Combination & Integration of DPF-SCR Aftertreatment

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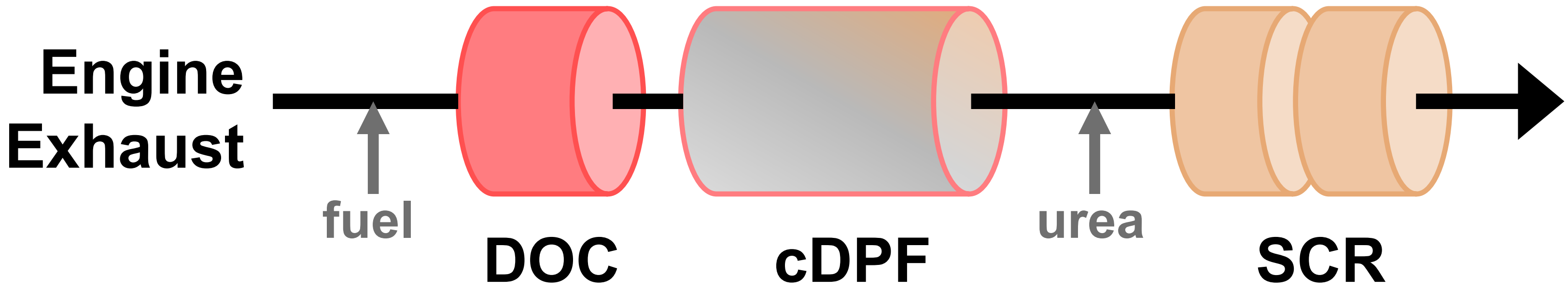
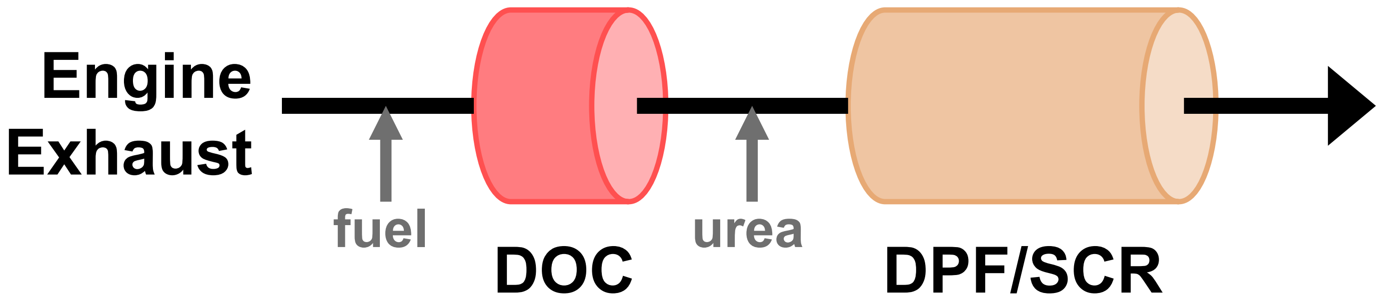
AFTER-TREATMENT COMPLEXITY

Integrating DPF & SCR functionalities for reducing cost and volume of engine after-treatment

Typical HDD EPA 2010 Layout



Possible Future HDD Layout



RECENT FIELD OF WORK

- GM (SAE 2011-01-1140) – integrated system able to meet cert. requirements w/ significant reduction in A/T volume; coating process & ***wash-coat loading*** need optimization; approach does not address passive soot oxidation feasibility.
- JM (SAE 2011-01-1312) – addressed passive soot oxidation feasibility by turning EGR off. SCR/DPF with EGR off (elevated NO_x) demonstrated ***improved passive regeneration capability***.
- Ford (SAE 2010-01-1183) – oven aging tests indicate DOC-SCRF-SCR configuration able to meet T2B5 tailpipe NO_x standards through 120k miles.
- BASF (DEER 2010) – operating window (NO_x conv., dP) ***determined by porosity, PSD***. Filter type, porosity determines catalyst utilization.

SCR – DPF INTEGRATION

OBJECTIVE: Fundamentally understand the integration of SCR & DPF technologies for HDD to provide a pathway to the next generation of emissions control systems

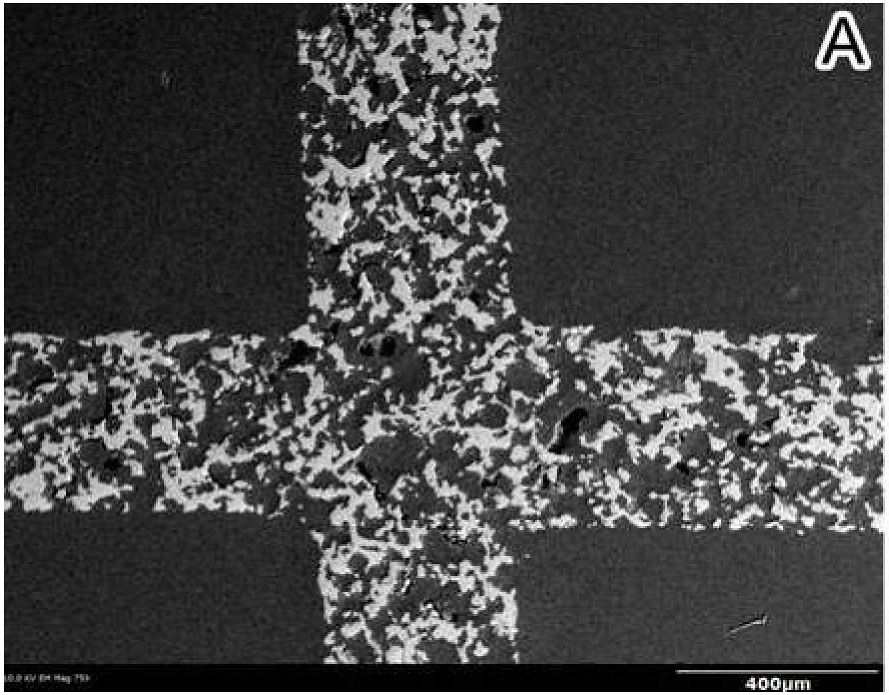
- CRADA with PACCAR, working intimately with PTC and DAF Trucks N.V.

- Evolving field of work (mostly LDD, some HDD); this effort focused on:
  1. Optimizing SCR catalyst wash coat
  2. Facilitating passive soot oxidation

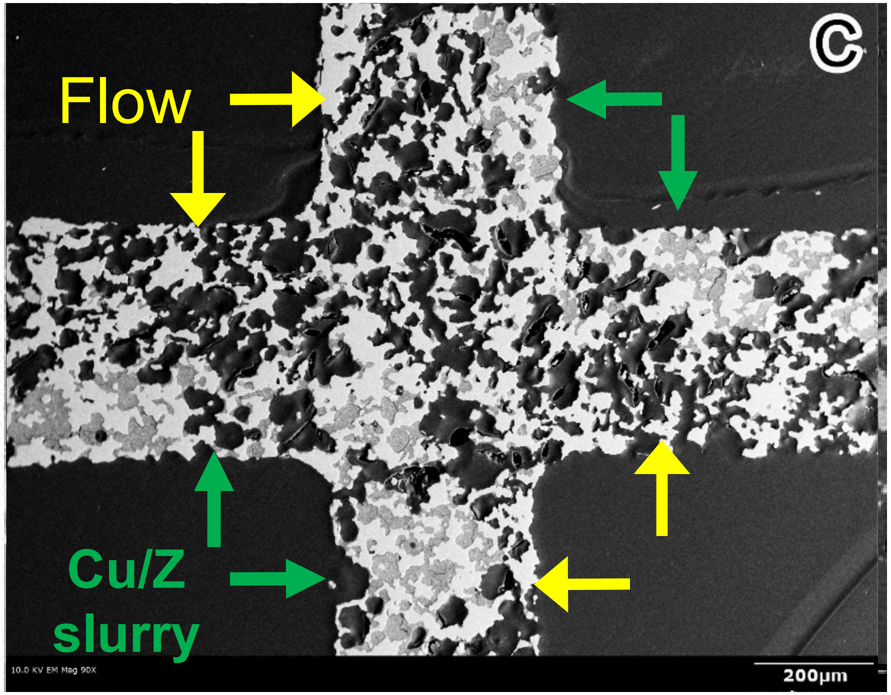
- Working relationship with BASF (HD Systems Development)
  - SCR catalyst (Cu/Z) expertise
  - Washcoating, manufacturability
  - UHP cordierite substrate samples coated

SEM IMAGING

- BASF Cu-Zeolite
- Directionally loaded on filter



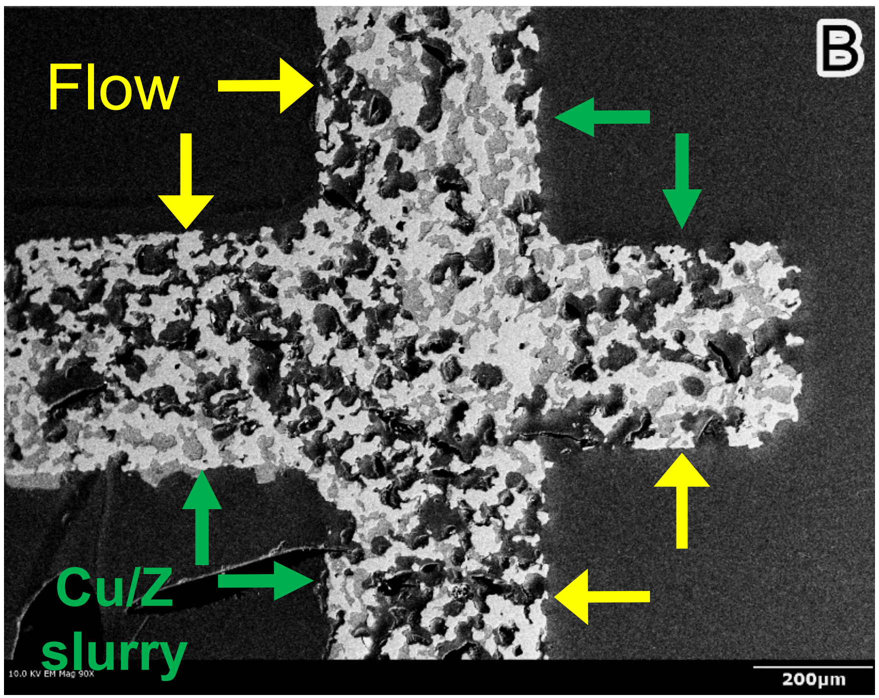
Bare filter, no catalyst



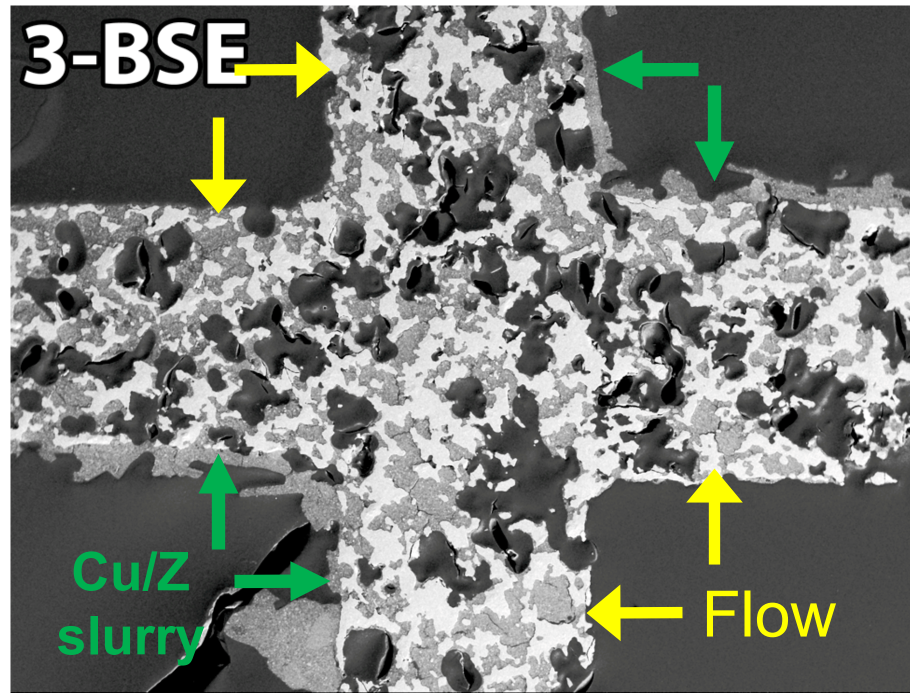
60 g/L catalyst loading

SEM IMAGING

- 90 g/L loading, distributed (in varying amounts) across full width of filter wall
- 150 g/L loading, significant deposition on channel wall



90 g/L catalyst loading

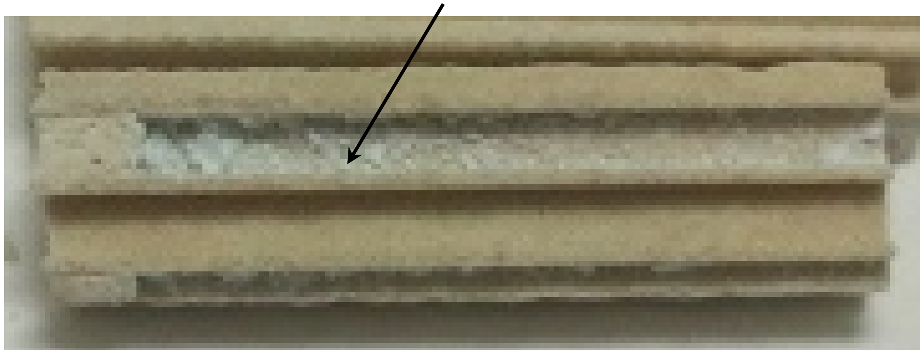


150 g/L catalyst loading

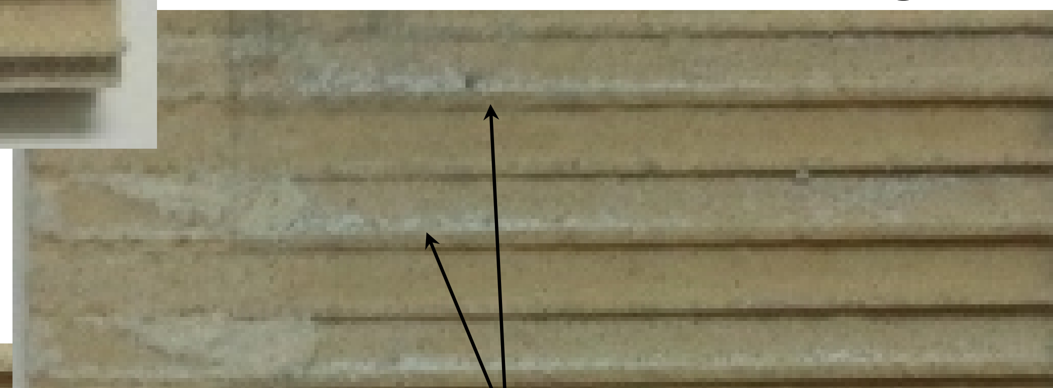
PHYSICAL EXAMINATIONS

150 g/L

Significant catalyst present on channel wall

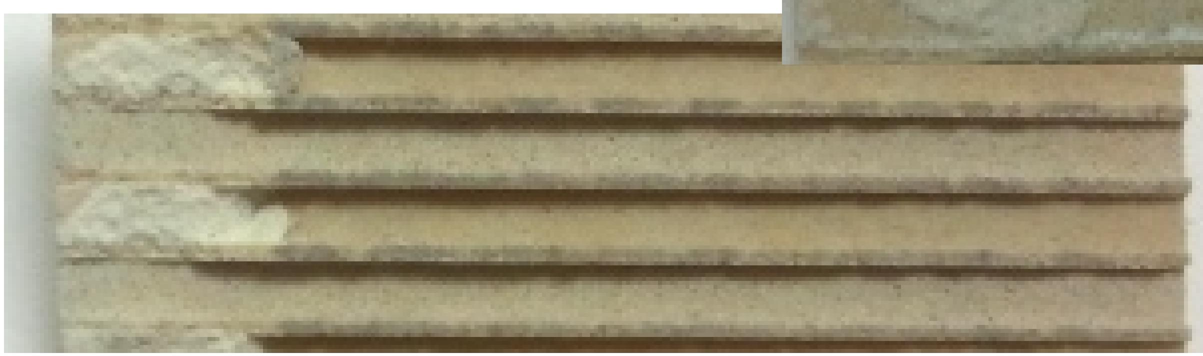


90 g/L



Small amount of catalyst on channel wall

60 g/L

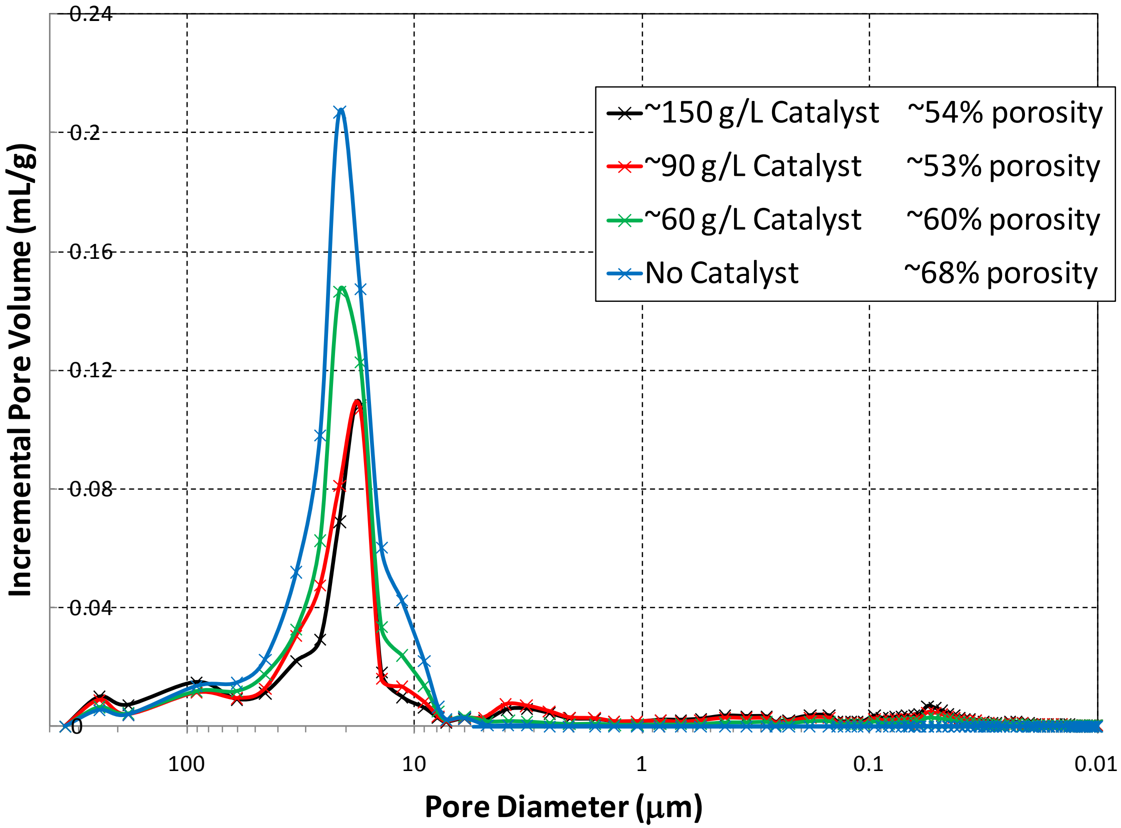


No catalyst on channel wall

Hg POROSIMETRY

Physical examinations of integrated system

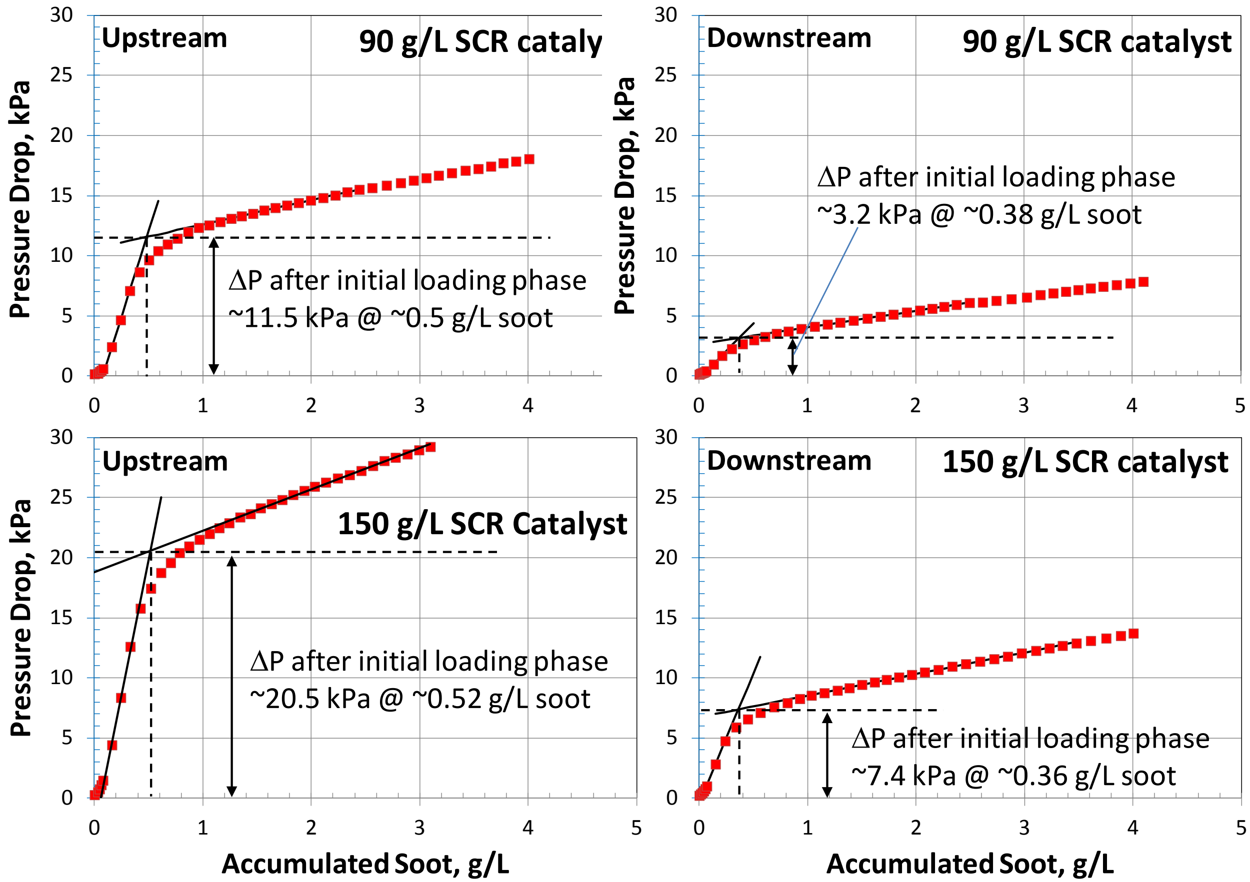
- Pore characteristics – high porosity cordierite



- 60 g/L appears to deposit completely into the porous microstructure.
- 60 – 90 g/L appears to largely deposit into the porous microstructure as well, with a small amount of catalyst remaining on channel walls.
- The majority of >90 g/L does not appear go into the porous microstructure, only goes into a *small number* of very large pores (>20 mm).

SOOT LOADING

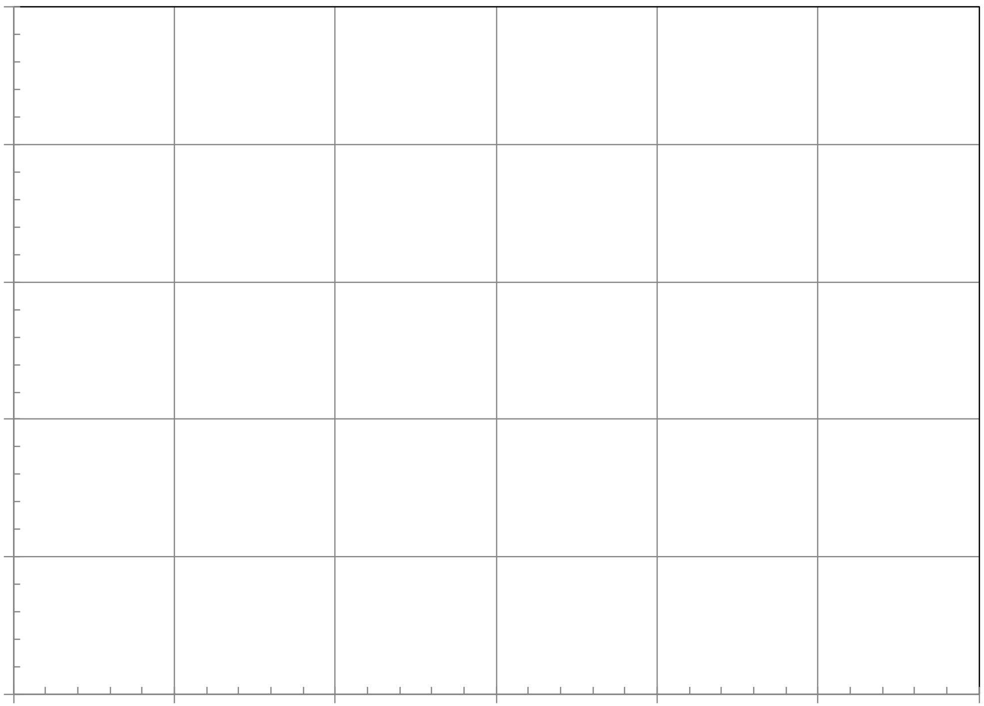
- Significant effect of catalyst location on pressure drop during soot loading (2003 Jetta, ~300°C, 55k GHSV)



- Both ***amount*** and ***location*** of SCR catalyst have measureable significant impact on dynamic permeability of filter during soot loading

FLOW THRU vs. WALL FLOW

- Standard SCR reaction – 500 ppm NO, 500 ppm NH_3, 35k GHSV
  1. **Effect of configuration (& catalyst loading) without soot**

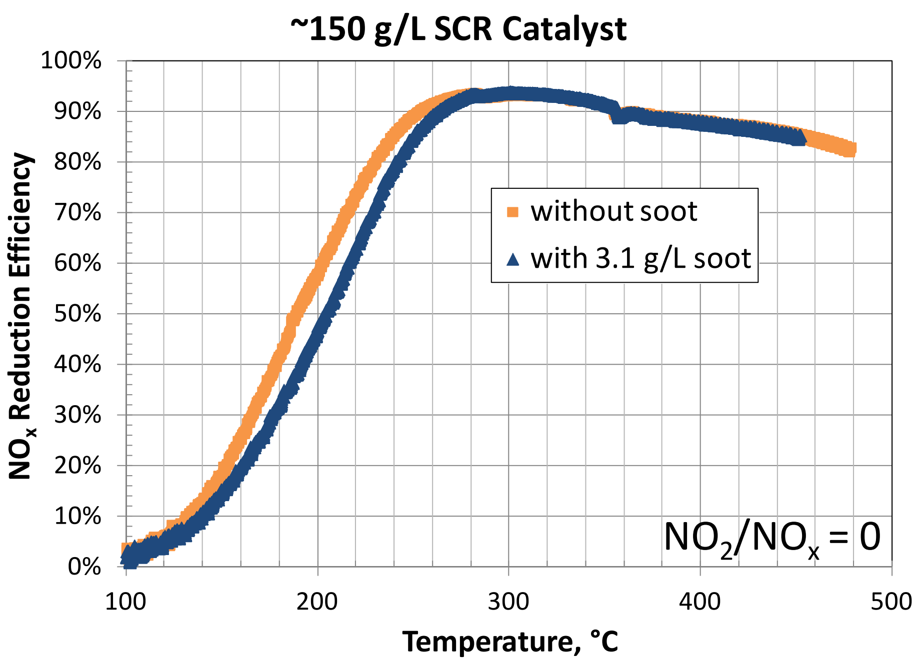


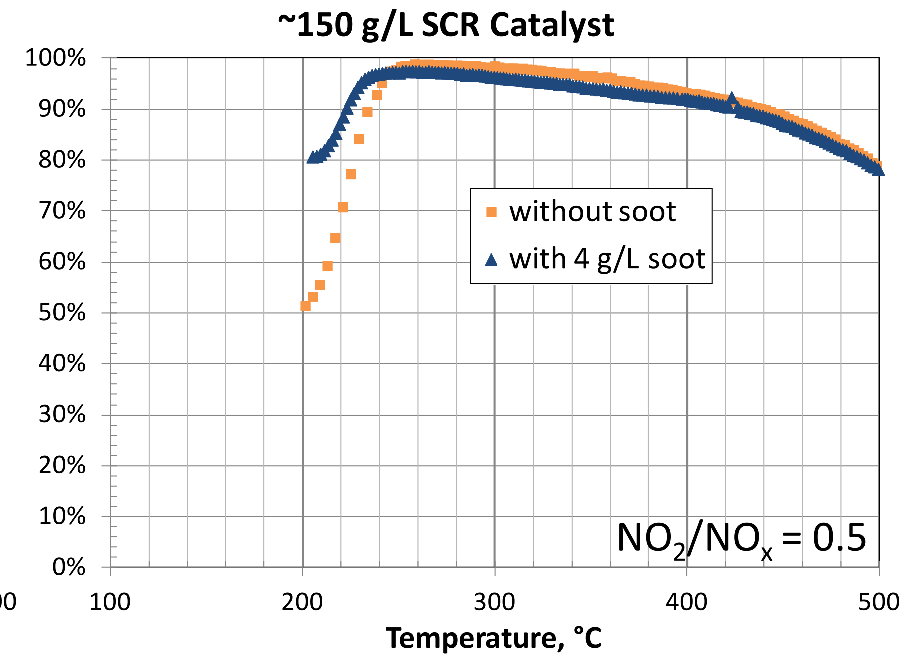
- Detrimental effect of configuration (i.e. flow through versus wall flow)*
- Catalyst deposited within porous structure (60 – 90 g/L) affects greater improvement in activity versus catalyst deposited on channel wall (90 – 150 g/L)

*Disagrees with previous SiC-based work (Boorse et al, DEER 2010)

EFFECT of SOOT on NRE

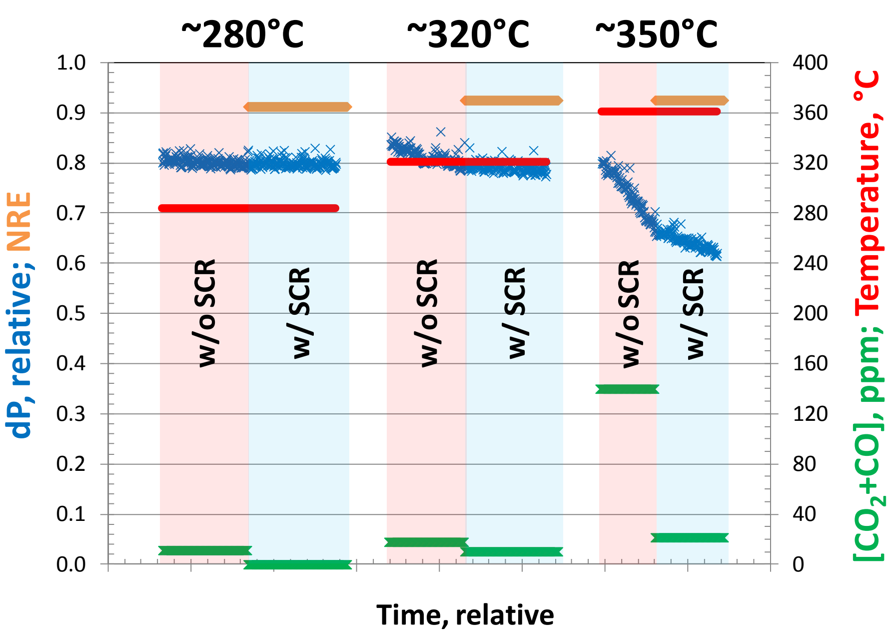
- SCR reaction, varying NO_2 fraction – 35k GHSV, ANR = 1
  - Subtle detrimental effect of the presence of soot on standard SCR reaction <280°C; >280°C no effect
  - Higher NO_2 concentrations see measureable benefiting effect of soot at low temperatures



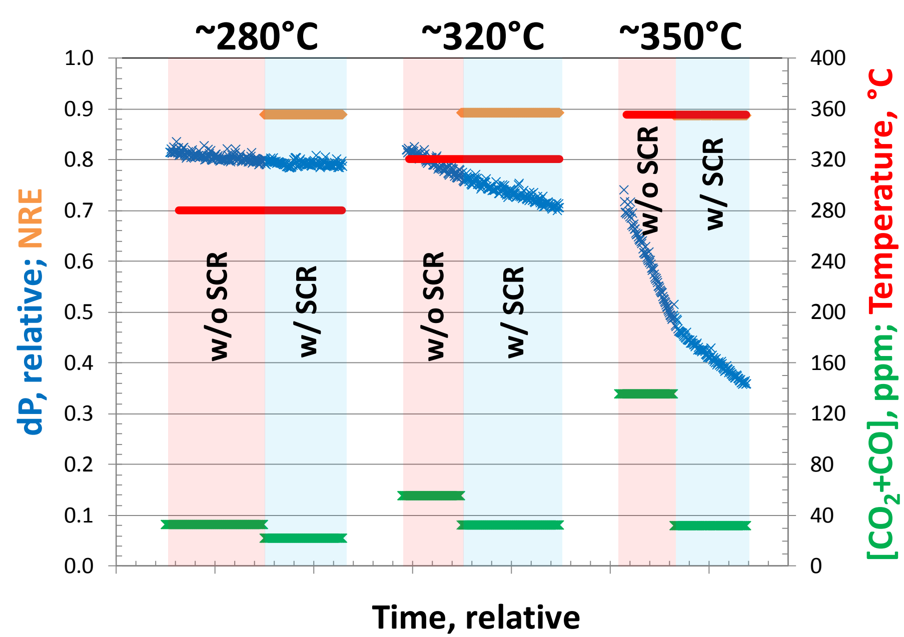


PULSED OXIDATION STUDIES

- Passive soot oxidation reaction – 150 g/L catalyst downstream
  - Effect of NO_2 concentration – 200 ppm (left) versus 500 ppm (right)
  - 1000 ppm NO_x, ANR = 1, 35k GHSV
  - More NO_2 minimizes retardation of passive soot oxidation reaction



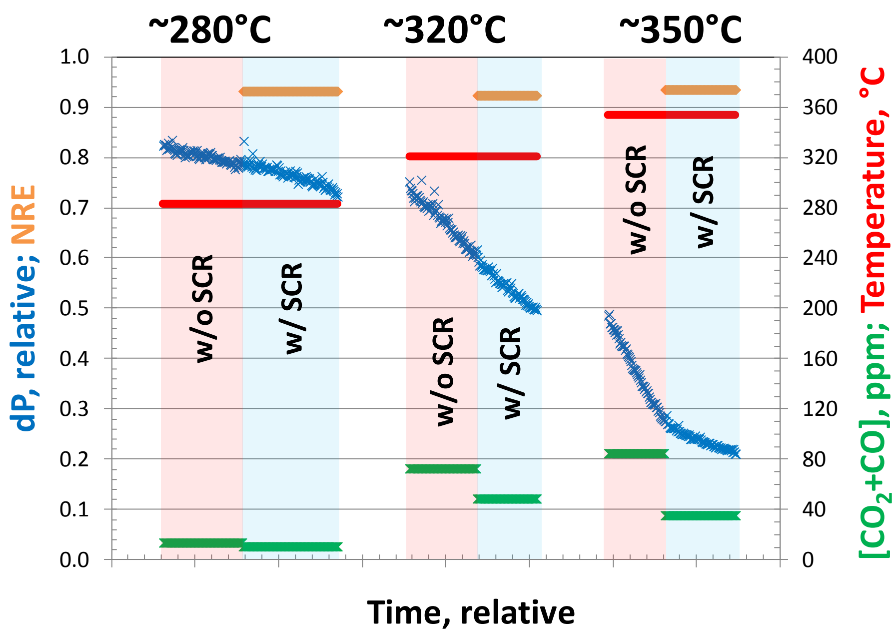
200 ppm NO_2



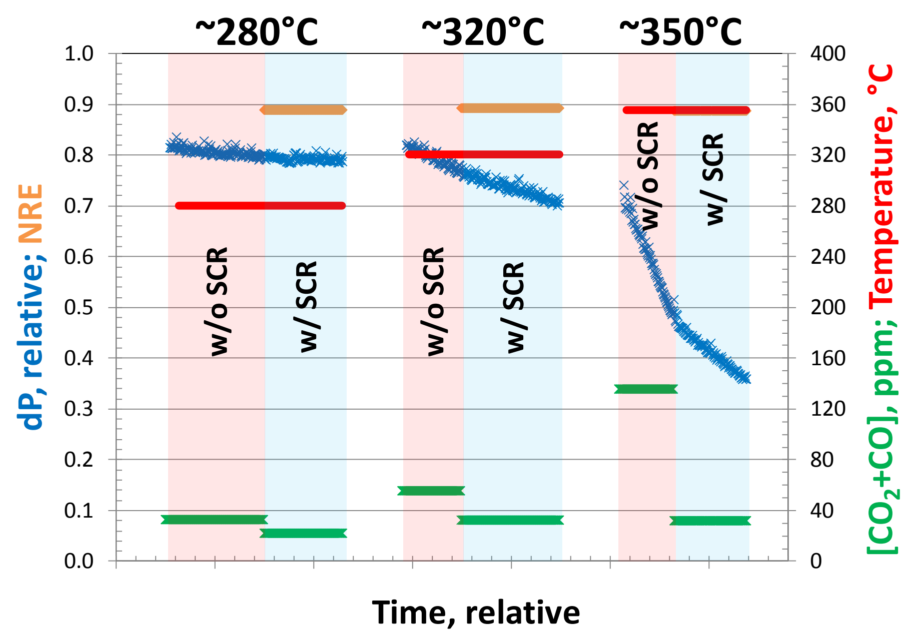
500 ppm NO_2

PULSED OXIDATION STUDIES

- Passive soot oxidation reaction – catalyst configured downstream
  - Effect of catalyst loading – 90 g/L (left) versus 150 g/L (right)
  - 500 ppm NO_2, 500 ppm NO, ANR = 1, 35k GHSV
  - Greater retardation of passive soot oxidation reaction observed <350°C with 150 g/L versus 90 g/L



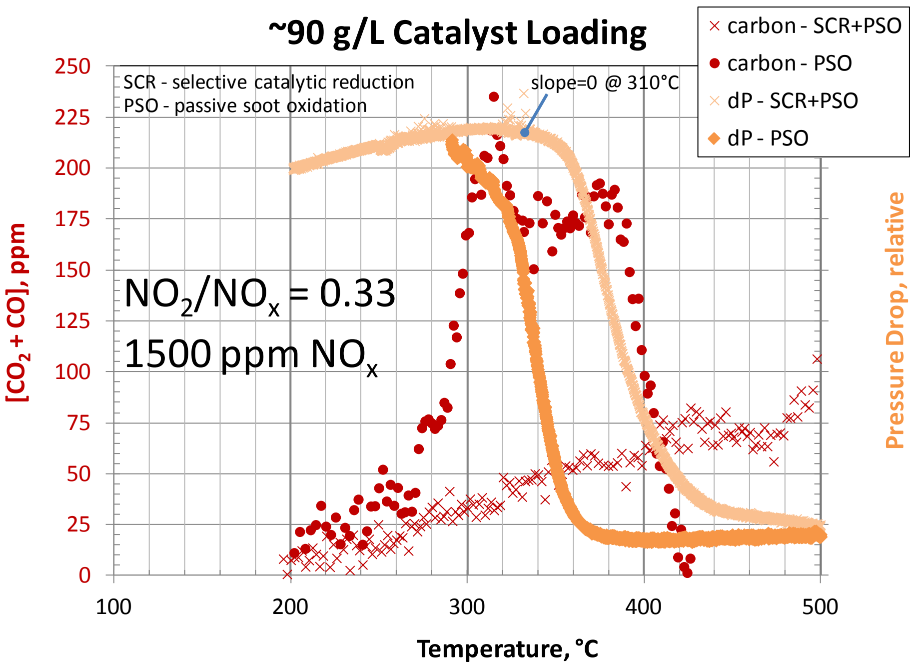
90 g/L SCR catalyst

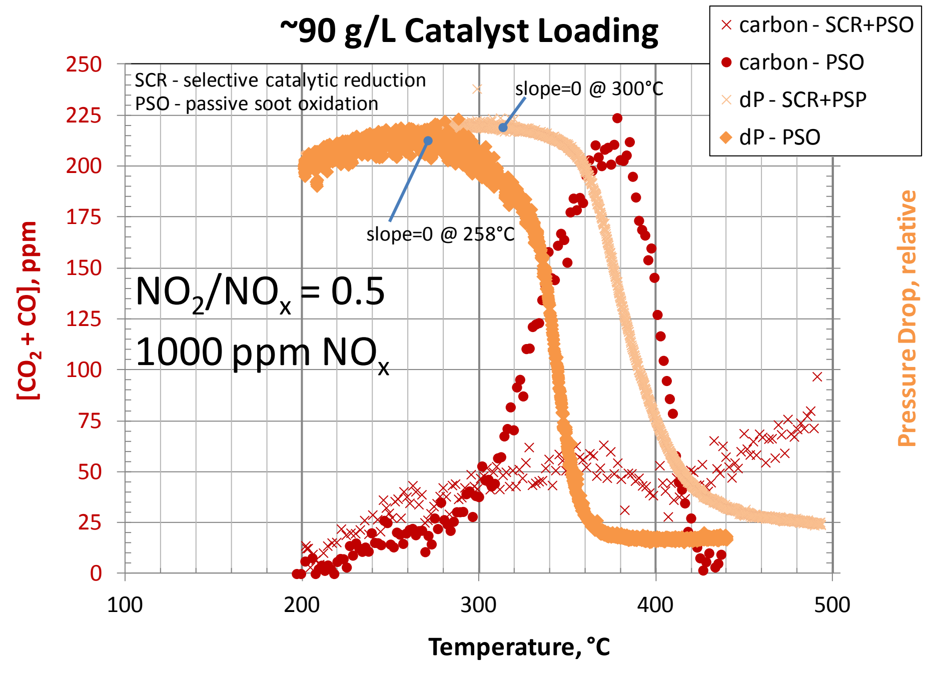


150 g/L SCR catalyst

TPO – PASSIVE SOOT OXIDATION

- 500 ppm NO_2, 35k GHSV
- ANR = 1
- 4 g/L soot loading

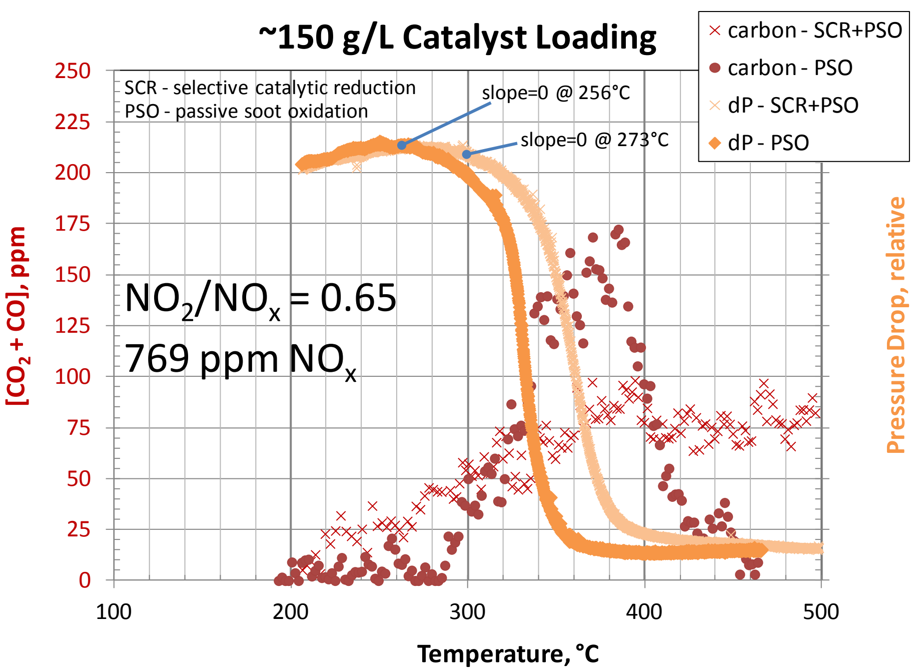


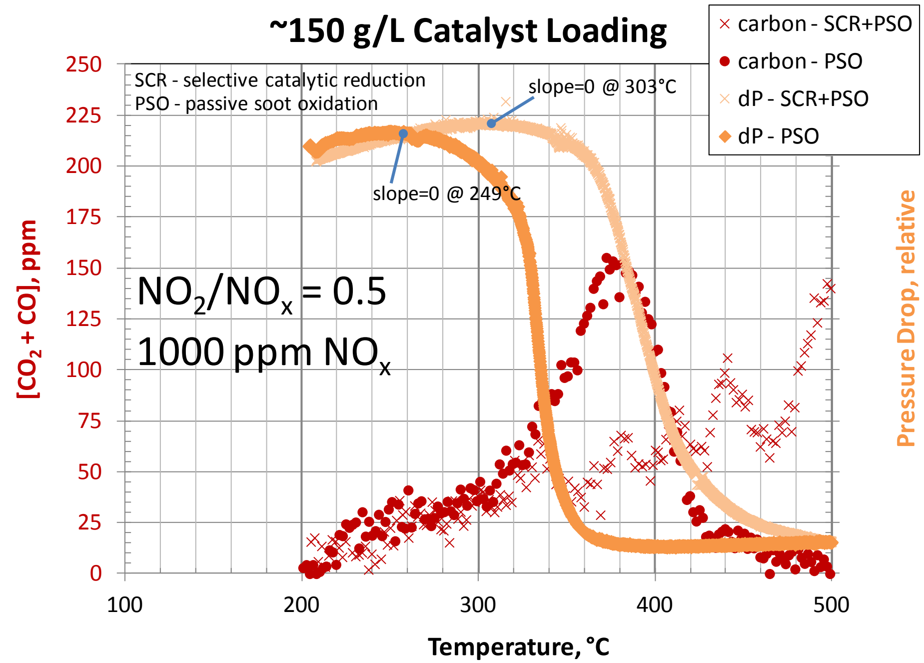


- Negligible impact of NO_2/NO_x fraction <0.5

TPO – PASSIVE SOOT OXIDATION

- 500 ppm NO_2, 35k GHSV
- ANR = 1
- 4 g/L soot loading





- Significantly less retardation of passive soot oxidation at NO_2/NO_x fraction >0.5

TPO – PASSIVE SOOT OXIDATION

- 500 ppm NO_2, 35k GHSV
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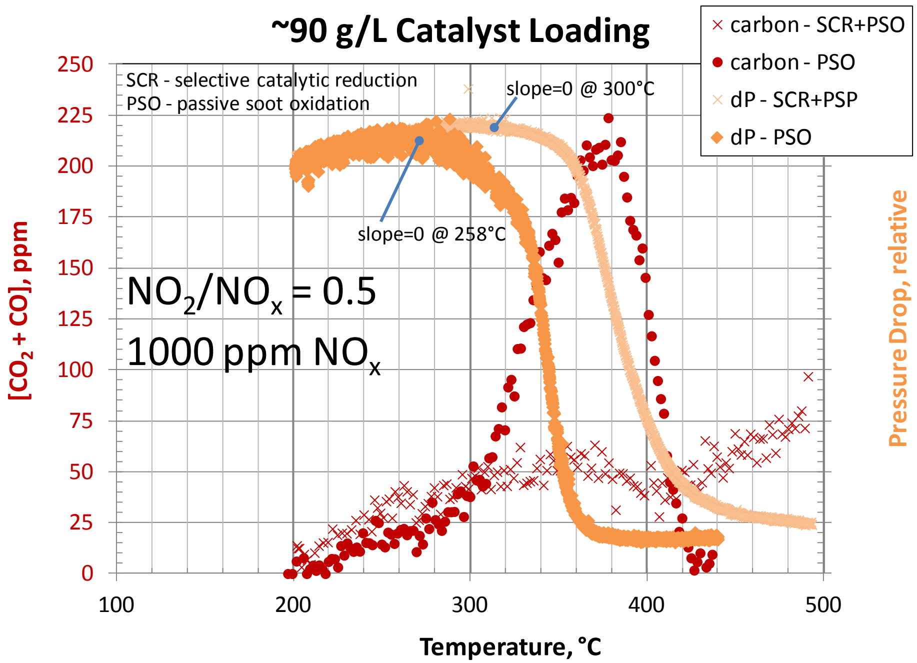
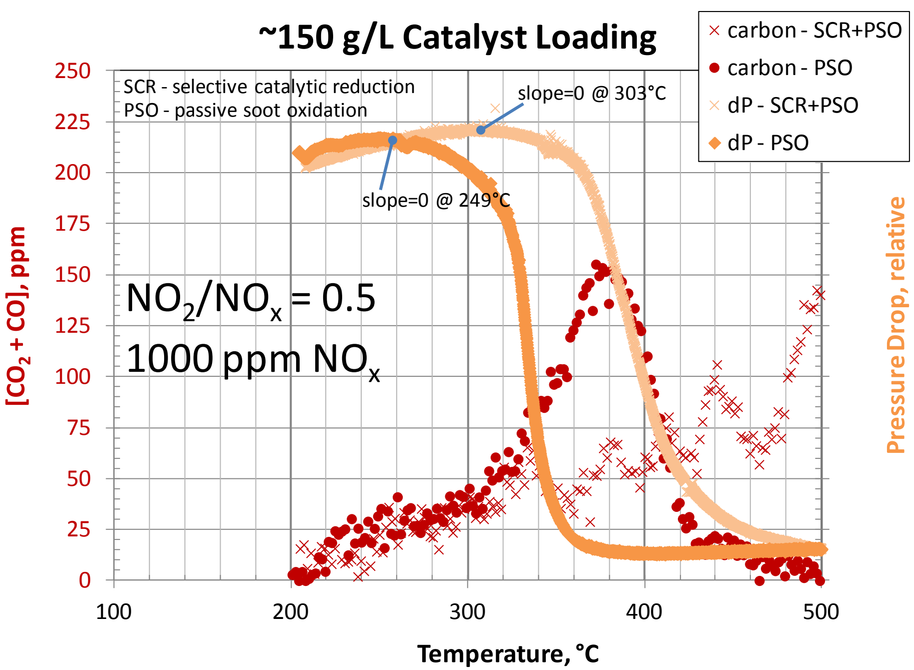
- 4 g/L soot loading





- 90 g/L SCR catalyst exhibits less retardation of PSO (~40°C) versus 150 g/L (~60°C)
- Indicates optimum catalyst loading target exists for facilitating PSO

SUMMARY DPF-SCR INTEGRATION

- Optimizing SCR catalyst wash coat
  - Catalyst better utilized embedded within wall microstructure versus channel wall
  - Location of catalyst has significant impact on wall permeability when loaded with soot
    - Preferred location is on downstream portion of filter
  - Suspected that cordierite does not facilitate optimum catalyst dispersion (and thus utilization) in porous wall microstructure
- Facilitating passive soot oxidation
  - Maximize NO_2 concentration; maximize NO_2/NO_x fraction
  - Optimize SCR catalyst loading (e.g. 90 g/L system exhibits less retardation of passive soot oxidation reaction versus 150 g/L)

ACKNOWLEDGEMENTS

- Work funded through DOE’s Vehicle Technologies Program
- BASF – Heavy Duty Systems Development Group
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