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Next Generation Gasoline Particulate Filters

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Information Security

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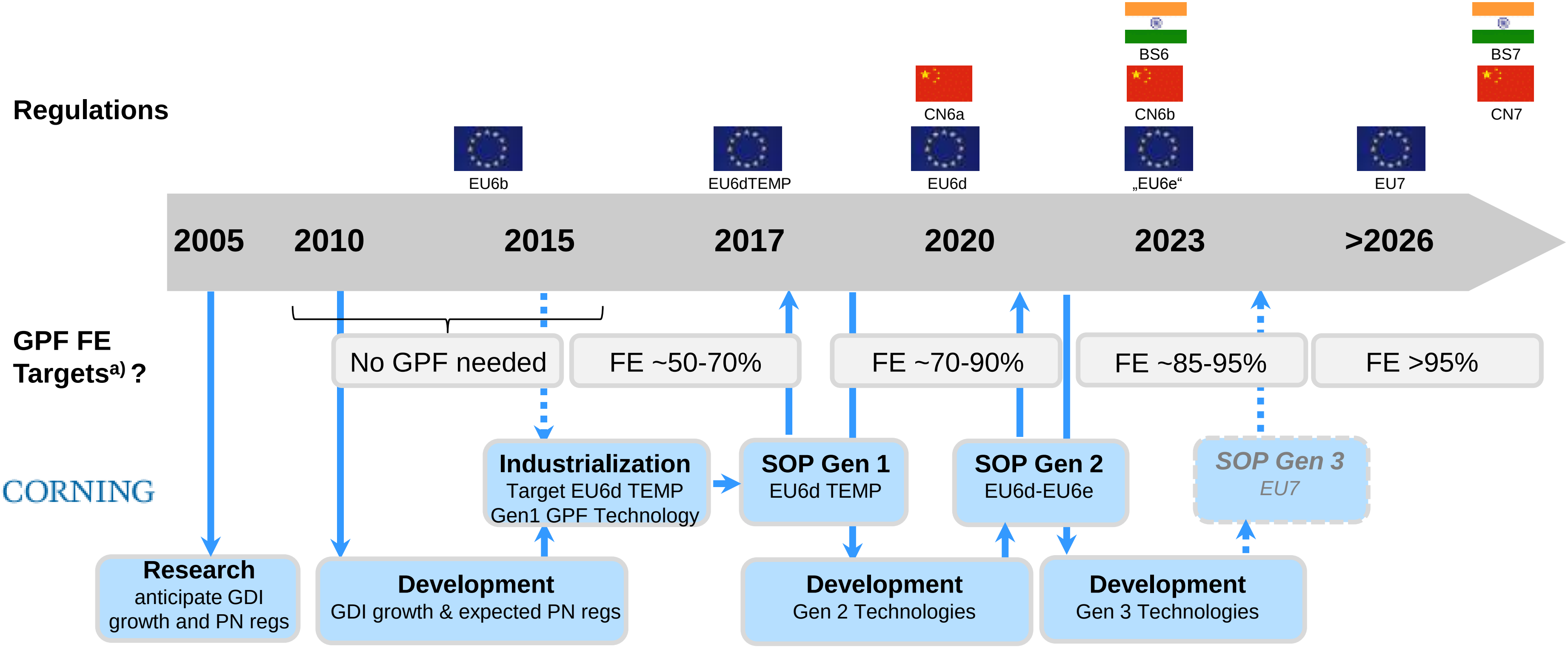
Outline

- Looking back – evolution of needs and targets
- Evolution of Gasoline Particulate Filter Technologies
- Application Experience

Looking back – evolution of needs and targets for GPFs

A dynamic evolution in filtration targets from 0% to close to 100% in a few years



[a] Numbers not meant to be exact, but rather describing the general trend and evolution

Evolution of Gasoline Particulate Filter Technologies

The beginnings

When we started, we had experience from DPF

- DPF are designed for high soot loads (20-30g)
- Usually large volume (2.5 – 4 liter) to manage the maximum volumetric soot load to 6-10g/l
- Low pressure drop at high soot load, especially in combination with ash
- Robustness to severe thermal oxidations (DTI) and heat release at high soot loads (high chemical energy storage)
- High filtration efficiency, but with significant aid from the collected soot

Gasoline applications were unknown, but …

- Soot load was assumed to be much lower due to the lower engine out emissions (assumed 0g/l to <3g/l)
- Soot oxidation was unclear, generally high temperatures but normally no O_2 (λ=1) or NO_2 (TWC)
- Worst case soot oxidation different from diesel DTI, which is hard to control, as change to λ=1 generally possible
- Ash mass was expected to be similar (similar SAPS oil)
- Filtration targets were moderate initially, but had to be delivered without much help from soot

- Typical DPF designs have
  - Material with **high volumetric heat capacity** (**AT, SiC**) to absorb heat during extreme soot oxidation events
  - Medium cell density (**300-350cpsi**) for a thin soot layer
  - Thick webs (**12-13mil**) to maximize volumetric heat capacity
  - **Asymmetric cell design** to maximize ash storage volume (ash plug in rear) at high soot loads (accepting the Δp penalty at low soot loads)

- The technical analysis resulted in GPF designs
  - **Cordierite** as material of choice, same as for substrates, due to thermal shock robustness and benefits of **low heat capacity** for cold starts (catalyzed GPF) and passive regenerations
  - Medium cell density (**300cpsi**), thin webs (**8mil**) and high porosity (~**65%**) for **coated GPF** (GSA, pore volume for catalyst)
  - Lower cell density (**200cpsi**), thin webs (**8mil**) and medium porosity (~**55%**) for uncatalyzed GPF for lowest Δp
  - **Symmetric cell design** as low soot loads

Source: Ref. [1]

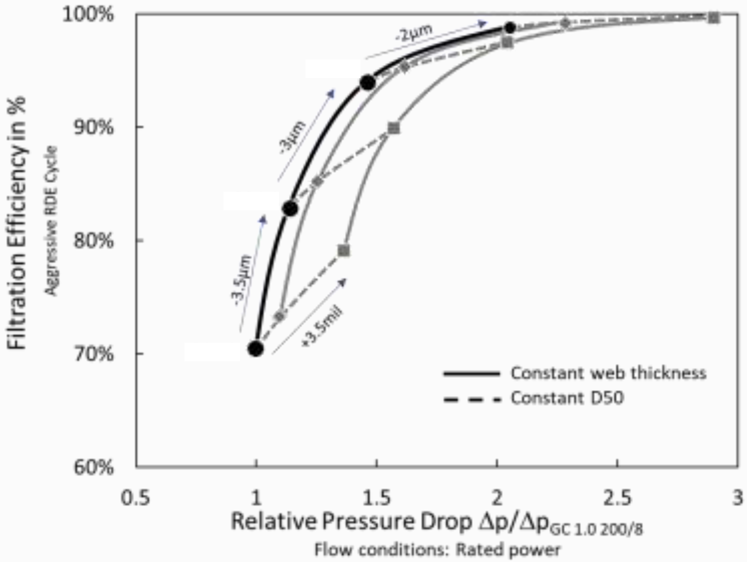
Evolution of Gasoline Particulate Filter Technologies

1st Generation Gasoline Particulate Filter Concepts

- Two families of GPF technologies
  - **Uncatalyzed GPF applications (DuraTrap® GC filters)**
    - Cordierite
    - Cell density 200cpsi
    - Web thickness 8mil
    - Porosity 55%
    - Median pore size – variable to tailor for Δp/FE trade-off
  - **Catalyzed GPF applications (DuraTrap® GC HP filters)**
    - Cordierite
    - Cell density 300cpsi
    - Web thickness 8mil
    - Porosity 65%
    - Median pore size – variable to tailor for Δp/FE trade-off

Example – Uncatalyzed GPF technologies

- Different products within each family
- Web thickness and pore size as main design variables with largest impact on filtration



Source: Ref. [1,2]

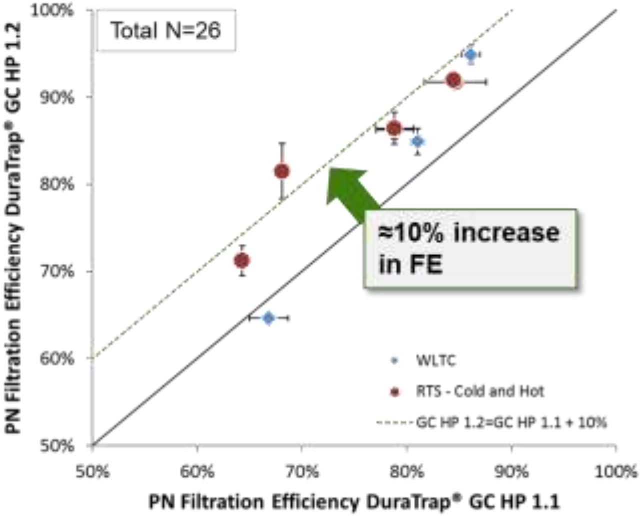
Evolution of Gasoline Particulate Filter Technologies

The impact of catalyst coating technology on the performance is significant

- The filter design concept with different median pore size is also applied to catalyzed GPFs
  - DuraTrap GC HP 1.1 vs. GC HP 1.2 have identical properties but different D50
  - Consistent impact on filtration and pressure drop, but the effect of the coating technology is significant

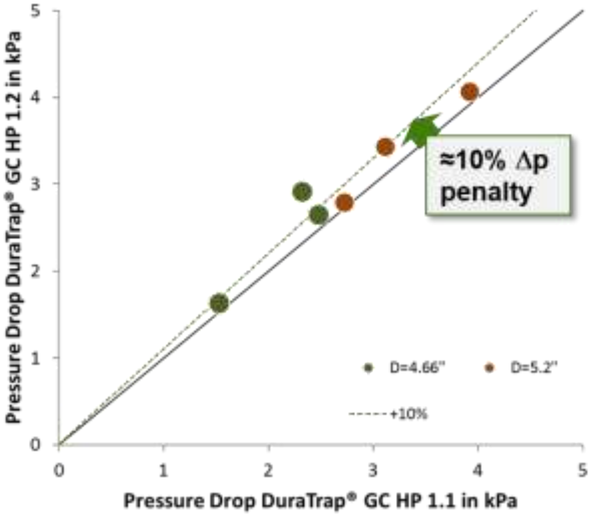
PN Filtration Efficiency

Data obtained on C-segment vehicle (Compact SUV) w/ 1.2L TGDI, WLTC & RTS95, different TWC coating technologies



Cold Flow Pressure Drop

Data obtained on cold flow bench; Data sets comprise two part sizes; Different TWC coating technologies



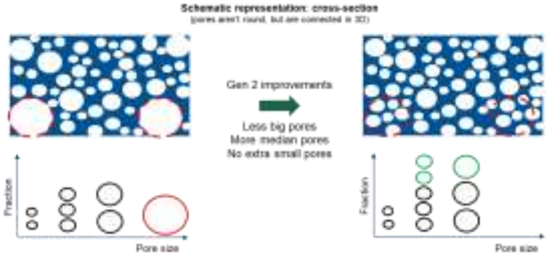
Source: Ref. [3]

Evolution of Gasoline Particulate Filter Technologies

Development of the 2nd Generation of GPFs

Catalyzed GPF

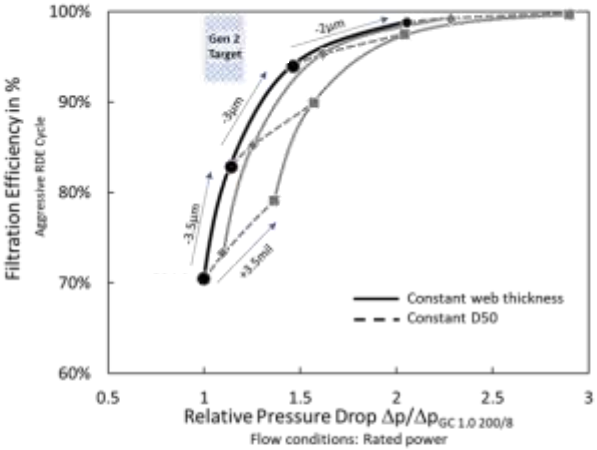
- Microstructure approach
  - Significant impact of the coating technology
  - Maximize uniformity of pore space (coatability, FE, Δp)
- Approach selected for Catalyzed Gen 2
  - Porosity (65%) and cell design (300/8) is maintained
  - Further tightening of the pore size distribution by eliminating the larges pores
    - …since they are not useful for coating or filtration



    - Results in an effective (mathematical) shift in D50

Uncatalyzed GPF

- Microstructure or cell design approach does not deliver the target requirements
- Permeability and filtration are coupled to the same physical properties (D_{50}, t_w, CPSI, ε)



- New approach required!

Source: Ref. [4]

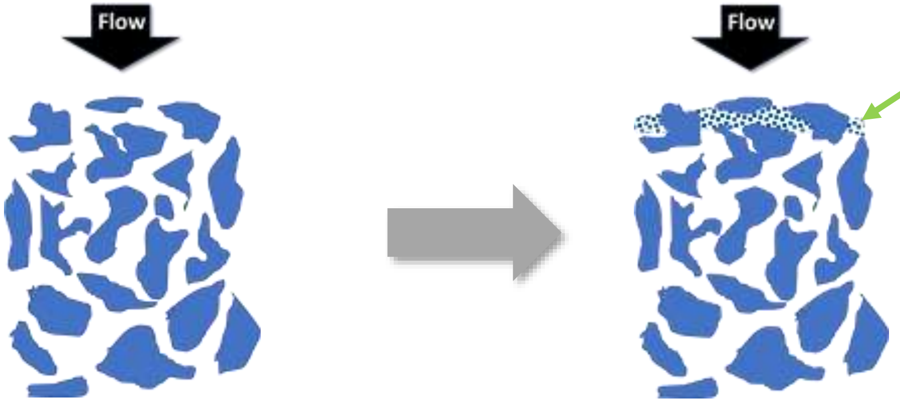
Evolution of Gasoline Particulate Filter Technologies

Development of the 2nd Generation of GPFs for uncatalyzed applications

- To solve this intrinsic trade-off between FE and Δp the typically statistically uniform microstructure is modified to a hierarchical structure
  - Only the surface pores are modified, adding a large number of small collectors with very high porosity
  - Essentially no change to the measurable bulk properties (ε, D50) as limited to surface pores

Modified pore entries of the surface porosity enabling very high localized collector efficiency
Pressure drop penalty low, due to short length

Gen 1



Gen 2

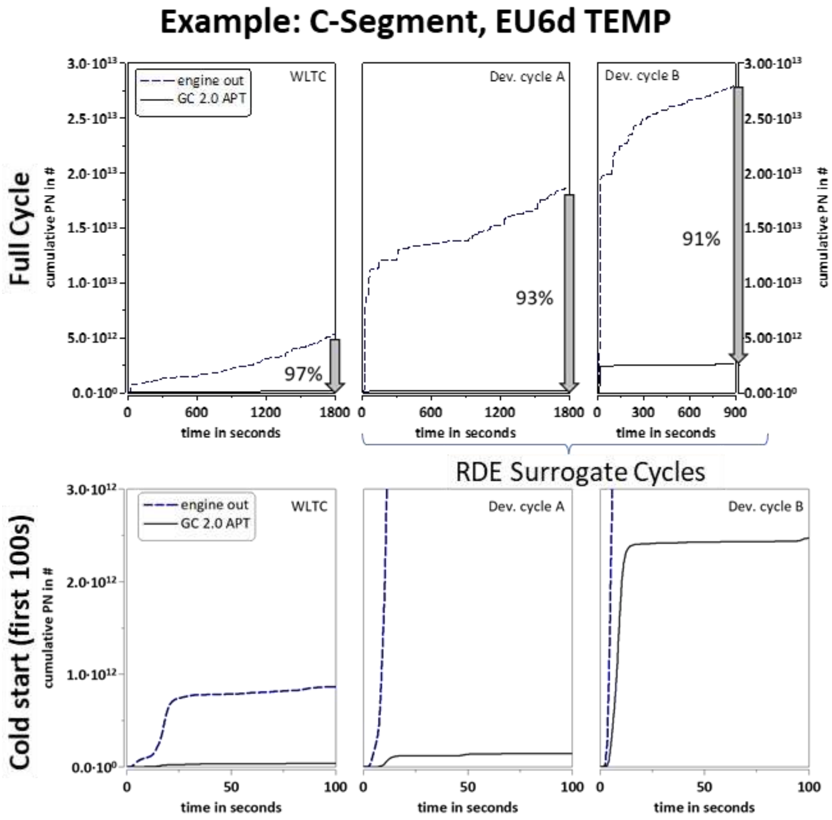
Conventional filter technology
(statistically uniform pores)

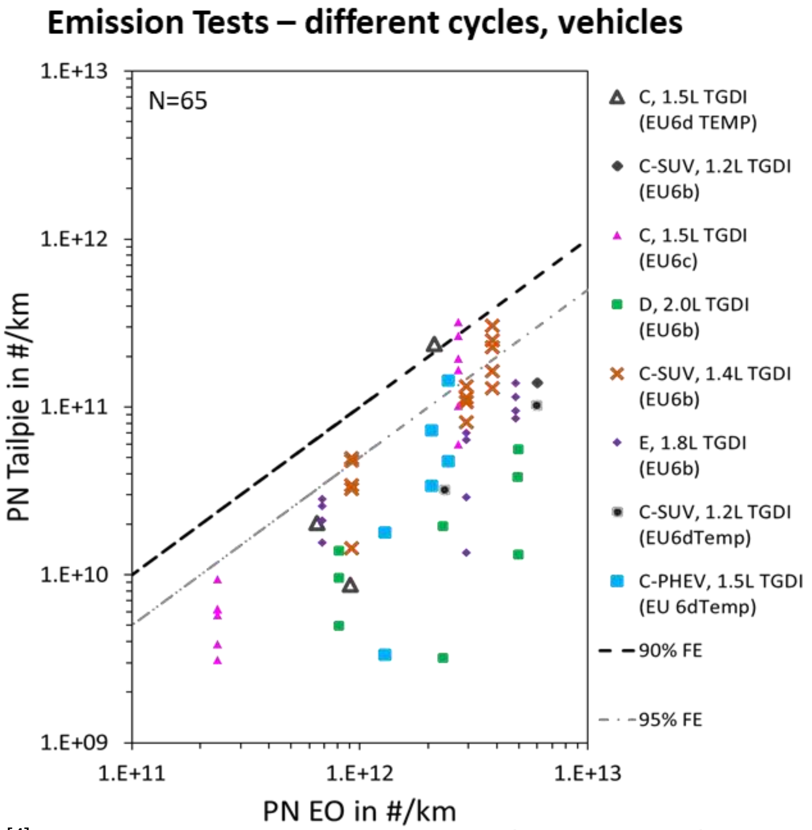
Hierarchical filter technology
(modified surface porosity)

Source: Ref. [3]

Evolution of Gasoline Particulate Filter Technologies

DuraTrap GC 2.0 APT enabling for very high filtration efficiencies >90%





Source: Ref. [4]

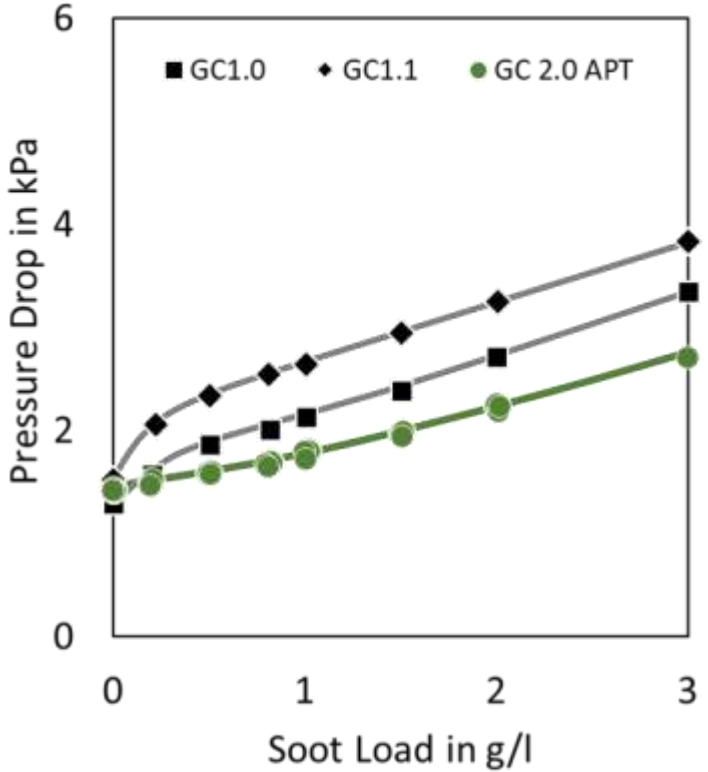
Evolution of Gasoline Particulate Filter Technologies

…at no or very low pressure drop penalty

- 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*



Source: Ref. [2]

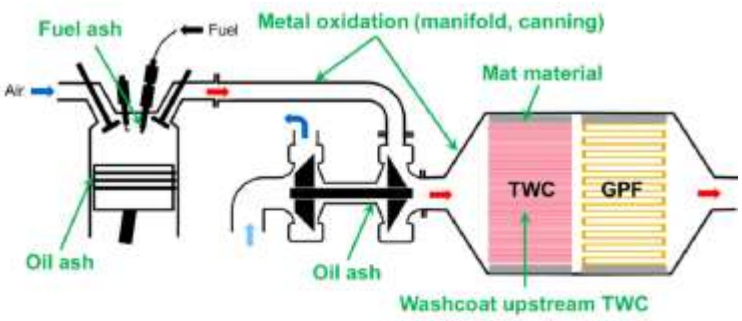
Application Experience

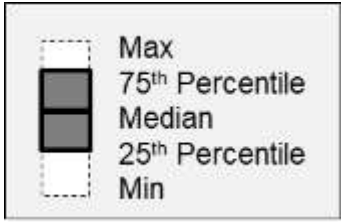
Knowledge that had to be developed for the new application

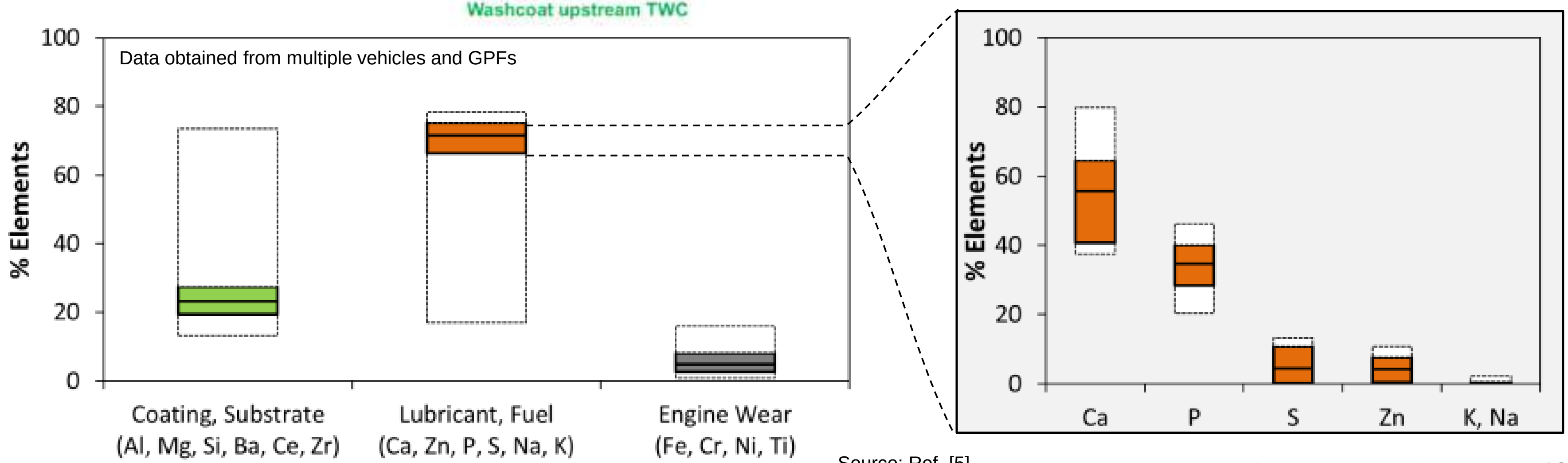
- Ash accumulation
  - Accumulation rate
  - Deposition of ash and impact on performance

Ash Accumulation

Sources of ash – Oil additives are dominating analogous to DPF





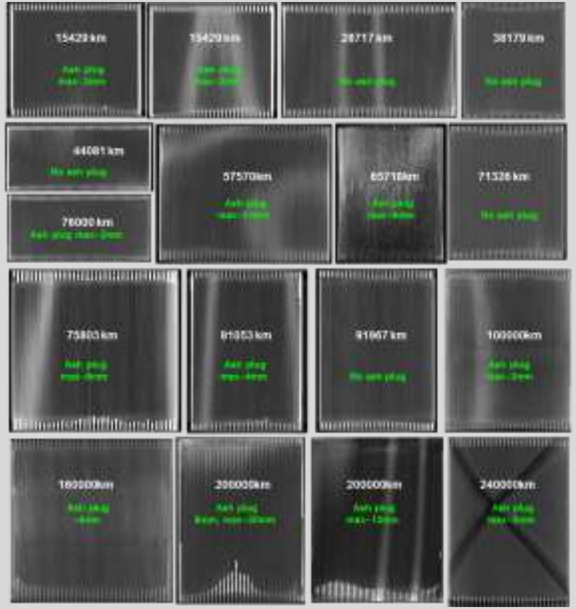


Source: Ref. [5]

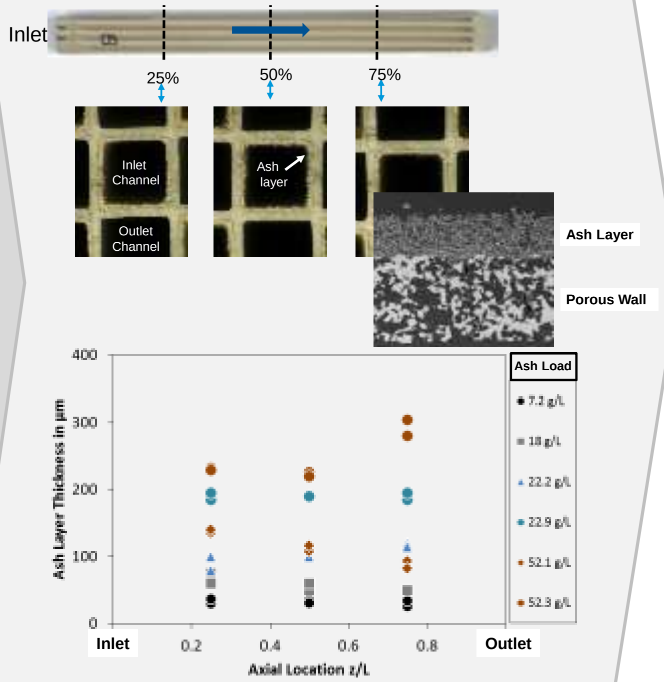
Ash Accumulation

Where does the ash accumulate?

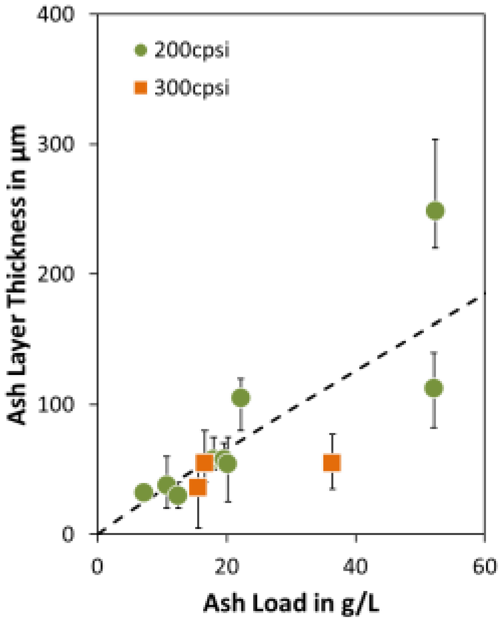
Analysis of a large number of filters from vehicle durability programs (examples)



Ash is found dominantly as uniform layer on the inlet channel walls (not as plug, not inside pores)



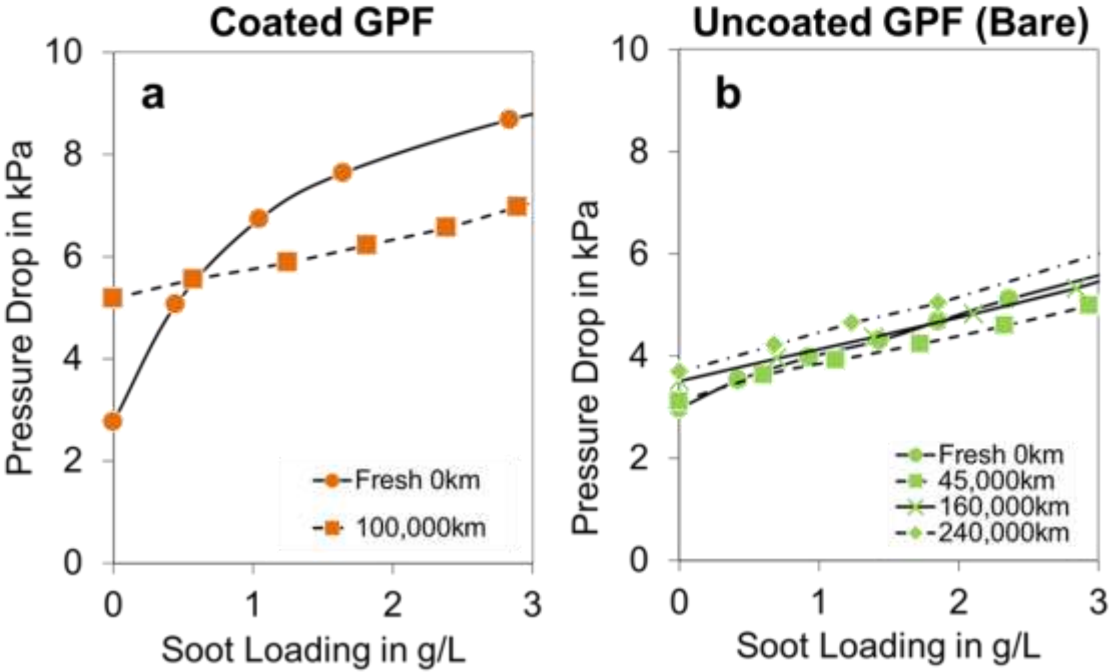
Ash layer thickness scales with quantity or mileage or oil consumption



Ash Accumulation

Impact on pressure drop

- Clean pressure drop increases → ash layer adds resistance, more pronounced for catalyzed GPF
- Soot loaded pressure drop can actually decrease → ash layer prevents deep bed penetration of soot



Source: Ref. [5]

Summary

- GPFs have been successfully integrated into exhaust systems since EU6d TEMP
- GPFs are a standard aftertreatment component in all exhaust systems following advanced regulations – US Tier4, EU7, CN7 and BS7
- The rapid evolution in filtration needs has resulted in a rapid development of new generations of filter technologies
  - Always trying to deliver the new filtration targets but at a minimal penalty in pressure drop or robustness
- Significant learnings have been made related to the application of GPF
  - Examples discussed were ash accumulation and design for useful life

References

1. Boger T., N. Gunasekaran, R. Bhargava, C. Bischof. *Partikelfiltertechnologien für DI Ottomotoren (Particulate Filters for DI Gasoline Engines).* MTZ - Motortechnische Zeitschrift 06/2013, p. 452-458
2. Boger T., T. Glasson, D. Rose, R. Ingram-Ogunwumi and H. Wu. *Next Generation Gasoline Particulate Filters for Uncoated Applications and Lowest Particulate Emissions*, SAE Int. Journal of Advances and Current Practices in Mobility (2021), SAE Technical Paper 2021-01-0584
3. Boger T., *Advanced Gasoline Particulate Filter Technologies - Experience gained and future perspectives*. Proceedings "After-treatment system and engine oil solutions meeting China 6 LD regulations", 2018 WICE, Wuxi, China
4. Rose D., T. Boger, P. Nicolin, F. Jung, T.A. Collins, R. Ingram-Ogunwumi. *Aftertreatment Technologies Supporting the Path Towards Zero-Impact Emissions*. Proceedings 30th Aachen Colloquium Automobile and Engine Technology (2021), p. 121-143
5. Chijiiwa R., D. Rose, P. Nicolin, B. Coulet, F. Jung, T. Glasson, Z. Lv, A. Bachurina, M. Shimizu and T. Boger. *Ash Accumulation in Advanced Gasoline Particulate Filter Technologies*. Proceedings of 2018 JSAE Annual Congress (Spring), Yokohama, Paper number 20185404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