Latest Particulate Filter Technology to Reduce Particle Emissions from Gasoline Engines

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Introduction

Nowadays the key drivers for automobile manufacturers are fuel efficient powertrains with high power output and low emissions to comply with the stringent Euro 6 limits and prepare for long term CO_2 targets in 2020. From 2017 the entire vehicle fleet must not emit more than 120g CO_2/km and from 2020 this limit is cut to 95g CO_2/km (REGULATION (EC) No 443/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009). A further reduction to 68-78g CO_2/km by 2025 is under discussion at the time of writing but not yet decided (Reuters 24.04.2013, *EU politicians back compromise on car emission targets*, http://www.reuters.com/article/2013/04/24/us-u-cars-idUSBRE93N12G20130424).

The way forward seems to be direct fuel injection for gasoline engines, similarly to diesel, usually combined with charged aspiration in order to increase combustion efficiency by improved mixture formation and higher compression ratios compared to conventional Port Fuel Injection (PFI). One side effect of Gasoline Direct Injection (GDI) is the increased particle formation due to wall wetting.

Since the release of Euro 6 on 29 May 2012 as part of COMMISSION REGULATION (EU) No 459/2012 the limitation of Particle Number (PN) emission from Positive Ignition (PI) engines with direct fuel injection (DI) was introduced. Starting in 2014 (Euro 6b) the PN limit for Gasoline Direct Injection will be 6E12 km^{-1} but later from 2017 (Euro 6c) it will drop down one order of magnitude to 6E11 km^{-1}, which is the same level for Compression Ignition (CI) diesel engines.

There is additional complexity for developers due to the new certification drive cycle called Worldwide Harmonized Light-duty Test Procedure (WLTP) as well as the demand for real driving emissions (RDE) to be conducted by a portable emission measurement system (PEMS).

While certain engine internal measures are already available to meet current PN limits during NEDC such as advanced injector design or dual injection systems consisting of GDI and MPI it may be necessary or more feasible to focus on additional emission control devices for aftertreatment in order to comply with future legislation under all engine operating conditions and ambient temperatures (off-cycle).

To reduce Particulate Matter (PM) from a diesel engine, the Diesel Particulate Filter (DPF) based on ceramic wall flow filter technology is a well-established emission control device for many years. The working principle of the Cordierite Gasoline Particulate Filter (GPF) is based on that of a DPF and therefore it could serve as an effective emission control device to reduce particle emissions from a gasoline engine as well.

The working principle of the Cordierite GPF and its superior choice of material have been explained in the previous years at ETH Conference on Combustion Generated Nanoparticles. A conventional particulate filter with cell structure 12mil 300cpsi can achieve outstanding filtration performance but has certain impact on backpressure. This paper focuses on the optimization of the filter's cell structure for minimum backpressure and low CO_2 but sustain high filtration efficiency under all engine operating conditions. There are two main concepts for GPF application, with and without catalyst integration. Here only the non-catalyzed GPF is presented.

Test Conditions

For these evaluations two different Cordierite GPF materials with 48% and 42% porosity were selected. The comparison was between 6mil and 5mil web thickness both having 220cpsi. All evaluations were done using non-catalyzed GPFs. The size of the samples was 118.4x127 mm round which corresponds to 4.66x5.0 inch.
The Pressure Drop was measured on a cold flow bench at 25°C increasing the flow rate from 0 to 10 Nm³/min.
The change of material porosity was necessary to keep the required material strength high enough for the canning process while increasing the filter's Open Frontal Area (OFA) for lower backpressure.

The test vehicles were 1.4L and 1.8L GTDI stoichiometric with Euro 5 certification released in 2009 and 2012 respectively. The installation position of the GPF was in underfloor approx. 150 cm downstream of the Three Way Catalyst (TWC).

The selected test cycles were NEDC, WLTC and in order to provide higher accelerations and velocities the Common Artemis Driving Cycle up to 160 km/h (CADC160). Each test followed the procedure of the Particle Measurement Program (PMP) i.e. running a conditioning cycle followed by a soaking period and a cold start measurement. Before each test the GPF was completely cleaned from any soot inside an electric furnace.

Results

NGK has developed a new robust material with 42% porosity that allows reducing the web thickness to 5 mil with a cell density of 220 cpsi offering a higher Hydraulic Diameter (HD) of the channels for increased Open Frontal Area (OFA) and low backpressure. At the same time the isostatic strength is high enough to allow conventional canning methods to be applied for installation inside the vehicle's exhaust system. Comparing this 2nd generation GPF with the 1st generation 48% porosity and 6 mil 220 cpsi it is possible to gain 11-24% backpressure reduction during wide open throttle acceleration with a stoichiometric Euro 5 GTDI vehicle.

The 2nd generation GPF was evaluated with regards to filtration efficiency under various drive cycles such as the conventional NEDC certification cycle, the newly developed WLTC and the CADC with peak velocity 160 km/h. The latter of which was considered in order to bridge the gap between the chassis dynamometer and representative dynamic driving conditions with high speeds as allowed and realized by many drivers on German motorways.

While there are readily vehicles available that undercut the Euro 6 PN limit for GDI during NEDC this may not be the case for other drive cycles and different engine operation points. One must keep in mind that RDE is being heavily discussed at the time of writing to be imposed in future as an additional step of vehicle certification by means of PEMS. Not yet fully defined such RDE may incorporate sloped roads and low ambient temperatures. Such driving conditions are different from the controlled environment on a chassis dynamometer and thereby more demanding to comply with.

NGK's 2nd generation GPF shows stable and reliable particle filtration from the very beginning of its operation to achieve even today the future limitation of Euro 6c. Even under sub-zero temperatures such as -7°C which is currently only mandatory for HC and CO emissions a GPF can compensate for the vast increase of engine out PN emissions and keep the tailpipe PN emission well below the limit of 6E11 km^{-1}. The impact on fuel consumption and CO_2 from the 2nd generation GPF is hardly measureable during NEDC, WLTC and CADC up to 160 km/h.

Conclusion

- ✓ The new Cell Structure 5mil 220cpsi has an additional backpressure advantage compared to 6mil 220cpsi during dynamic drive cycles.
- ✓ The trade-off between pressure drop and material strength must be considered.
- ✓ Significant increase of engine out Particle Number emission for off-cycle conditions was observed without GPF.
- ✓ GPF reduces Particle Number emission significantly and reliably under transient driving conditions and different ambient temperatures.
- ✓ Applying a GPF shows already now a Particle Number emission reduction below the future Euro 6c Particle Number limit of 6E11 km^{-1} valid from 2017.

Outlook

- ✓ Results from a catalyzed GPF will be available within 2013.
- ✓ Further vehicle tests under real driving conditions via a Portable Emission Measurement System (PEMS) are under consideration.

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17th ETH-Conference on Combustion Generated Nanoparticles, Zurich, 23rd – 26th June, 2013

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Definition

Background: Engine Technology
Nowadays the key drivers for automobile manufacturers are fuel efficient powertrains with high power output and low emissions to comply with the stringent Euro 6 limits and prepare for long term CO_2 targets in 2020.

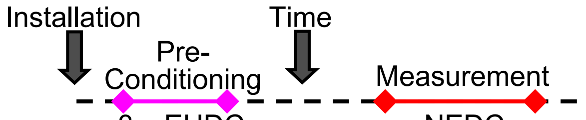
Background: Regulation
COMMISSION REGULATION (EU) No 459/2012 of 29 May 2012 describes the emission limits for Euro 6 for Gasoline Direct Injection engines. From 2014 the PN limit is 6.0E12 km^{-1} and from 2017 it drops further down to 6.0E11 km^{-1}.

Objective of this study:
The Gasoline Particulate Filter (GPF) made of Cordierite is based on the well established ceramic Diesel Particulate Filter technology. Its working principle and initial results were presented at ETH during previous years. There are two main concepts for this technology:

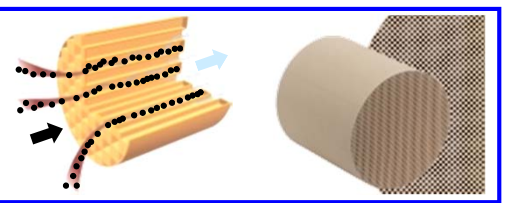
1. Non-catalyzed GPF
2. Catalyzed GPF with integrated TWC function

This work mainly focuses on the concept of a non-catalyzed filter to show its feasibility with respect to efficiency and durability. Thus we evaluate latest GPF materials on state of the art Euro 5 vehicles. The test conditions include NEDC, WLTC and CADC160.

Measurement System:
Following PMP Protocol

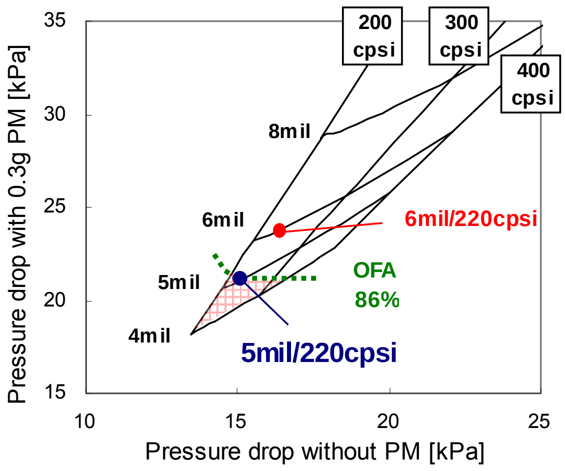


GPF is regenerated by Electrical Furnace before installation and before each test.



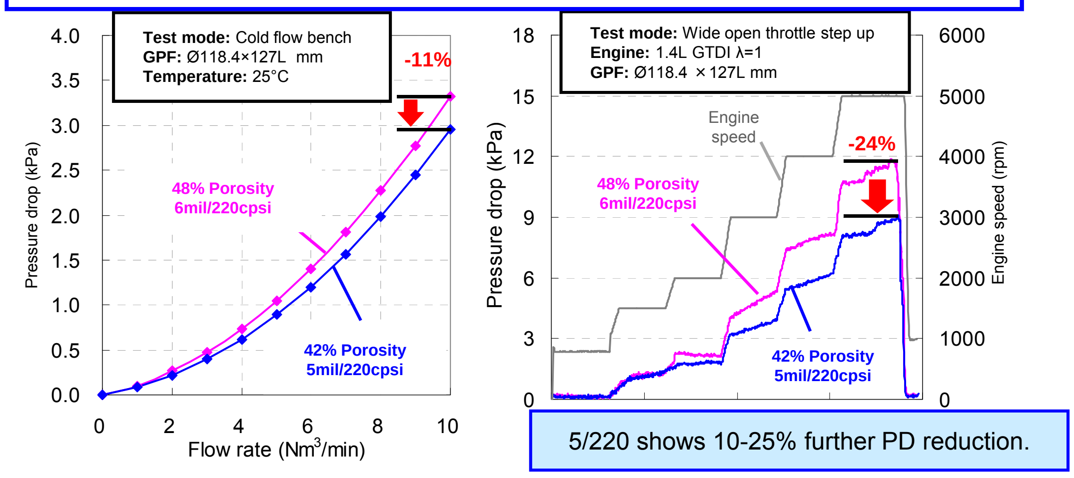
Results of Concept 1

Pressure Drop Considerations for optimized Cell Structure



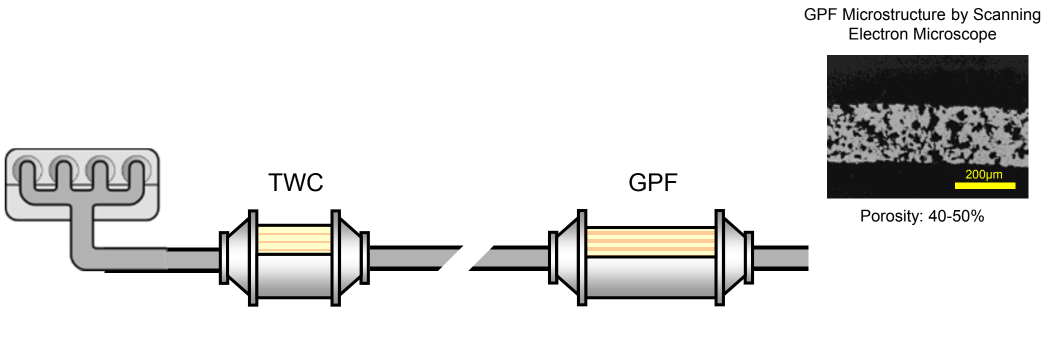
Further material optimization from 6/220 as balanced cell structure for Pressure Drop and Strength to 5/220 for even more Pressure Drop reduction.

Pressure Drop Reduction by optimized Cell Structure



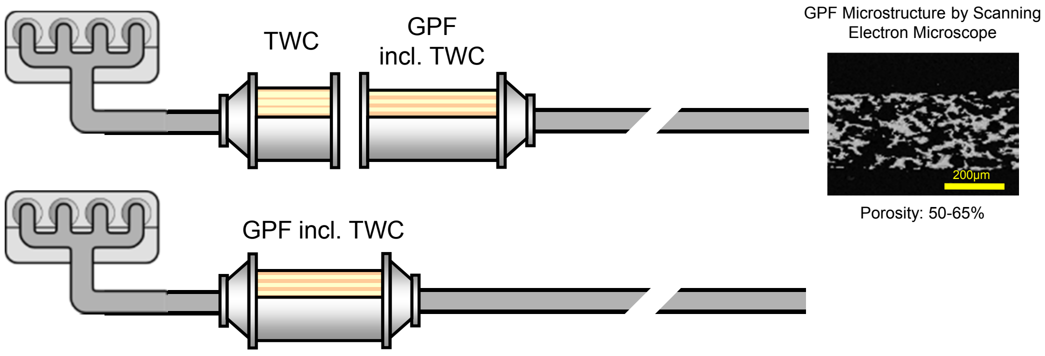
5/220 shows 10-25% further PD reduction.

1. Add-on type GPF for none/low Catalyst Applications



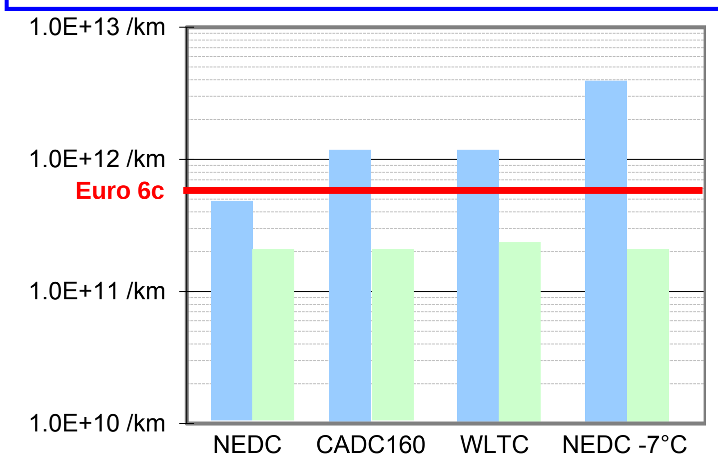
Cell Structures: 5mil 220cpsi; 6mil 220cpsi; 5mil 360cpsi

2. Replace type GPF for medium/high Catalyst Applications



Cell Structures: 10mil 300cpsi; 12mil 200cpsi; 12mil 300cpsi

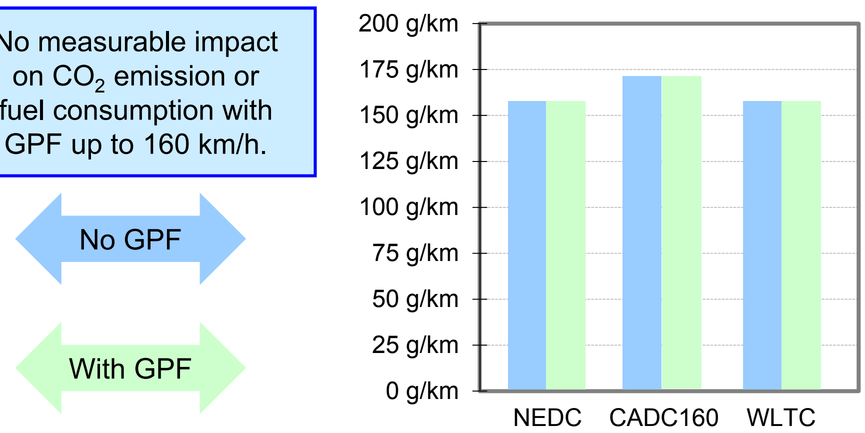
Particle Number Emissions for different Test Cycles



- Euro 5 vehicles 1.4L and 1.8L GTDI λ=1 available to meet 6.0E11 during NEDC but not WLTC
- Significant engine out PN increase for off-cycle emissions
- GPF shows a general PN emission reduction below Euro 6c limit.

CO_2 Emissions during different Test Cycles

No measurable impact on CO_2 emission or fuel consumption with GPF up to 160 km/h.



Conclusion

Pressure Drop Optimization

- ✓ The new Cell Structure 5mil/220cpsi has additional Pressure Drop advantage compared to 6mil/220cpsi during dynamic drive cycles.
- ✓ Tradeoff between Pressure Drop and Strength need to be considered.

Particle Number Emissions

- ✓ GPF reduce Particle Number significantly and reliable under transient conditions and different ambient temperatures.

Impact of GPF on CO_2 and Fuel

- ✓ No measurable impact on CO_2 and fuel consumption during dynamic drive cycles up to 160 km/h.

Outlook

- ✓ Results from Concept 2 (catalyzed GPF) available within 2013.
- ✓ On-line evaluation of real driving emission by portable emission measurement system is under consideration.

GPF: Gasoline Particulate Filter

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