Evaluating performance of uncoated GPF in real world driving using experimental results and CFD modelling

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- The present work focuses on an experimental durability study on road under real word driving conditions. Two sets of experiments were carried out. The first study analyzed a Gasoline Particulate Filter (GPF) (2.4 liter, diameter 5.2" round) installed in underfloor (UF) position driven for up to 200,000 km. A 1.6 liter Gasoline Direct Injection (GDI) engine was used for the investigation. Ash accumulation versus mileage and soot loading were of interest. A parallel investigation up to 160,000 km with same engine (2 identical vehicles on road on a "specific average" cycle) and GPF installed in closed coupled (CC) position was also carried out. Both UF and CC GPF are NGK 360 cpsi 5 mil wall thickness.
- As a route to develop a robust 3-D Computational Fluid Dynamics (CFD) model to gather information on the fluid flow and pressure loss characteristics of GPF, a baseline model is introduced in this work. The computational domain refers to full length individual 3-D channels and focuses on two quarters of an inlet and two quarters of an outlet channels with the aim of reducing complexity of the problem and its computational cost. Although this baseline version does not include yet the soot and ash loading models, it can be used to understand real physical problems and gather insight on velocity and pressure distributions inside filter and its channels

Experimental Results

Two identical vehicles (OPEL Zafira Tourer) with a 1.6 litre turbo GDI engine 125 kW/170 hp (16 XHT) were equipped with NGK GPF filter in underfloor (UF) and close-coupled (CC) position respectively for a durability study on road.

Specification	
Displacement	1,598cm^3
Valves/cylinder	4 & 4
Air Charging system	Turbo charger
Max power hp	170hp/6000rpm
Max power Nm	280Nm/1650-320rpm with overboost
Bore/Stroke	79 mm/81.5 mm
Compression ratio	10.5:1

Table 1. Specification OPEL 1.6 SIDI Turbo Engine

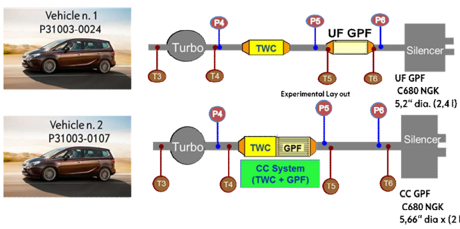

Fig. 1. Vehicle set-up with CC and UF GPF

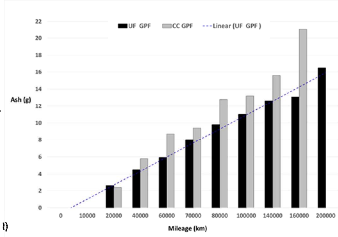

Fig. 2. Ash accumulated versus mileage up to 200,000 km for the UF and the CC GPF case.

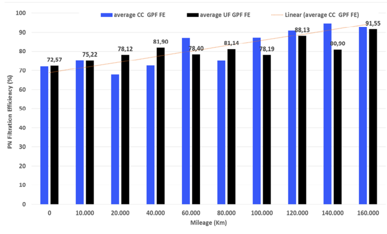

Fig. 3. PN GPF filtration efficiency (FE) versus mileage over the "average customer cycle" on road for UF & CC GPF

- GPF Weighing and CT scan were performed every 20,000 km to identify ash distribution in the GPF. Ash was more easily visible after 160,000 km when using CT scan. PN measurements were conducted over the WLTP cycle previous preconditioning every 20,000 km. The UF GPF Post-Analysis (PA) shows a homogeneous ash distribution along the inlet channel, albeit it is not clear how the ash layer deposition occurs overtime. The ash did not penetrate into the filter walls. Cold flow bench BP measurement for the UF GPF vehicle study at 200,000 km showed an increase in back pressure of ~ 19% due to ash accumulation of ~ 17 g total.

CFD modelling

- The clean CC GPF behavior (no soot load) was investigated using the 3D CFD model to gather an insight on its fluid flow and pressure loss characteristics, and results were compared with experimental data (ECU BP measurements) and 1D prediction using NGK model.
- ANSYS FLUENT software was used in the investigation. The GPF domain consists of two channel types, inlet and outlet, and a filter wall. Individual 3-D GPF channels 108.22mm long, with front plugs and back plugs were modeled to obtain flow information such as velocity and static pressure distributions inside inlet and outlet channels, as well as across the porous filter wall. Two quarters of the channels were modelled taking advantage of the system symmetry in order to reduce computational time. A cordierite GPF 360 Cell Per Square Inch (CPSI) with 5 millionth of an inch wall thickness filter was simulated. The filter wall was treated as a fluid domain and the flow resistance was based on the mean pore diameter within the wall. The mass flowrate and temperature at inlet were set to match the experimental value representative of the GPF conditions. A mesh with uniform edge sizing was used.
- A total of 145,111 nodes and 135,000 elements were used in the computational domain with a typical cell size of 0.000127m^3. A sensitivity study allowed mesh independent solutions to be achieved. Despite the 3-D nature of the computational domain, computational cost was not excessive and one simulation would run for 30 minutes on an Intel Core i5-6500 Processor.

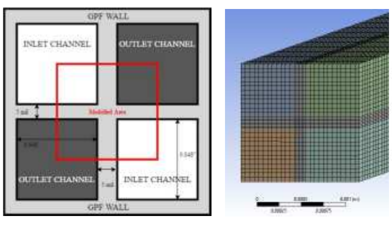

Fig. 4. GPF section geometry and mesh

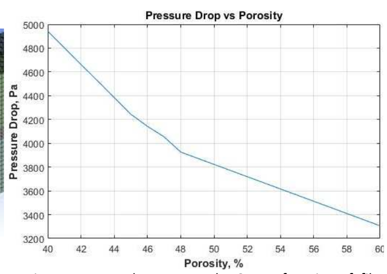

Fig. 5. Pressure drop across the GPF as function of filter porosity

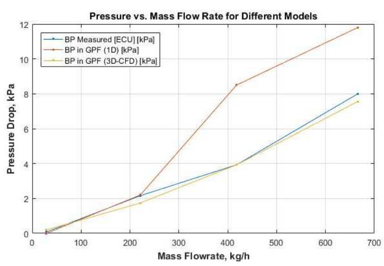

Fig. 6. Comparison 1D model vs 3D CFD model and ECU BP values for a clean CC GPF case (no soot no ash).

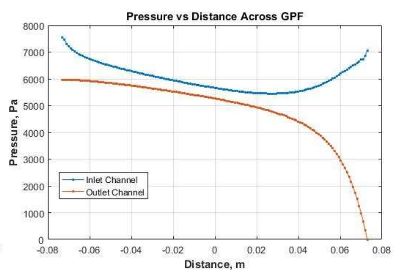

Fig. 7. Pressure distribution along GPF simulated channels, measured at centerlines.

Conclusions

- A Zafira Tourer, equipped with same NGK GPF in UF and CC position, showed respectively ~ 13 g ash after 160,000 km for the UF GPF case and ~ 21 g for the CC GPF at the same mileage.
- PN raw emissions where similar and stable for the vehicles. PN GPF filtration efficiency (FE) increased with mileage and was dependent on the "driving mode"; FE increased from ~ 70% at 0 km to ~ 92% after 160,000 km with both UF and CC GPF
- Post-analysis of the UF GPF after 200,000 km vehicle operation on road over the "average customer cycle" showed a homogeneous ash distribution along the inlet channel on the whole length (inlet to outlet). The ash did not penetrate into the filter walls; ash plugs was also found and estimated to be ~40% of the total ash accumulated in the GPF. The ash plugs in front of the outlet plugs showed a half-elliptical distribution.
- 3-D CFD modelling of the GPF channels were used to predict pressure drop across the GPF filter, achieving considerable smaller errors compared to 1-D models. Comparison of the 3D CFD model and 1D model for the clean GPF case showed good agreement at lower exhaust flow rates but as expected better accuracy of the CFD model at higher flow rates.
- Clean (no soot load) pressure drop across the filter decreased with a decrease in filter wall porosity. Filter wall porosities smaller than 48% led to a steeper increase in pressure drop compared to wall porosities greater than 48%.
- 3-D CFD simulations showed that inlet channel static pressure was relatively flat compared to pressure along outlet channel. The downstream half of the outlet channel saw a rapid decrease in pressure, forcing the majority of the filtration to occur toward the end of the channel. Further CFD modelling and analysis is ongoing.

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