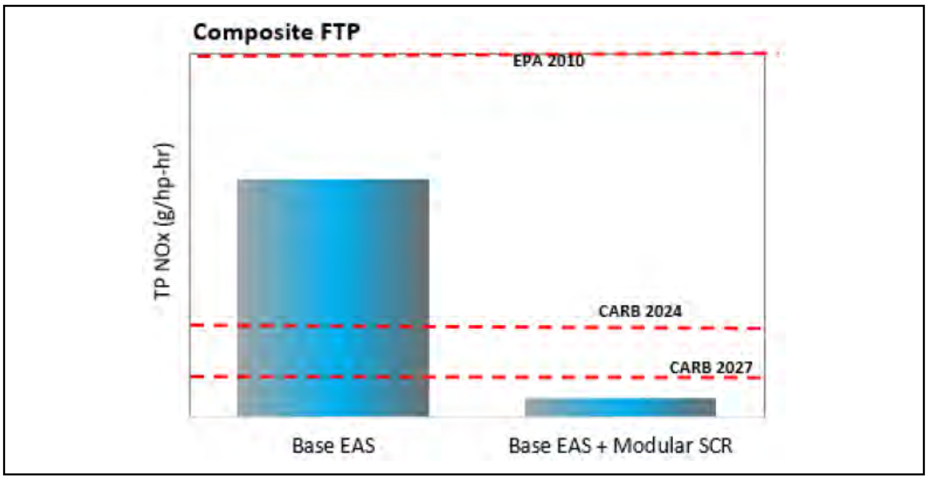

Fig. 7: Composite FTP results with modular cc SCR system and main ATS

The effectiveness of the electrical heating has been reported also in LD Commercial Vehicle application [8]. In this study the EATS has been upgraded by means of a pre-catalyst eDOC (electrically heated DOC). With the integration of the new ATS system, the optimization of the combustion and the use of an electrical heated DOC the NO_X emission is reduced by additional 88%. Also the tailpipe NO_X emissions during a NEDC are improved drastically.

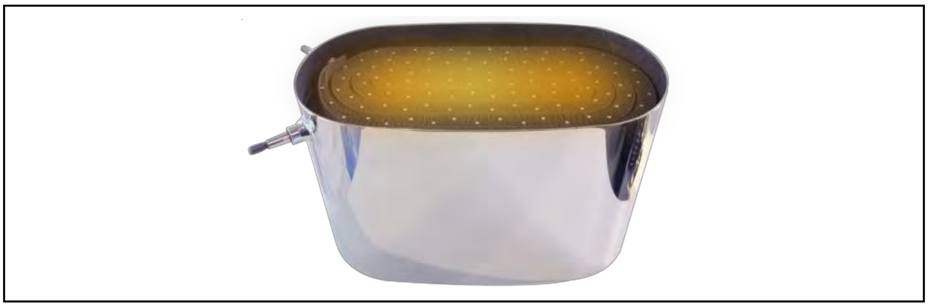

Fig. 8. Race track shape EHC for LD and HD applications

3.3 The Compact Catalytic Heater (CCH)

One additional approach to integrate the electrical heating has been described in [3]. The result of the joint development by Emitec Technologies GmbH and BIN Boysen Innovationszentrum Nagold GmbH & Co. KG consists of an advanced catalytical heater capable to provide a high amount of heat-energy (up to 50 kW) during cold start and low load operation utilizing only a limited electrical energy (max 4.3 kW).
The compact catalytical heater (CCH) can provide the heat-energy mostly independent from the engine operation point allowing the engine to be driven in a fuel-efficient (or hybrid supported) mode. The goal is to continue using already existing and well-established exhaust components (muffler) to reduce R&D efforts & tooling costs.

This is achieved by means of controllable mass flow management through a flap. Electrical heating power and flap position are adjusted to each other based on the operation condition. Injection of hydrocarbons takes place as a function of the exhaust gas mass flow, -temperature, surface temperature of the EHC and the desired temperature level. It is essential to obtain a high mixing quality of the injected HC onto the EHC within one universal module/component. It is important to have an evenly distributed ratio between heat flow through the EHC, exhaust gas (oxygen) and the concentration of the fluid being metered in. This can be achieved by a uniform local "lambda".
Bypassing the EHC (the first DOC) at high exhaust temperatures also reduces aging effects on it.

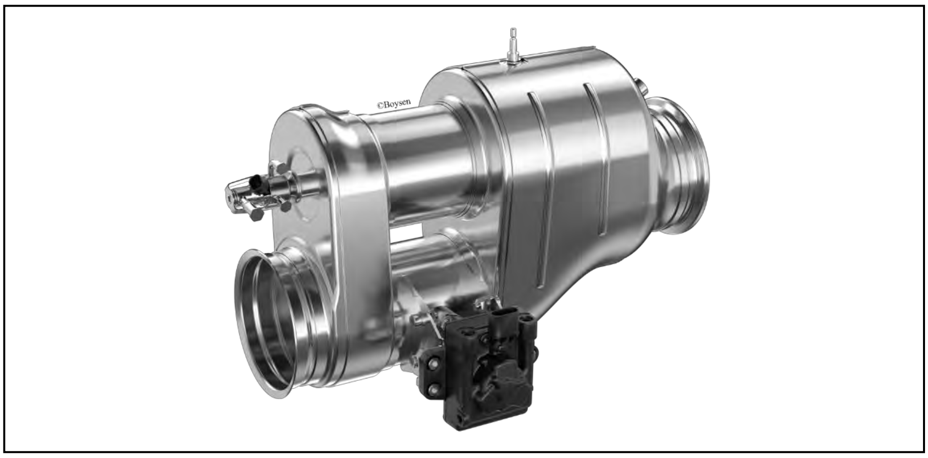

Fig. 9. Design of the Compact Catalytical Heater (CCH) – Source: Boysen

With the compact design of the arrangement, installation space, (thermal) mass, and surface area can all be reduced to achieve a fast light-off characteristic of the first DOC included in CCH and the second (main) DOC in the muffler box. A large cross-section of the components helps to keep the pressure drop of this add on device low.
Fig. 10 shows the temperature profile of an FTP cold start, upstream and downstream the SCR catalysts and the urea dosing. With active CCH-heating (max. 4.3 kW

electrical power) the urea dosing can be released earlier in the cycle, resulting in an improved NO_X conversion.

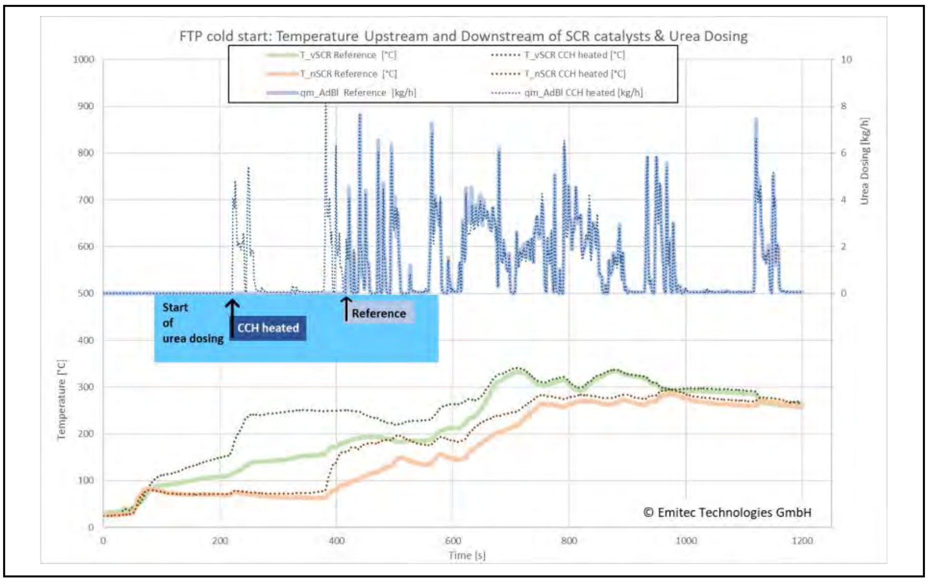

Fig. 10. Temperature up- and down-stream of the SCR catalysts & urea dosing in FTP cold start (© Emitec Technologies GmbH)

4 The EHD – Thermal management integration made easy

4.1 Design

The Electrically Heated Disc (EHD) is a newly developed product, based on the same field proven components as the EHC. Based on extensive voice-of-customer interviews, a new shorter heater was developed to allow flexible installation at different locations in the exhaust aftertreatment system. To achieve this, the support catalyst matrix was removed, and replaced with a stainless-steel frame, also called the support structure.
All other key components have been carried over from the EHC in order to design a robust heater while keeping the number of new components to an absolute minimum.

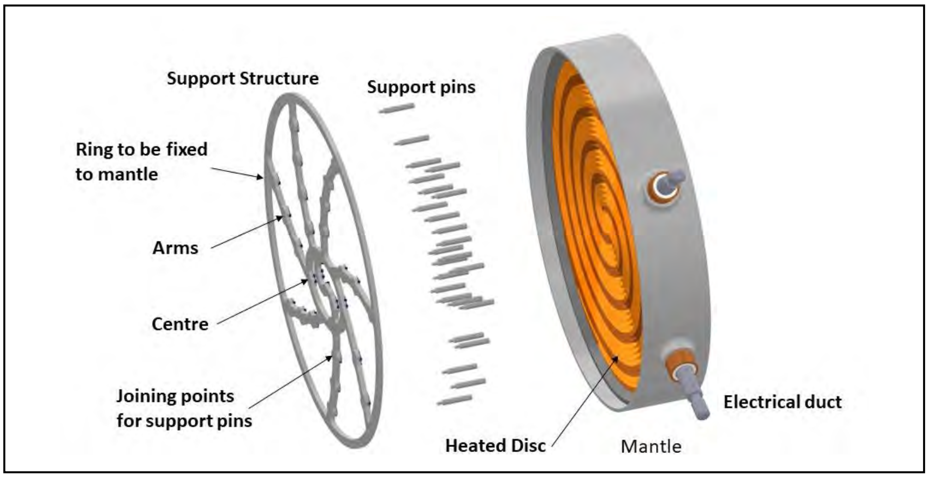

Fig. 11. Design of the Electrically Heated Disc

The support structure has the following significant design characteristics:

- Outer Ring to fix the structure to the mantle
- Regular Curved Arms which allow the necessary rigidity and flexibility to compensate for mechanical and thermal loads
- To connect the heated disc to the support structure via isolated support pins

Mechanical and thermal Simulations show that the design does not exceed-the allowable limits in terms of stress and movement.
A simulation was conducted to calculate the stress inside the heater unit under simultaneous mechanical and thermal loads. The mechanical loads were based on a PSD-Profile which is used also for the KLT (key life test) to validate the mechanical robustness. This Profile was developed over many years of mass production experience in both the LD and HD market sectors and is based on measurements and experiences from different application and covers real life loads.

A key challenge was to develop a robust support structure that provides the lowest possible flow disturbance and allows best possible flow distribution across the heater.
The new heater design was validated on a flow bench under different flow rates with ideal inlet flow distribution. The result shows a good flow distribution measured directly behind the heater with very minimal impact of the support structure.

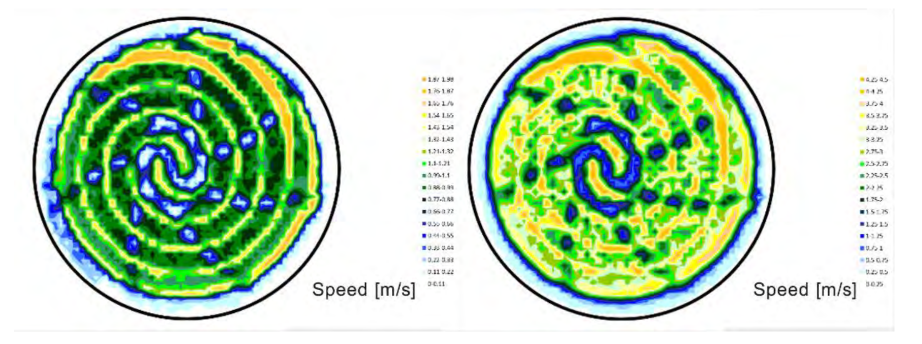

Fig. 12. Flow distribution EHD at 60 kg/h (left) and 170 kg/h (right) mass flow

Another very important design goal was rapid heat up and uniform heat distribution over the heater. Infrared camera tests were conducted to evaluate the maximum electrical power that can be applied to the heater under low flow conditions, such as engine idling. The results with the newly developed EHD are shown below.
While these first results indicate a good power capability at low flow, opportunities for further improvement have been identified. An updated heating disc shape is currently being designed and tested.
-The back pressure was tested on a cold flow bench under uniform inlet flow conditions. The EHD with its low-profile support structure showed very low flow restriction.

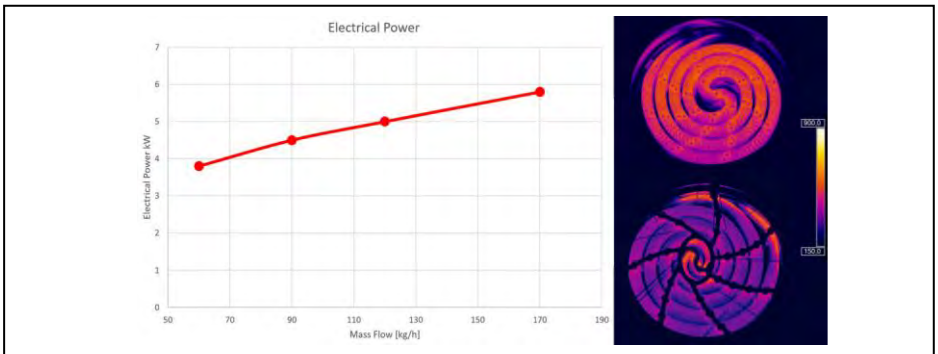

Fig. 13. Electrical power map from 60 to 170 kg/h mass flow

A simulation was carried out to investigate the heat up benefits of either position for an exhaust heater for a particular low load engine start. For this study, a small 6 inch (150 mm) diameter heater was compared with a typical large 13 inch diameter heater. The results in Figure 14 show the benefit with a smaller diameter heater - the gas outlet temperature downstream of the heater is increased quicker than with the large diameter heater. For the given conditions used in this simulation, a SCR dosing release as early as 30 seconds after engine start could be considered possible, if a LO-SCR was to be installed directly downstream of the small heater.

This simulation result is in line with other studies-that have carefully weighed the emissions benefits and the impact on fuel penalty or CO^2 emissions, and who concluded that the addition of a small electrical heater in close coupled position, upstream of the LO-SCR, yields better results [6][7].

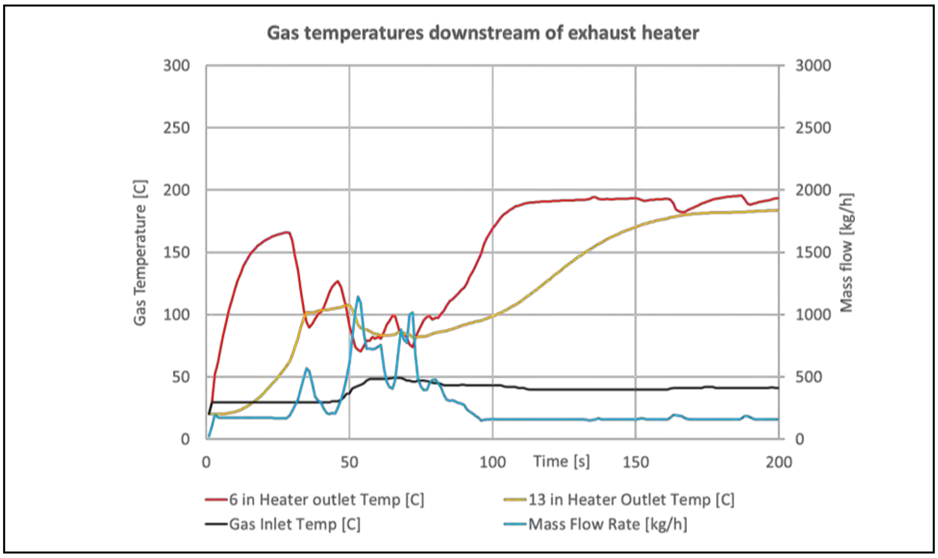

Fig. 14. Heat-up efficiency of a Small vs. Large diameter EHD

In a typical automotive application, the exhaust heater shall be powered only when the engine is running and exhaust gas flow is present, to prevent overheating. A constant supply of exhaust gas flow is required to transfer the heat generated in the heater matrix, away from the heater surface and into the exhaust gas. Due to its extremely low thermal mass, the EHD exhibits a very rapid heat up when powered without gas flow or even under low flow conditions.

A first functional test was developed to demonstrate the functionality and confirm the fast heat up behavior of this heater. The EHD was placed on concrete ground and powered by a large battery pack with 48V. Power to the heater was disconnected manually as soon as the matrix was visibly glowing. Figure 15 shows the test result - as expected, the EHD exhibited a rapid heat up and was found to be glowing red hot within 4 seconds of the power being switched off.

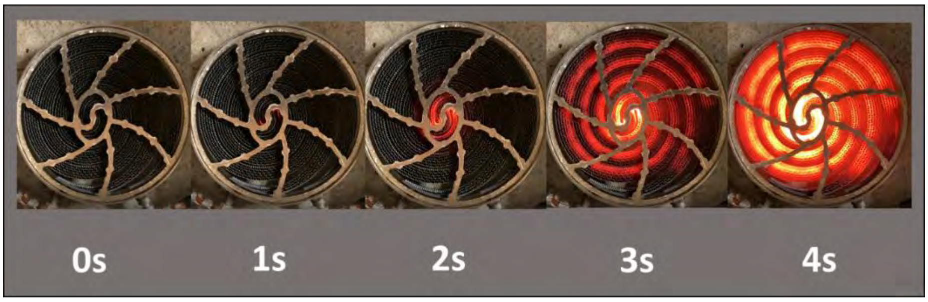

Fig. 15. Heat-up test of a 6 inch EHD

In addition to its impressive heating capabilities and minimum flow restriction, the EHD excels also from a packaging/installation point of view, given its very small size. In Fig. 16 a schematic example of the tight EHD integration in an existing DOC package is illustrated.

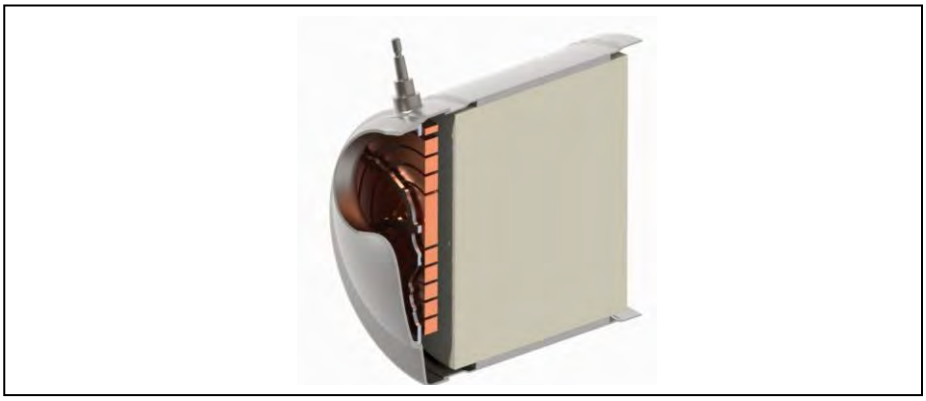

Fig. 16. Installation of an EHD in front of an existing DOC package

5 Conclusions

Despite the continuing turmoil in finalization of the EU7 emissions legislation package, development of advanced EATS is still ongoing with particular focus on real life usage profiles including low load and cold start.
-This paper presents different technical approaches, from the well-known and established EHC, to the newly introduced EHD.
Results are presented in both experimental and simulated form, with a focus on the impressive packaging capabilities of the EHD into existing EATS architectures.
Furthermore, the smart combination of limited electrical heating with additional fuel injection, as shown in the CCH jointly developed with BIN Boysen Innovationszentrum Nagold GmbH, has proven to be a very powerful tool to achieve significant cold start benefits with a very limited impact on the CO^2 footprint of the application.

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