GPF field experience obtained from On-Road testing

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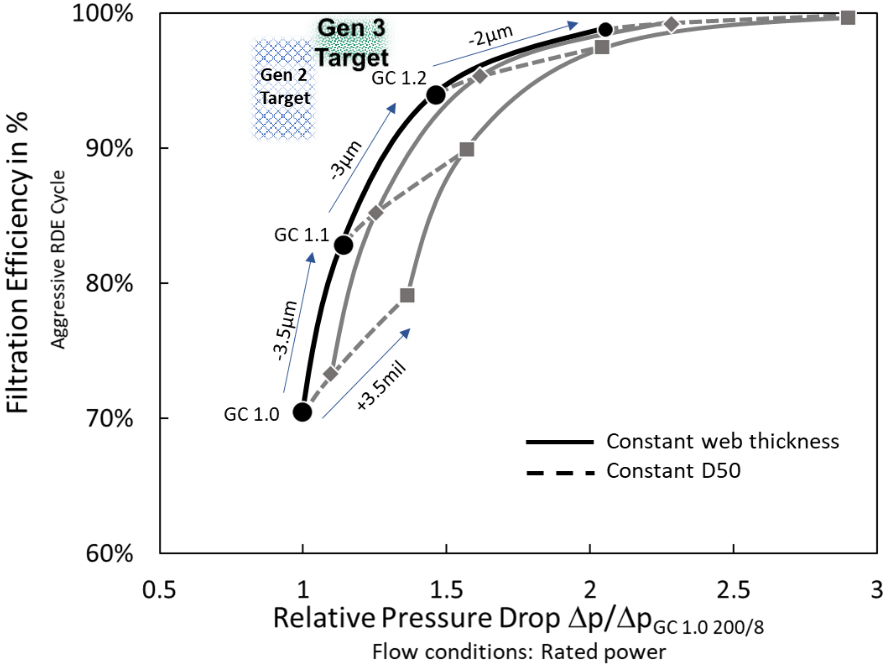
Outlook

- Overview of GPF technologies (uncatalyzed)
  - Pressure drop
  - Filtration Efficiency
- Experience from “On Road” testing & considerations for retrofit
  - Ash accumulation
  - Soot oxidation evaluations
- Summary and Conclusions

Overview of GPF technologies

- 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: 200cpsi, 8.5mil web thickness, 55% porosity and range of D50 to enable different filtration efficiency

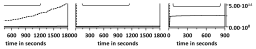


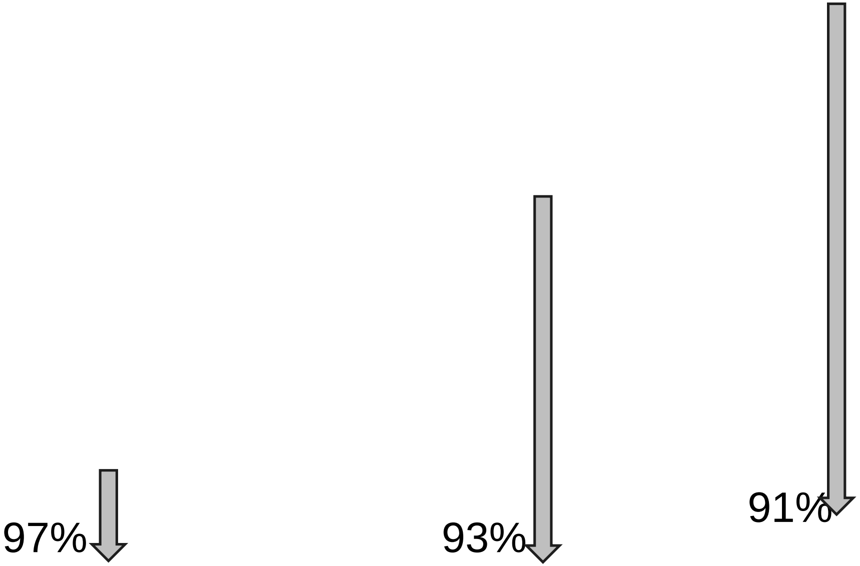
- GC 2.0 GPF have a modified microstructure at pore entries of the surface porosity enabling very high localized collector efficiency
- Remaining microstructure optimized for permeability
- Porosity, cell design and thermo-mechanical robustness maintained and equivalent to Gen 1 technologies

Filter Technology	GC 1.0	GC 2.0
Generation	1	2
Porosity	~55%	~55%
Pore Size	Base	Hierarchical
Application	EU6d Temp.	EU6d, e

Overview of GPF technologies GC 2.0 Filtration Efficiency

GC 2.0 “Out of the Box” = low mileage results





Experience from On Road testing
Ash accumulation - basics

- Ash accumulation has significant impact on filtration efficiency for Gen 1 GPF
  - For generation one GPF the FE does improve with ash accumulation
  - GC 2.0 and (GC 3.0) are designed to have targeted FE already **w/o** ash, “fresh”
- Impact from ash on pressure drop:
  - Ash particles deposit in the inlet channels
  - They “occupy” areas of the inlet channel volume
  - They can change the permeability of the filter walls
  - They can act as “barrier” for soot particles

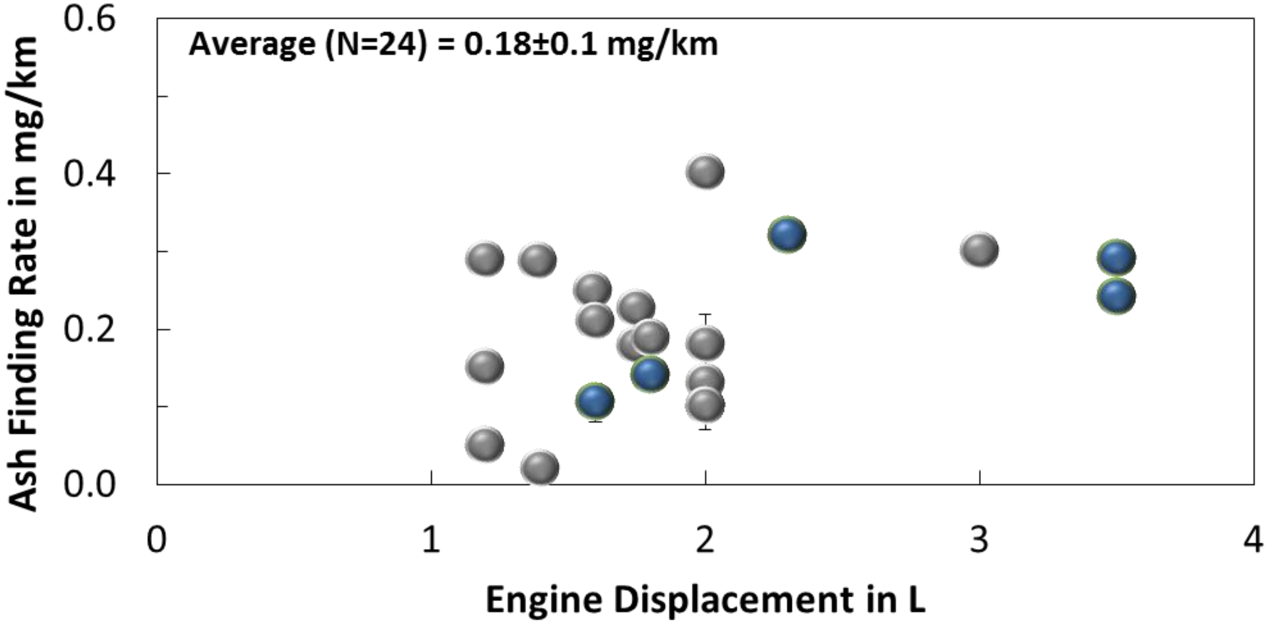
Experience from On Road testing

Ash accumulation - examples

- Ash accumulation evaluations based on On-Road Testing
- Dedicated test vehicles with high mileage per time and company cars with lower mileage per time (normal use)
- Ash analysis includes
  - accumulation rate
  - distribution
  - composition
  - performance impact

Experience from On Road testing

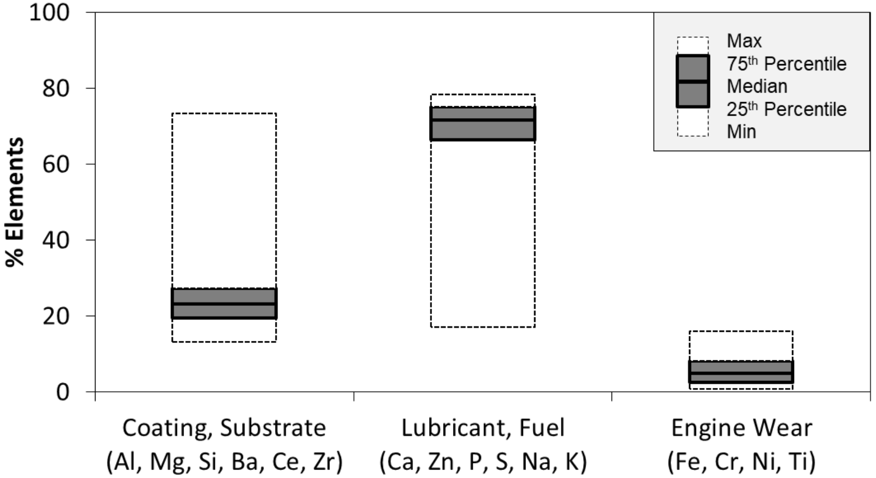
Ash finding rate in mg/km based on gravimetry

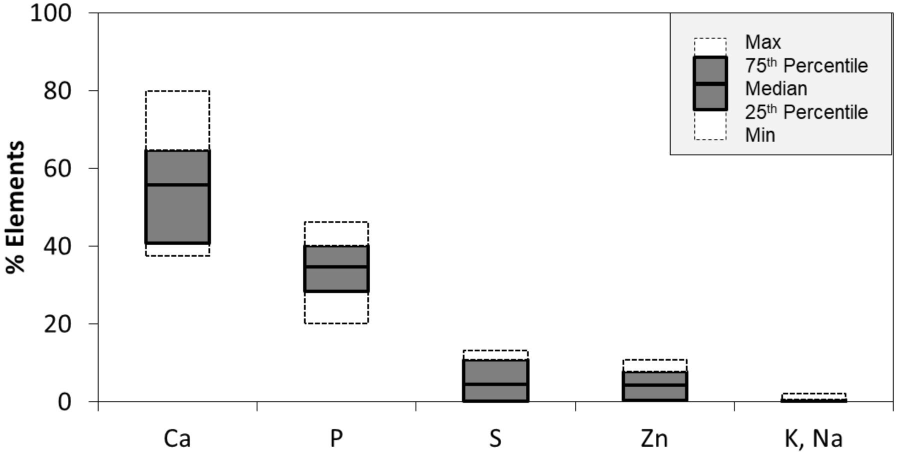


JSAE 2018-5404, Chijiiwa et.al., “Ash accumulation in advanced gasoline particulate filter technologies”

Experience from On Road testing

Ash composition





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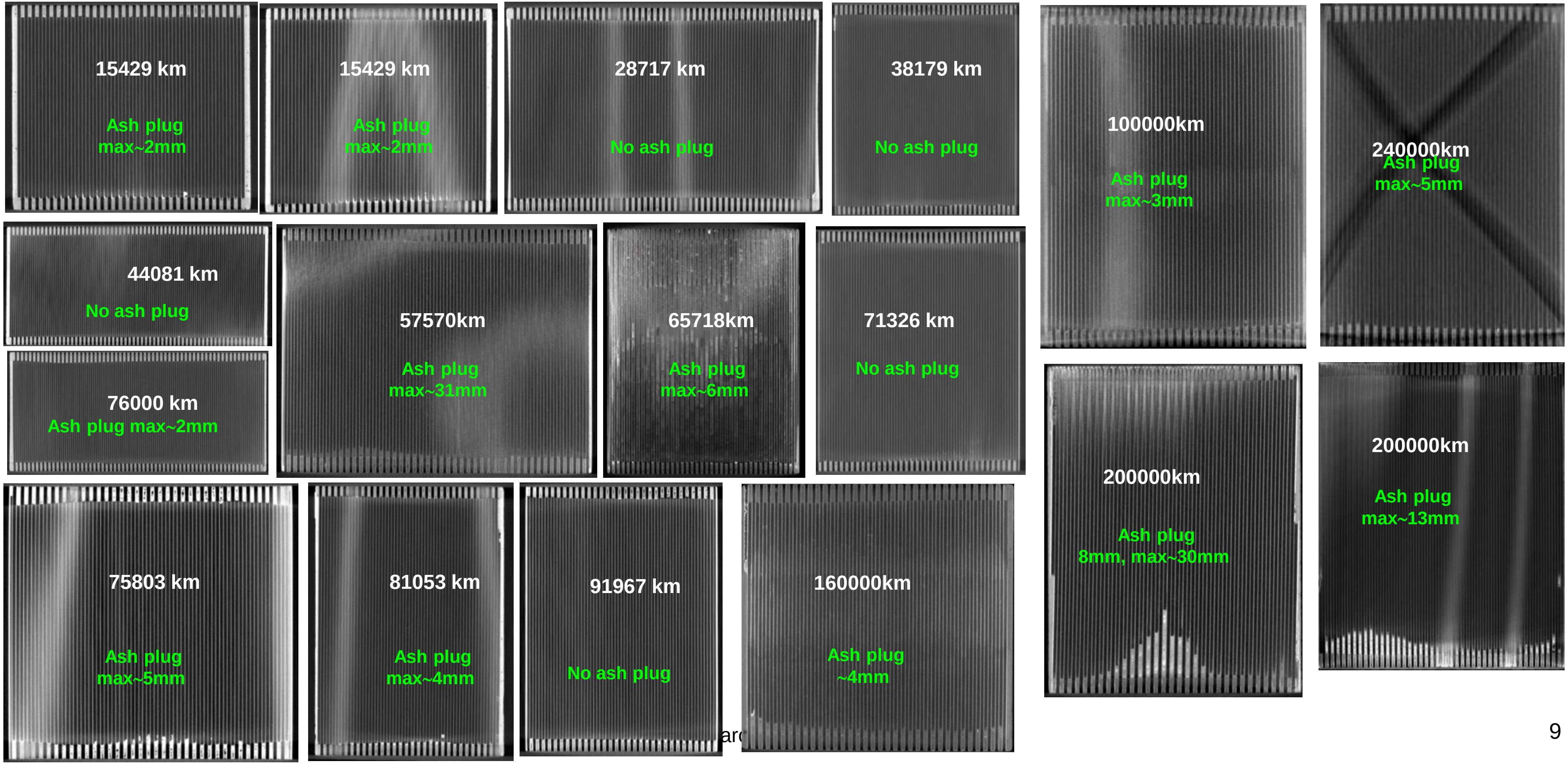
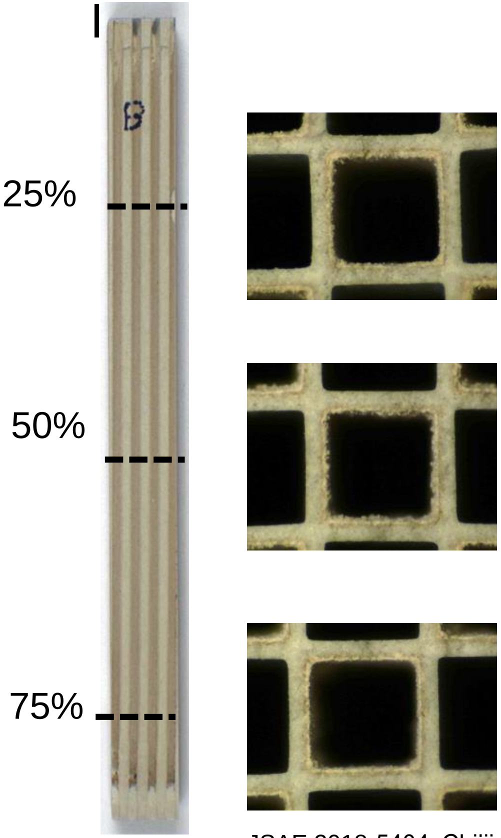
Experience from On Road testing

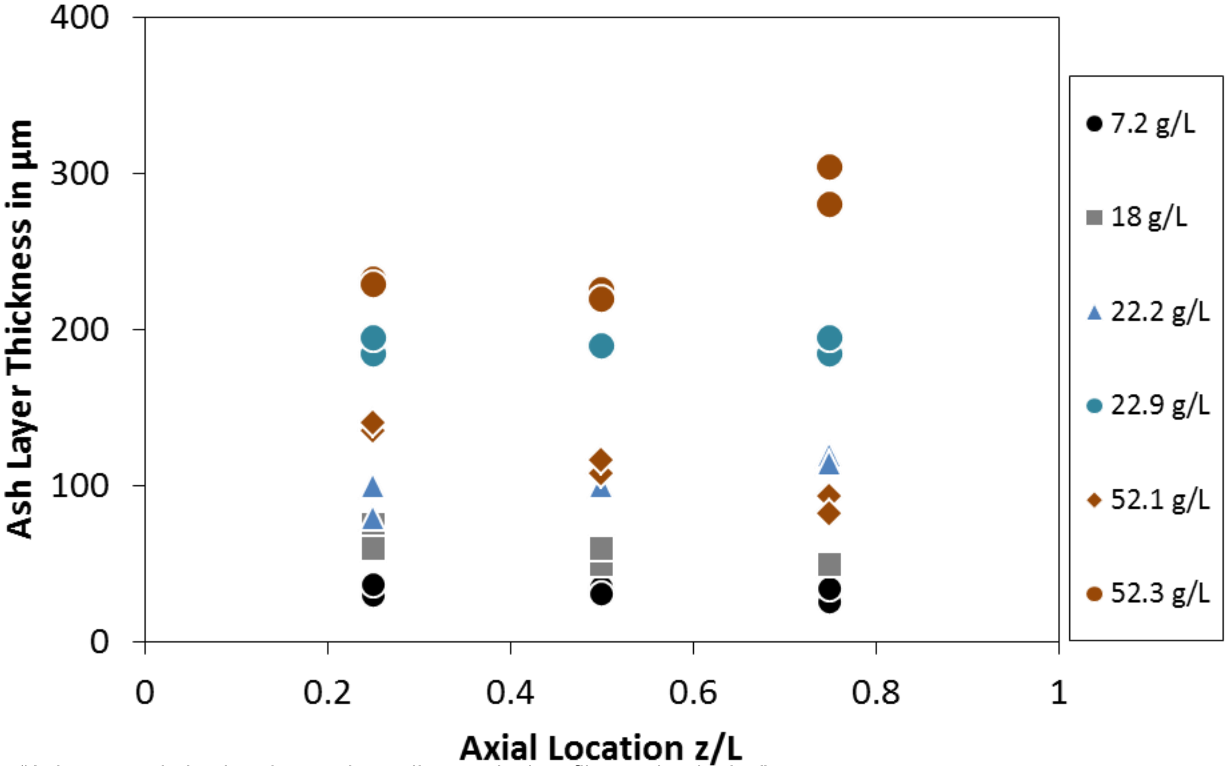
Ash distribution – pictures are not true to scale



Experience from On Road testing

Ash distribution - axial





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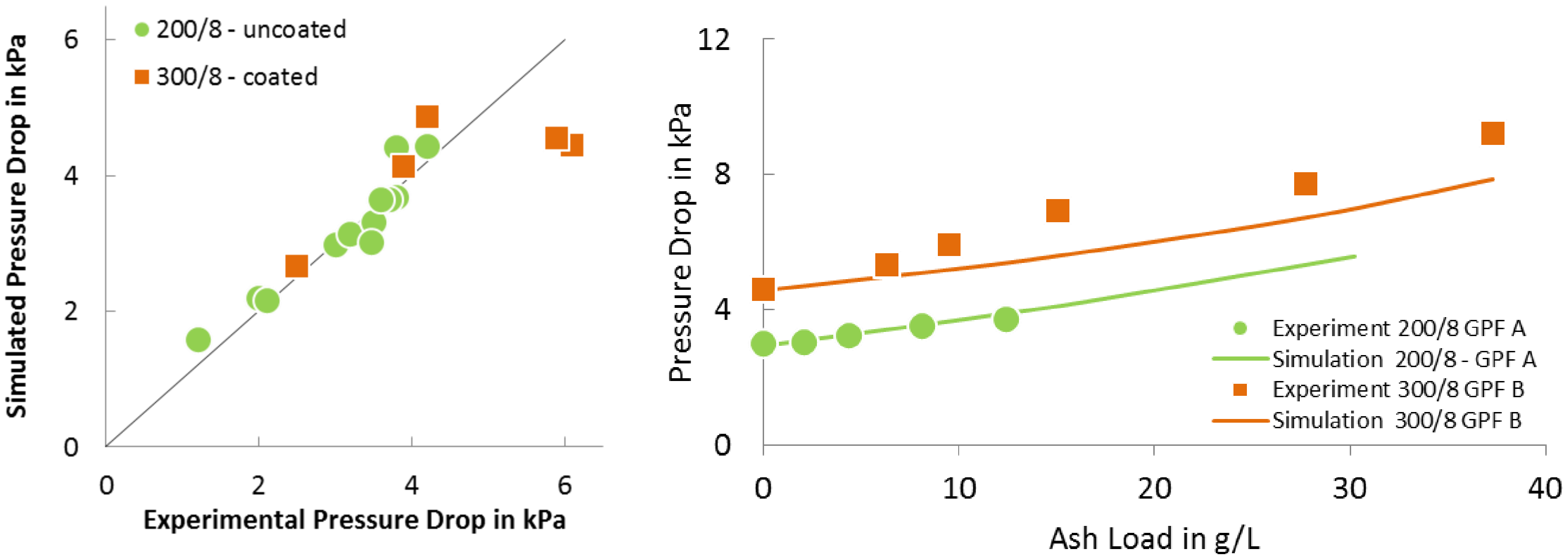
Experience from On Road testing

Impact from ash on pressure drop



JSAE 2018-5404, Chijiiwa et.al., "Ash accumulation in advanced gasoline particulate filter technologies"

Soot oxidation evaluations - fundamentals

- Soot particulates are trapped in the GPF and accumulate over time
  - Increasing backpressure
  - Heat release due to soot oxidation

- Boundary conditions for passive soot oxidation in gasoline applications:
  - Passive means that the oxidation occurs under normal operation of the engine, without any measures that would enhance its rate or generally facilitate it
  - Gasoline engines are typically operated stoichiometric; hence, under normal operating conditions there is no oxygen
  - NO_2 is reduced to low levels over the upstream three-way catalyst and not available for the oxidation of soot

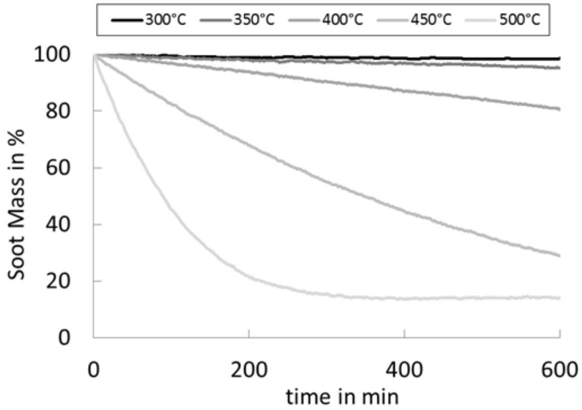
Soot oxidation evaluations (cont.)

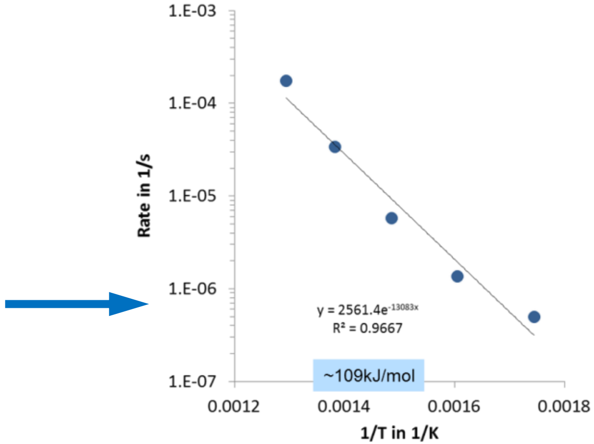
Hypothesis of conditions which enable a passive oxidation of the accumulated soot

- Passive soot oxidation is based on O_2 oxidation during fuel cuts (λ > 1 events)
- Soot oxidation rate at lower temperatures is slow but there are many events and
- the incoming soot mass from the engine is relative low (e.g. compared to Diesel)
- Results suggested that soot oxidation occurs at lower but measurable rates at lower temperatures

Isothermal TGA* experiments Addressing the low temperature region of 300-500°C

*TGA = Thermo Gravimetric Analysis





SAE 2015-01-1048, Nicolin et.al., "Modeling of the Soot Oxidation in Gasoline Particulate Filters"

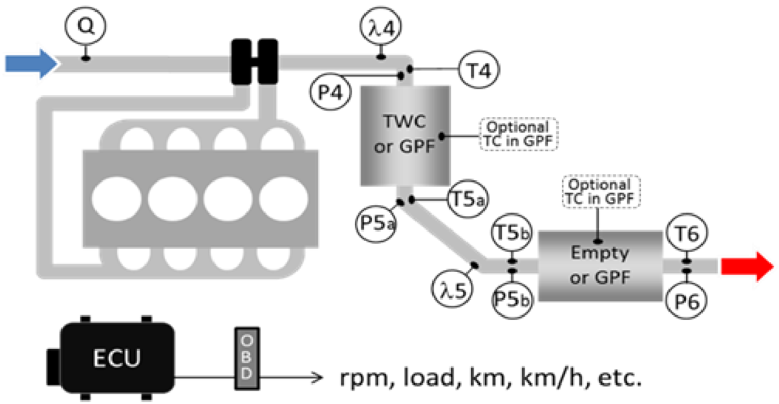
Soot oxidation evaluations (cont.)

Validation and Vehicle experiments - Instrumentation and Setup

- Different vehicles were equipped with on-board data acquisition systems, monitoring a number of relevant engine parameters available from the ECU and obtained via the OBD interface as well as data from additional sensors installed on the vehicle.

Schematic of the instrumentation and data acquisition system on the test vehicles.

Q = Air Mass flow
P = Pressure
T = Temperature
λ = Oxygen.



SAE 2015-01-1048, Nicolin et.al., “Modeling of the Soot Oxidation in Gasoline Particulate Filters”

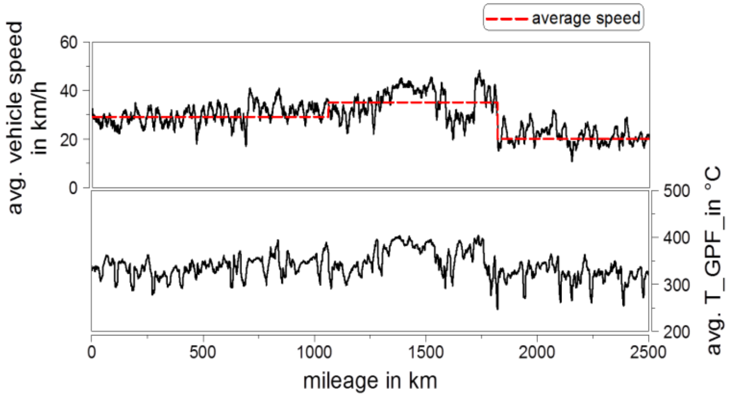
Soot oxidation evaluations (Cont.)

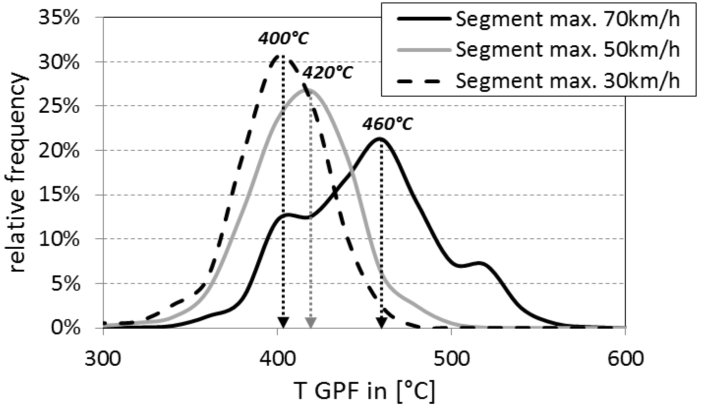
Testing procedure - example

- Vehicle experiment with C-Segment, 1.4l GDI - TC, EU6b, 90kW
- Original TWC in place and uncoated GPF installed in underfloor position (DuraTrap GC 200/8 in 5.2“x6“)
- GPF was soot loaded ex-situ in laboratory (Printex U) to 6g total
- 2.500 km driving have been accomplished and recorded in different traffic conditions, GPF weighing at end of everyday’s shift

Soot oxidation evaluations (Cont.)

Example - Soot oxidation on vehicle





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The campaign was separated into three discrete phases:

<u>Phase 1:</u>

- 1100km, ~38h
- average velocity of ~29km/h
- maximum velocity of ~50km/h.

<u>Phase 2:</u>

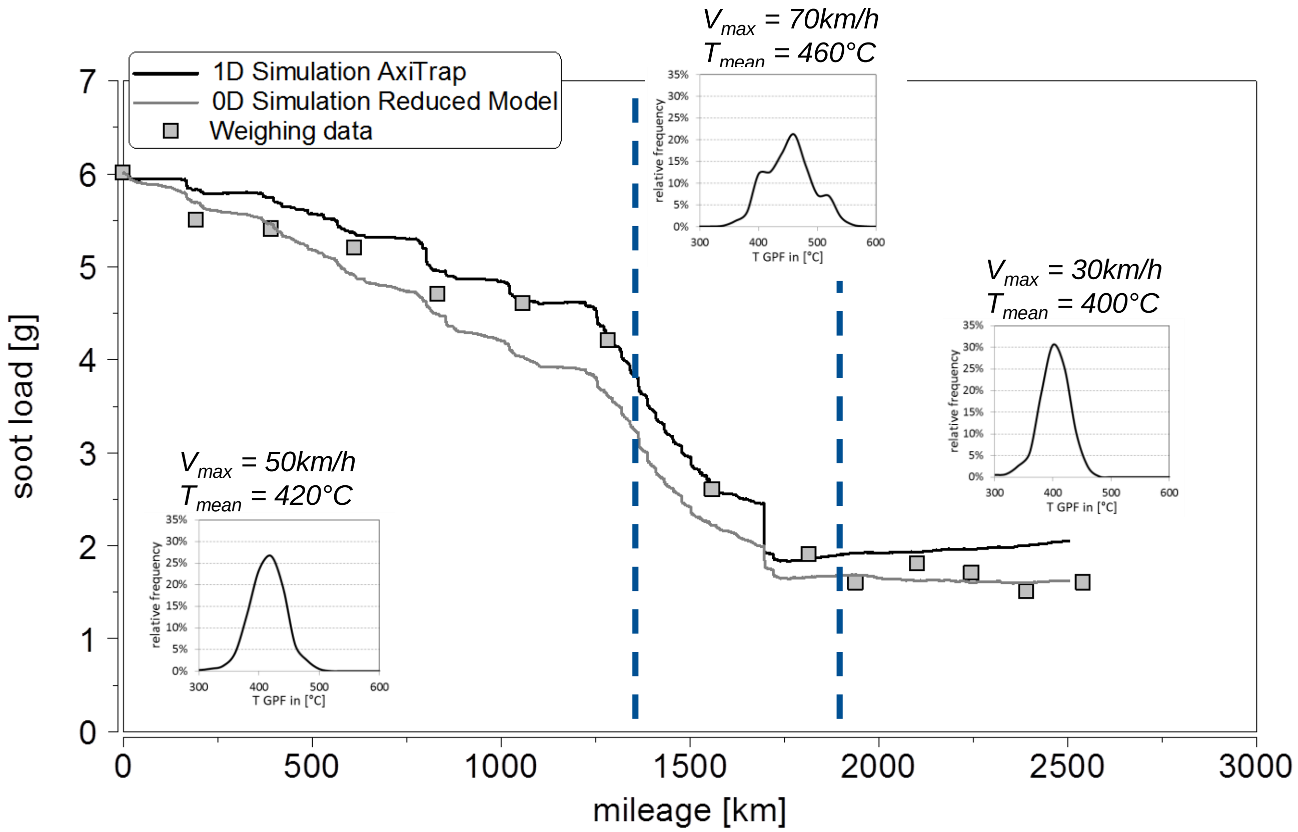
- 700km, ~20h
- average velocity of ~35km/h
- maximum velocity ~70km/h

<u>Phase 3:</u>

- 700km, ~35h
- average velocity of ~20 km/h
- maximum velocity of ~30km/h

Soot oxidation evaluations (Cont.)

Example – Simulation of soot oxidation on vehicle



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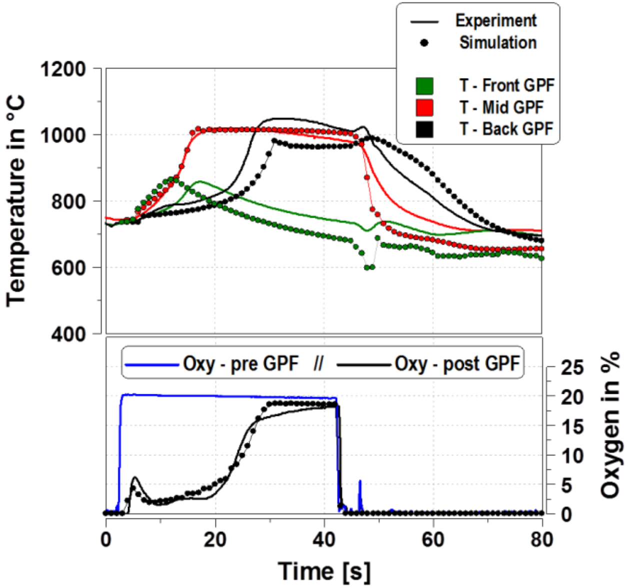
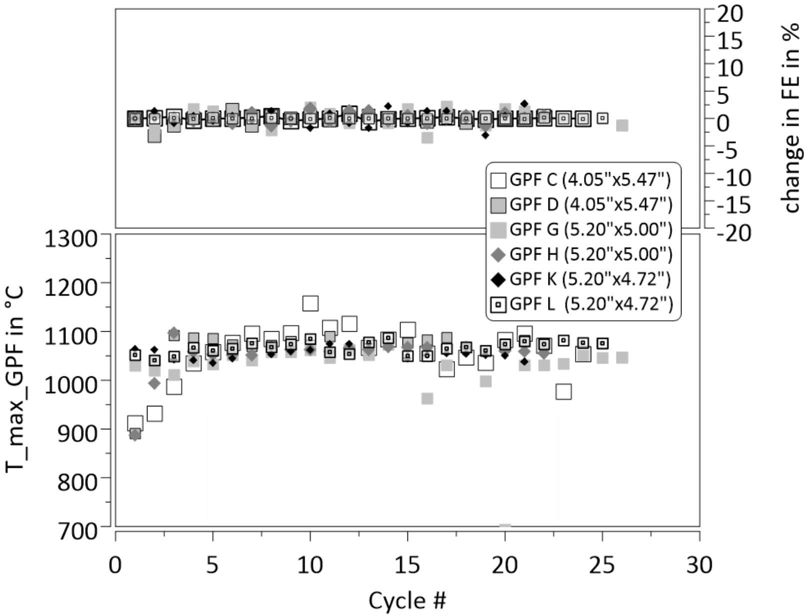
Soot oxidation evaluations (Cont.)

Soot loaded fuel cut condition and thermomechanical robustness





- Results from the detailed 2-dimensional AxiTrap simulation.
- Soot oxidation by oxygen was the only active reaction
- The soot oxidizes very rapidly, resulting in a rapid increase in the temperature inside the filter.

- Results from engine bench testing
- Each GPF >= 20 cycles at 1050°C +/-50°C
- No change in FE observed

Summary and Conclusions

- GPFs are a proven technology to reduce tailpipe PN emissions
  - Generation 2 has high “out of the box” efficiency
- Extensive on-road testing revealed:
  - Accumulated ash quantities are within life-time capacity of typical GPF volumes
- Soot oxidation studies showed:
  - Typically, GPF can be operated “passive” – no active regeneration required
  - The oxygen quantities introduced through “fuel-cut” are sufficient
  - Based on our results is “City-only” operation possible, even with U/F GPF

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