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New Generation Gasoline Particulate Filters for Uncatalyzed Applications and Lowest Particulate Emissions

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Outline

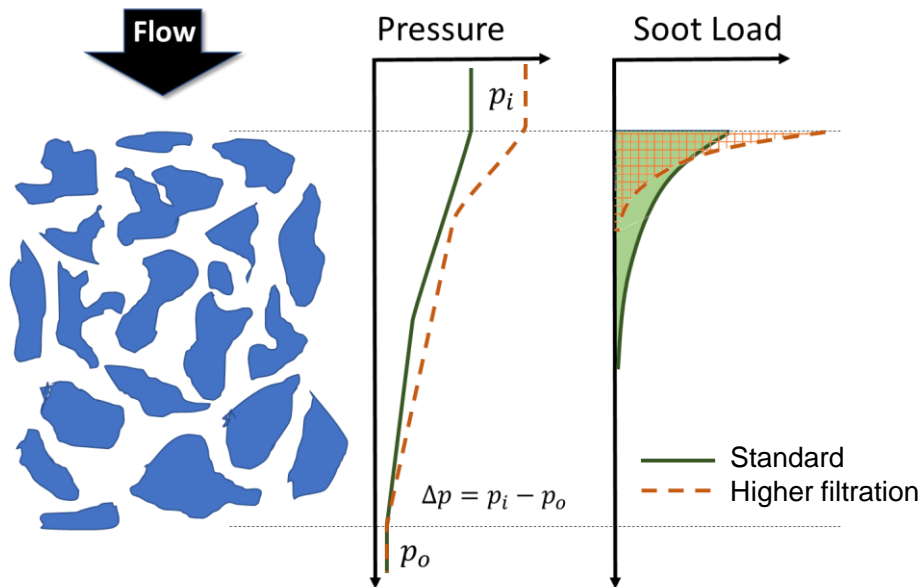
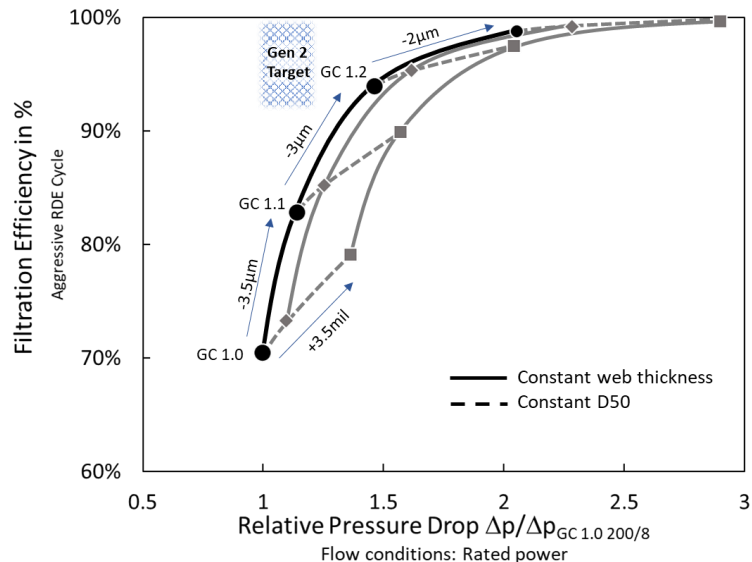
- Introduction
- Product Concept - Next Generation Filter Technology GC 2.0 APT
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Introduction

- First generation gasoline particulate filters have been introduced successfully with millions of vehicles on the road today certified to EU6d and CN6
 - Enabling a significant reduction in particle number emissions
- Upcoming future regulations like EU7 maintain the focus on further reductions in particulate number emissions
 - Inclusion of smaller particles in the particle count, likely down to 10nm vs. 23nm today
 - Potentially reduced limit values of particles per kilometer
 - Tightened RDE regulations with shortened urban RDE trip length, reduced compliance factors (CF), reduced extended range factors, lower temperature, ...
- Objective of the next generation gasoline particulate filters is to address these enhanced requirements and enable very high filtration efficiency at a pressure drop close to the best Gen 1 technologies

Product Concept - Background

- The design of first generation GPF technologies was based on statistically uniform microstructures and the traditional approach of optimizing the porosity, median pore size and cell geometry
 - Best results – GC family: 200cps, 8.5mil web thickness, 55% porosity and range of D50 to enable different filtration efficiency
- Permeability and filtration are coupled to the same physical properties (D_{50} , t_w , CPSI, ε) limiting this approach
- Gen 2 approach is to break this trade-off



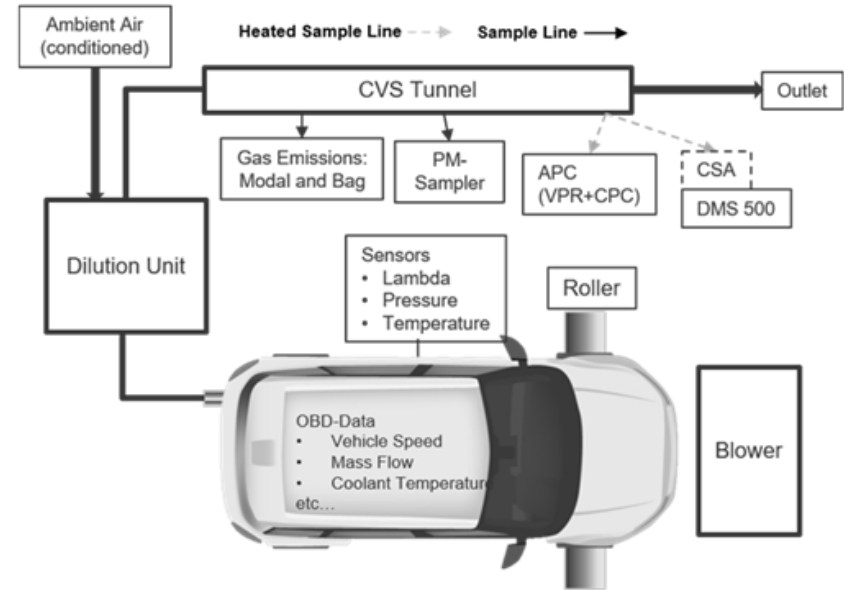
Product Concept - Next Generation Filter Technology GC 2.0 APT

- The technology approach chosen for the next generation of filter technologies (GC 2.0 APT) is based on a decoupling of permeability and filtration
- The material design strategy is based on a hierarchical wall microstructure
 - Modification of the surface porosity using the proprietary APT® technology
 - Modified microstructure at pore entries of the surface porosity enabling very high localized collector efficiency
 - Remaining microstructure optimized for permeability
 - Porosity, cell design and thermo-mechanical robustness maintained and equivalent to Gen 1 technologies

Filter Technology	GC 1.0	GC 1.1	GC 2.0 APT
Generation	1	1	2
Cell Design	200/8	200/8	200/8
Porosity	~55%	~55%	~55%
Pore Size	Base	Base – 3.5µm	Hierarchical

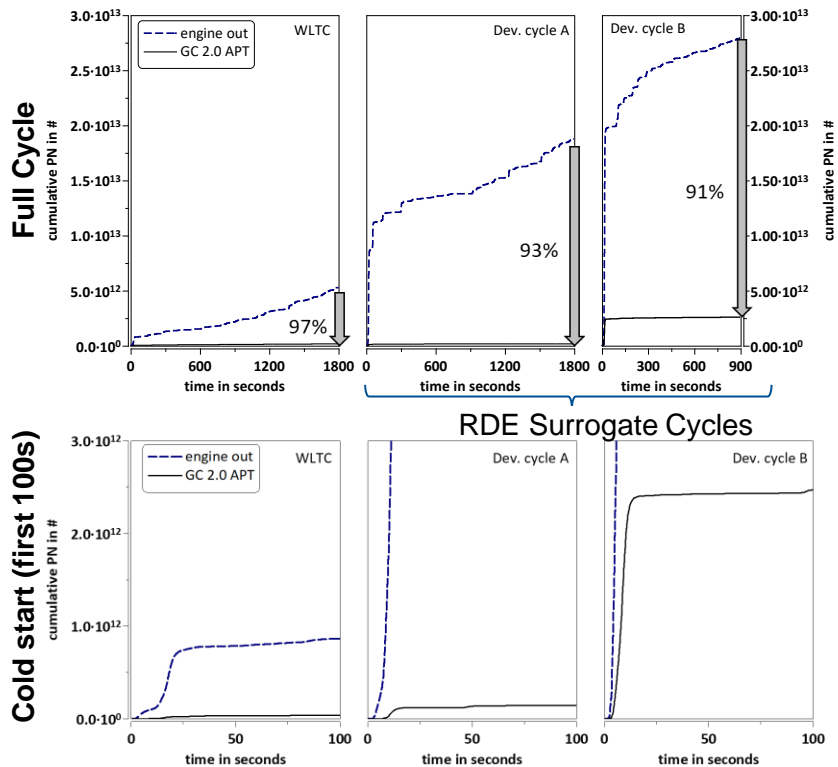
Results from Vehicle Emission Testing – Typical Test Setup

- Extensive vehicle emission testing has been performed with filters of the next generation GC 2.0 APT technology
 - With vehicles certified to EU6bm Eu6dTEMP and CN5
 - WLTC and different RDE surrogate cycles
 - 23°C and commercial market fuel
 - Standard lube oil
- Testing was done with fresh filters
 - Directly „out of the box“, installed at the chassis dyno or low mileage (<200km)
 - Installation of the GPF using prototype exhaust systems
 - For EU6d TEMP vehicles the OEM filter was replaced
 - GPF installation was close-coupled and underfloor
- PMP compliant particle measurement
 - Some additional measurements using a DMS500

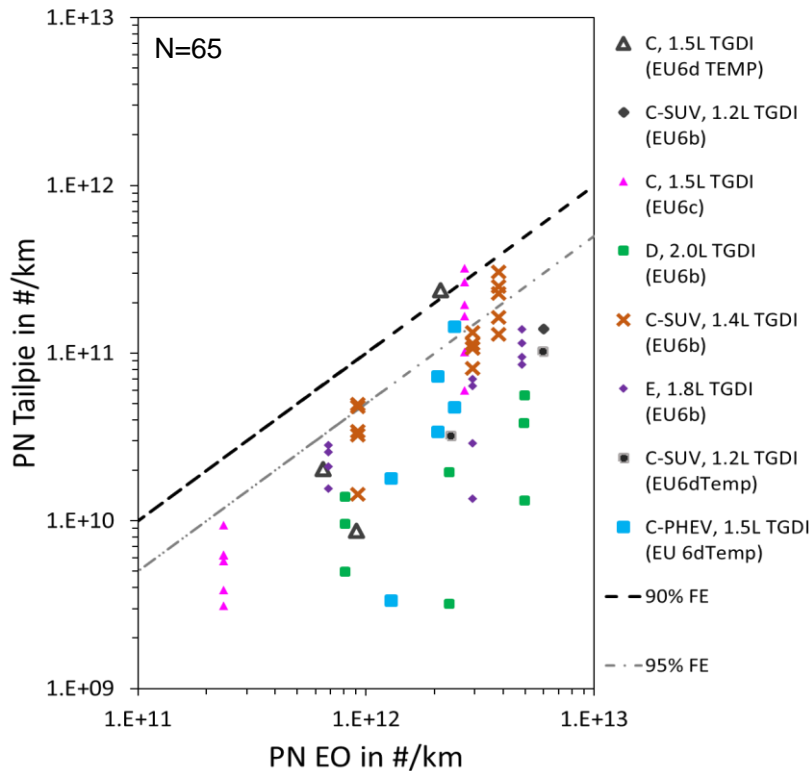


Results from Vehicle Emission Testing – PN Emissions

Example: C-Segment, EU6d TEMP

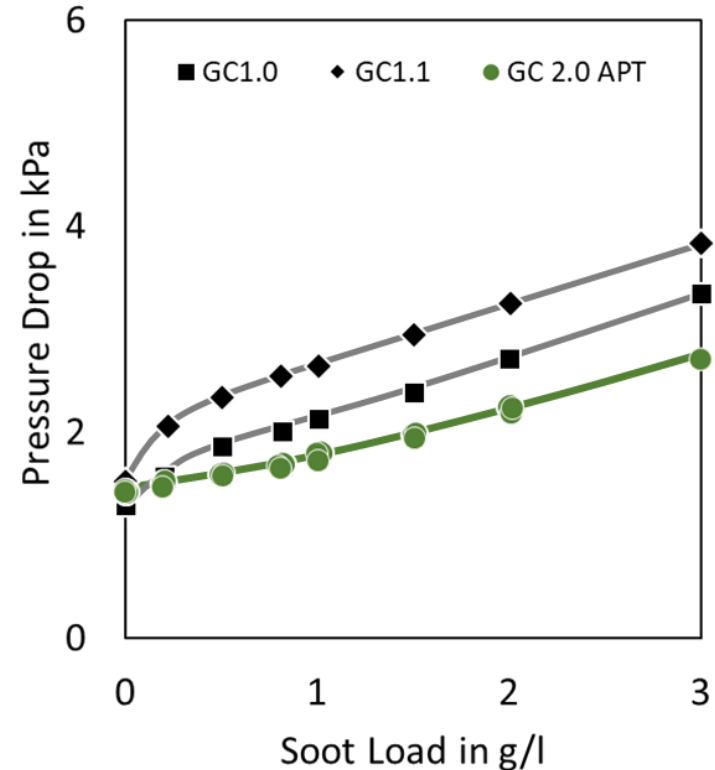


Emission Tests – different cycles, vehicles



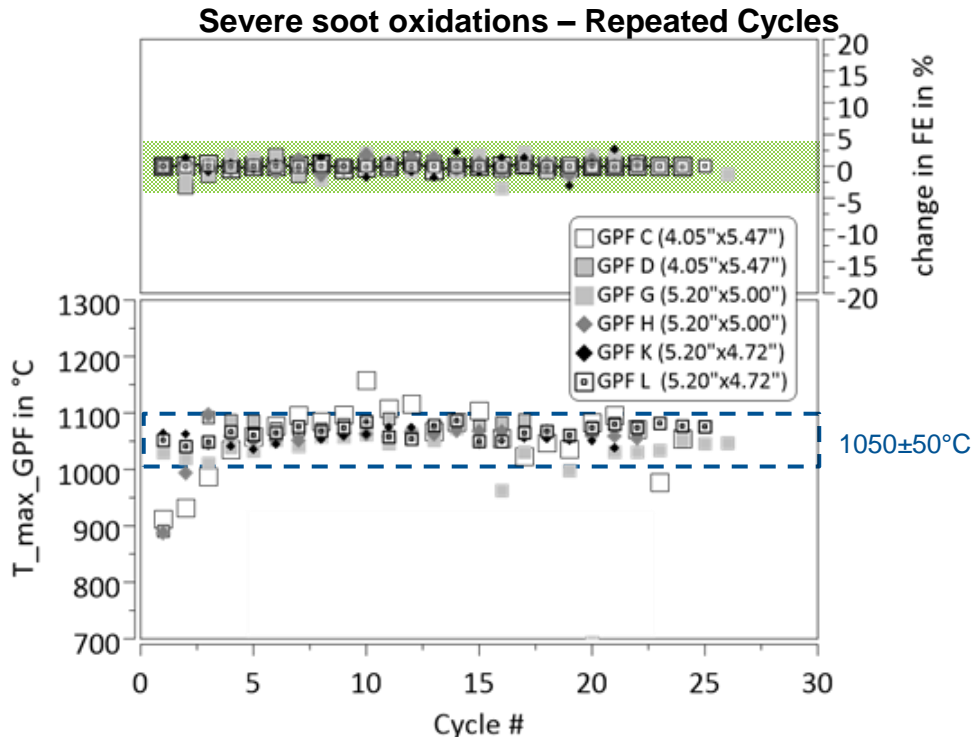
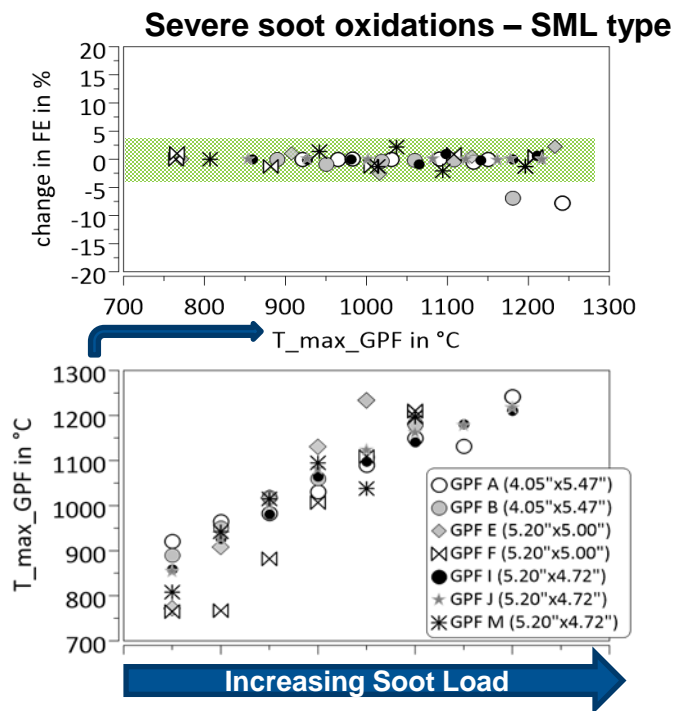
Pressure Drop

- Soot loaded pressure drop measured in the laboratory
 - Fresh filters
 - Soot load with Printex U
 - Gen 1 technologies as reference
 - GC 1.0 and GC 1.1
 - The pressure drop of the Gen 2 technology
 - Is comparable to the Gen 1 technologies in the clean state
 - Can be lower compared to Gen 1 technologies in the soot loaded state
- *Very high PN filtration efficiency of GC 2.0 APT is achieved at no or low Δp penalty*



Durability and Thermomechanical Robustness – Engine Bench Testing

- The new Gen 2 filters been tested on engine bench for robustness to severe soot oxidation events analogous to the Gen 1 filter technologies



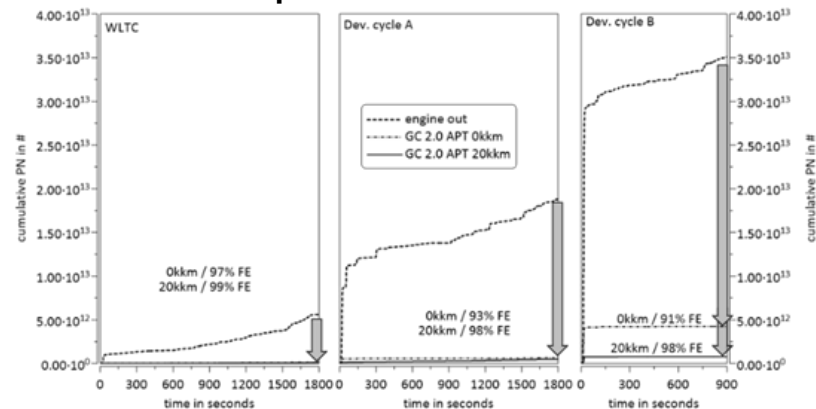
Durability and Thermomechanical Robustness – Vehicle Durability

- On road vehicle durability was evaluated using several test vehicles
 - Test approach analogous to Gen 1
- Fleet of company cars in normal user drive pattern
 - On some vehicles 2 filter have been tested sequentially

Example: underfloor retrofit



Example: Emission test results

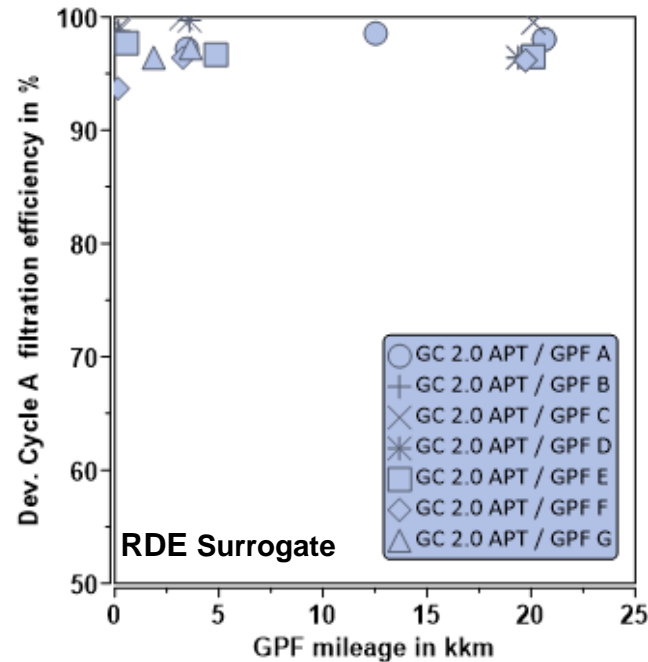
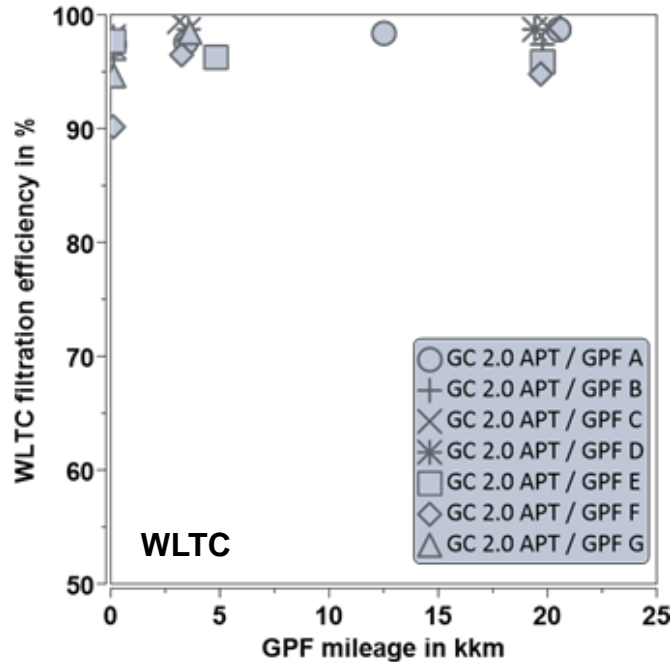


Vehicle Segment, Engine	Exhaust Layout	Commute Distance home to office	Avg. driving velocity
C-SUV, 1.4l TGDl	TWC + U/F TWC + GPF	3.3km	21km/h
D, 2.0l TGDl	TWC + U/F GPF	3.6km	24km/h
D, 1.8l TGDl	TWC + U/F GPF	14km	56km/h
D, 2.0l TGDl	TWC + U/F GPF	22km	57km/h
C, 1.5l TGDl	TWC + U/F TWC + GPF	96km	98km/h

- Emission tests fresh, 3000km and 20,000km

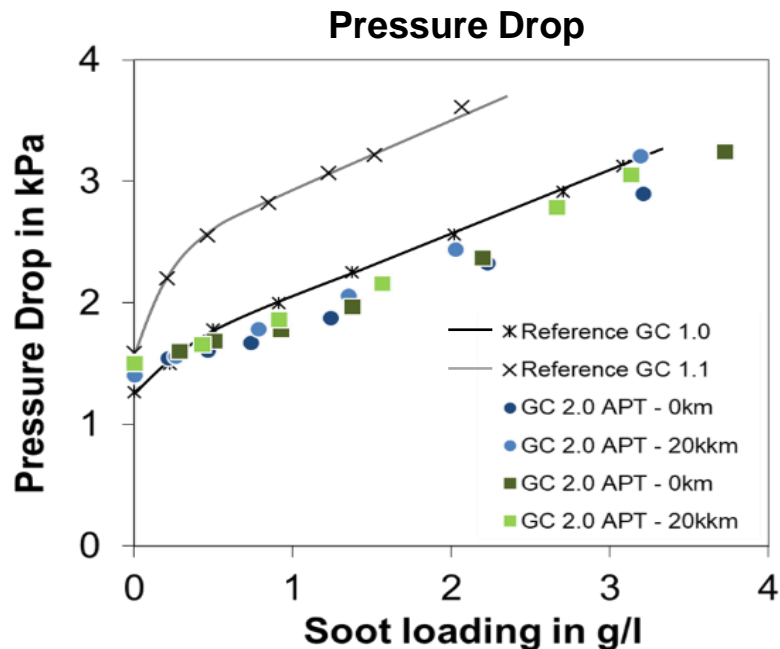
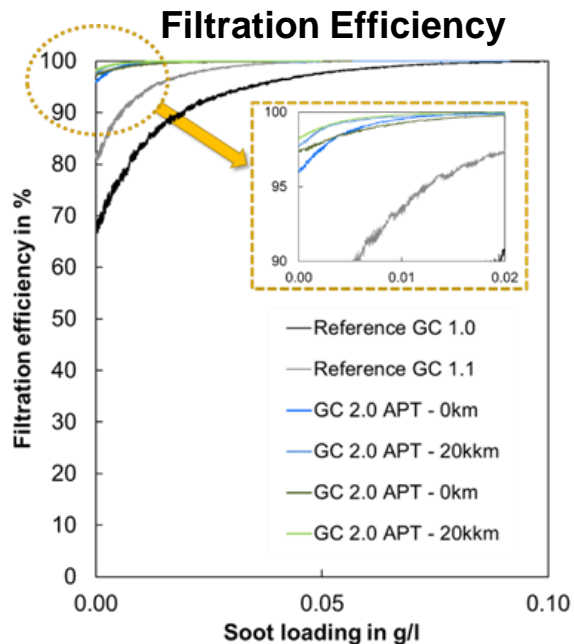
Durability and Thermomechanical Robustness – Vehicle Durability (cont.)

- Filtration efficiency results from PN Emission test results after different mileage



Durability and Thermomechanical Robustness - Vehicle Durability (cont.)

- The filters from the durability program have also been tested in the laboratory before and after the mileage accumulation



Conclusions

- Gasoline particulate filters are a new standard component used in all or most gasoline engines certified to advanced particulate emission regulations
- The new generation of gasoline particulate filters introduced in this presentation, GC 2.0 APT, significantly extends the portfolio of filters with respect to the filtration efficiencies achievable
- The new hierarchical microstructure design allows to achieve the significantly increased filtration efficiency at very low to no penalty in pressure drop vs. the best Gen 1 technologies
- The PN filtration performance has been demonstrated using a large number of different vehicles and test cycles, and over extended on-road mileage
- The robustness of the new filter generation has been demonstrated to be equivalent to Gen 1 filters

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