Investigation on continuous soot oxidation and NOx reduction by SCR coated DPF

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DEER. Emission Control Technologies
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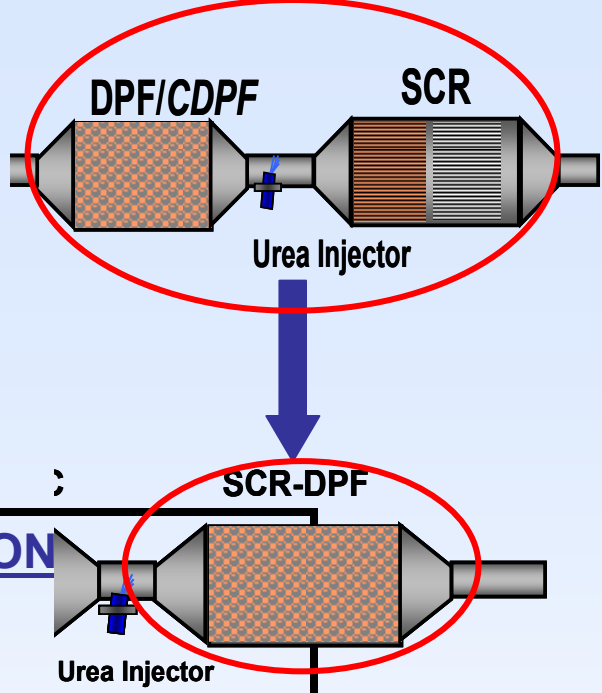
Outline

- Requirements for combined SCR-DPF catalyst
- Evaluation of CSI catalyst for NO_x removal and soot oxidation
- Engine tests on continuous soot oxidation and NO_x reduction by combined SCR-DPF
- Summary

SCR-DPF. Two Functions:

NO_x reduction and Soot oxidation



SCR with ammonia (urea)

$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$
(standard SCR reaction)

$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$
(fast SCR reaction)

$NO + ½\ O_2 \rightarrow NO_2$

$6\ NO_2 + 8\ NH_3 \rightarrow 7\ N_2 + 12\ H_2O$
(slow SCR reaction)

SOOT OXIDATION

$C + O_2 \rightarrow CO_2$

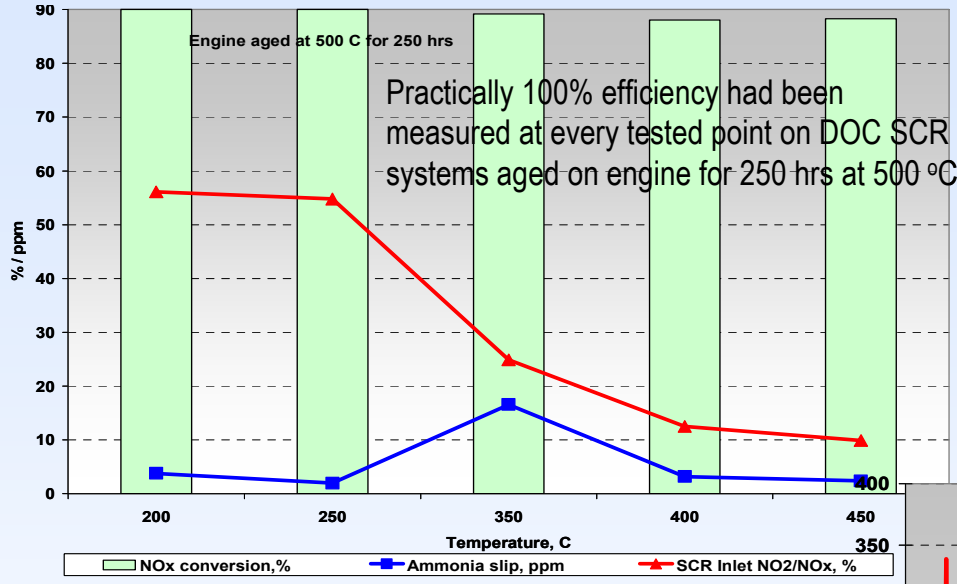
$C + ½\ O_2 \rightarrow CO$

$C + NO_2 \rightarrow CO + NO$

$C + 2\ NO_2 \rightarrow CO_2 + 2NO$

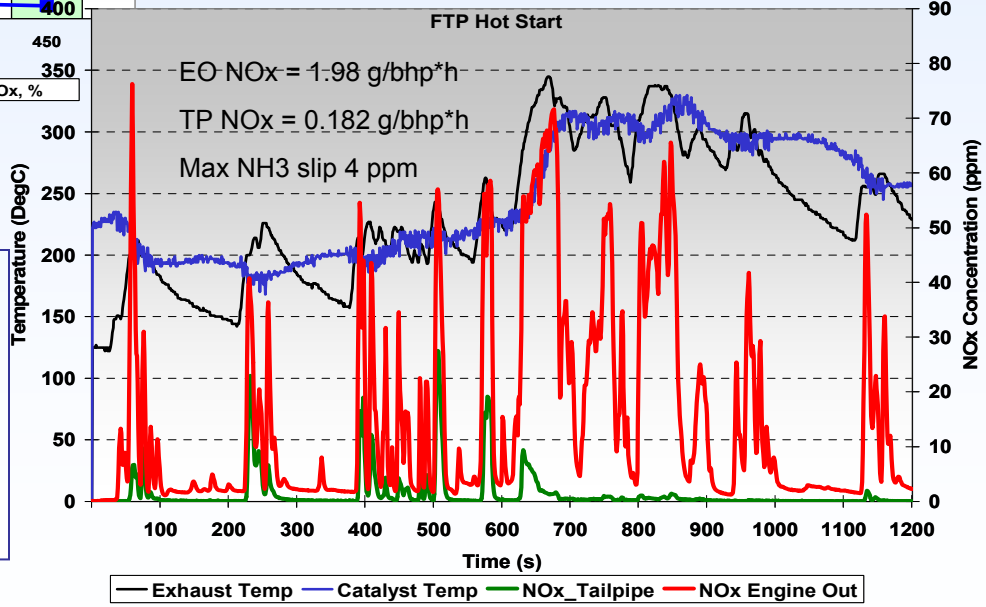
CSI SCR catalysts activity on Flow-Through substrates

More than 90% NOx reduction



Various steady state and transient tests:

> 90% NOx reduction

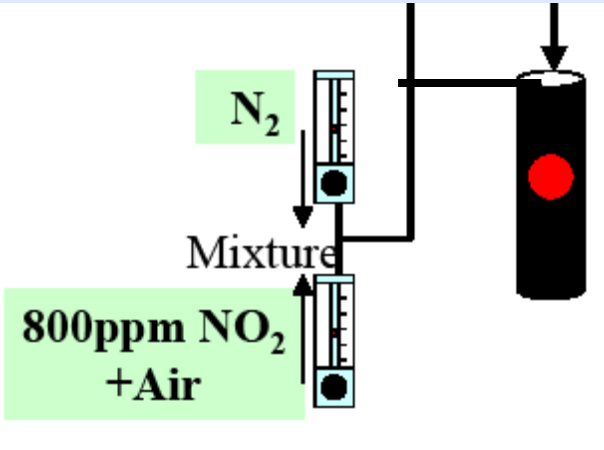


Re: "Two Catalyst Formulations – One solution for NOx after-treatment systems"

DEER 2008, August 6th.

TermoGravimetric/DerivativeThermalAnalysis (TG/DTA) test

Lab tool to evaluate catalysts soot oxidation quality



Gas composition:

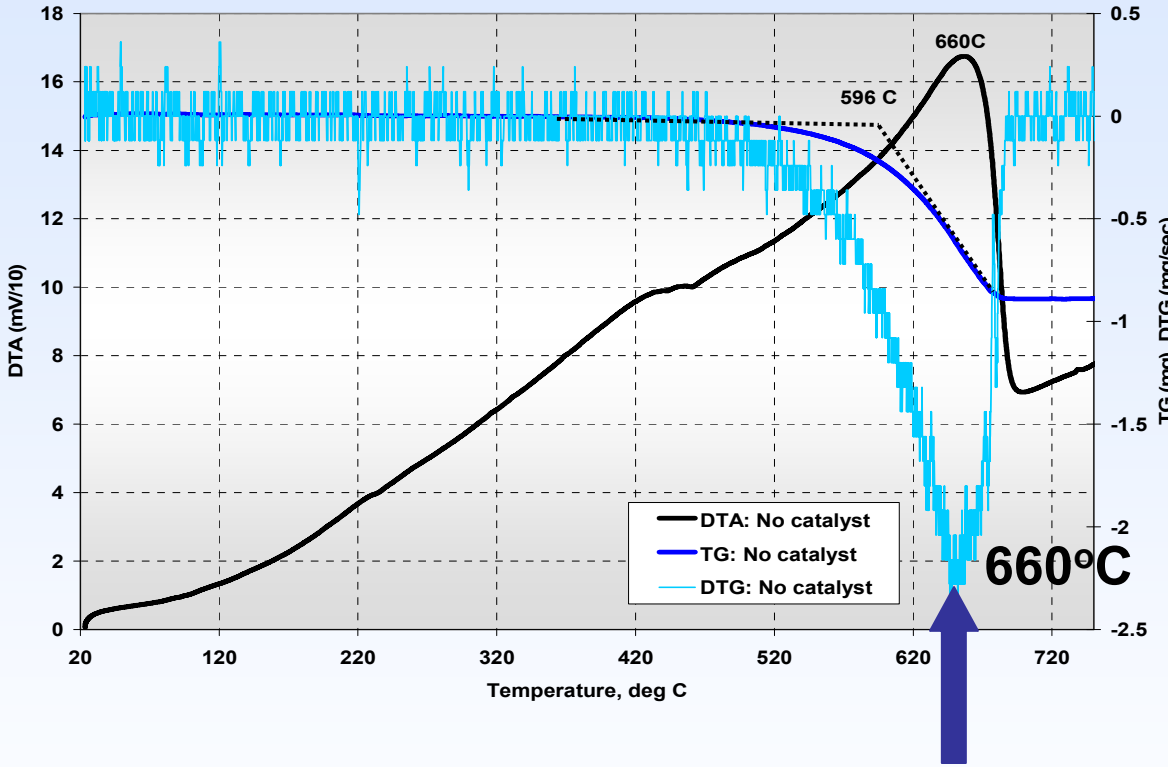
0 or 400 ppm NO_2

10% O_2

N_2 – balance

Temperature: 20ºC →500/700 ºC at 10 ºC/min

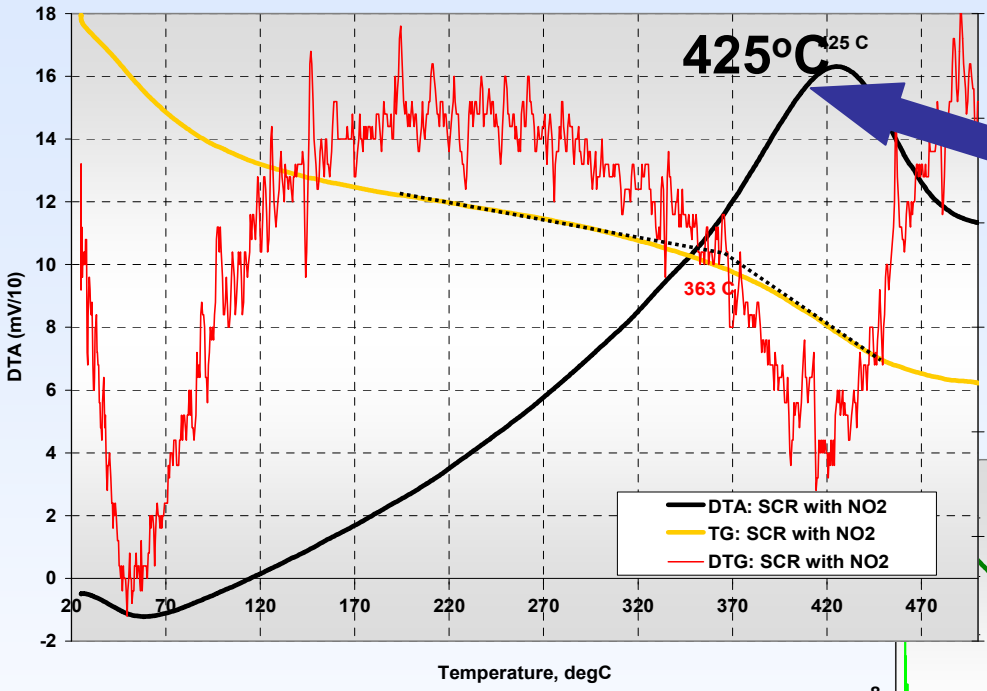
Soot (from engine) mixed with Catalyst at 5/95 wt/wt



Soot Oxidation without catalyst: peak of oxidation: **660 ºC** = soot combustion

Soot oxidation by LT-SCR. TG/DTA tests (@TCC)

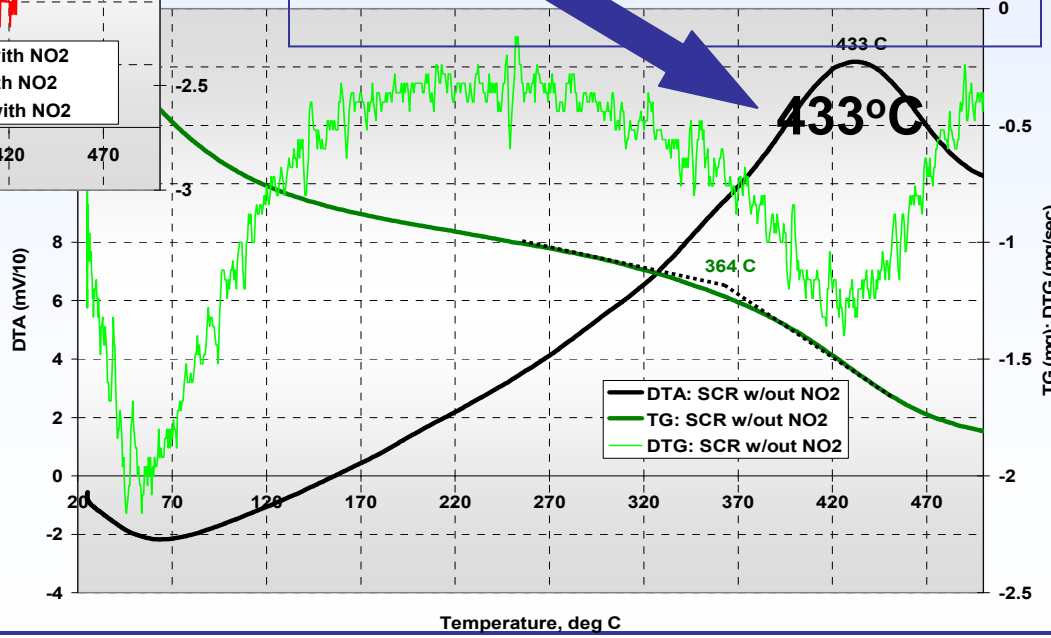
Catalytic soot oxidation



Soot Oxidation with LT-SCR catalyst:

with NO_2 in feedgas peak of oxidation: **425 °C**

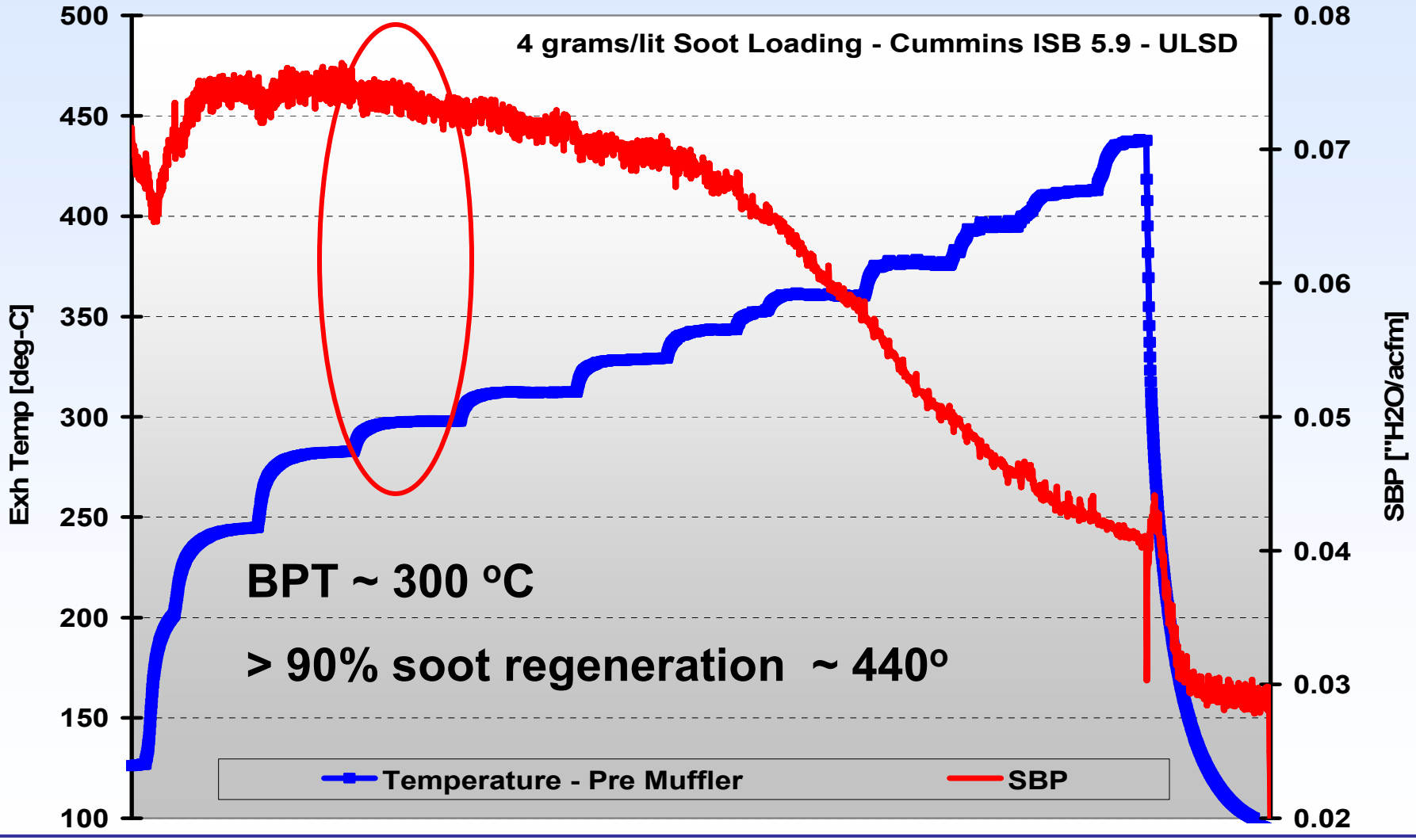
without NO_2 in feedgas peak of oxidation: **433 °C**



Catalytic Soot oxidation had been observed **with and without NO_2** in feed gas.

Balance Point Temperature Test (@ ECS)

No urea injection. 5.9L engine. 14L SCR-DPF.



SCR-DPF:
NO_x Reduction and Soot oxidation

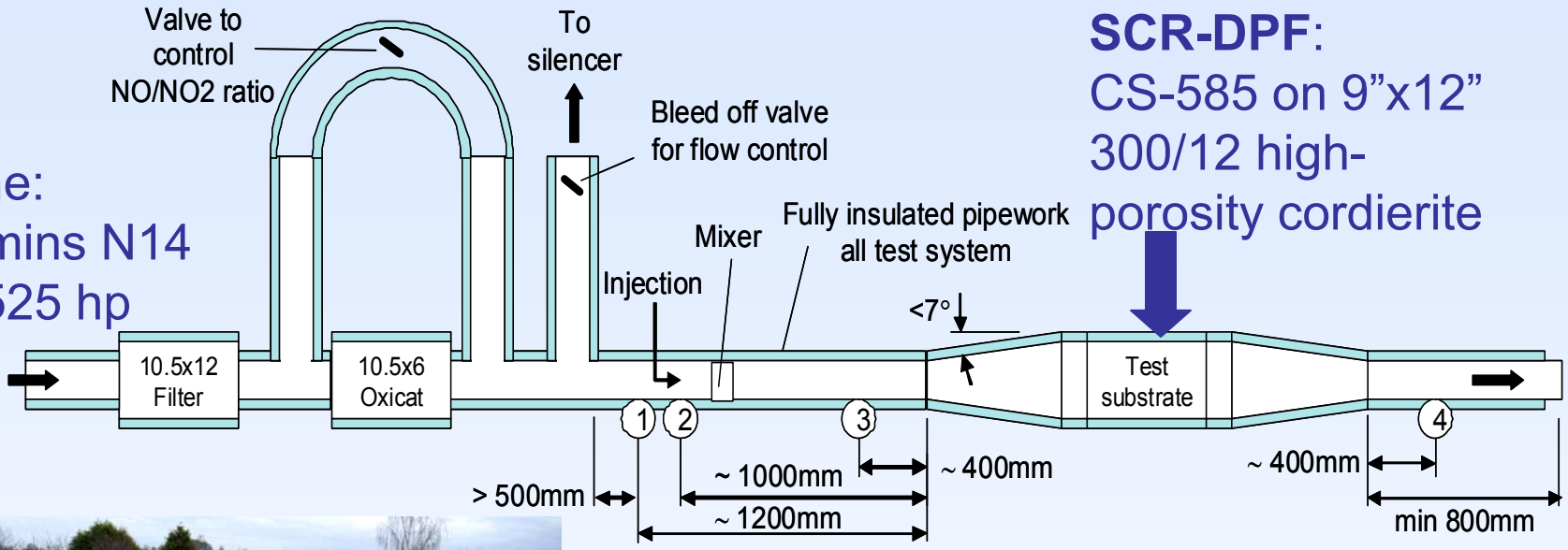
- CSI Low-temperature SCR catalyst showed
  - good SCR activity at various conditions and
  - also soot oxidation properties:
    - TG/DTA – lowering peak of soot oxidation by > 200 ^oC
    - Balance Point Temperature on engine test was found to be around 300 ^oC (in presence of NO_2)

- Big Question: would LT-SCR catalyst keep SCR and Soot oxidation properties simultaneously?

- Questions addressed in the current study:
  - does presence of soot on filter affect SCR performance
  - does urea-injection affect soot oxidation properties
  - does NO_2 concentration limit SCR or soot performance

Test Set Up (@ Eminox)

Engine:
Cummins N14
Eu2 525 hp



SCR-DPF:
CS-585 on 9"x12"
300/12 high-porosity cordierite

NOx, NO,NO2, T, P static (emissions measured with CL)
Adblue injection rate
T, P static, exh flow rate
T, P static, NOx, NO, NO2, NH3 (emissions measured with FTIR)

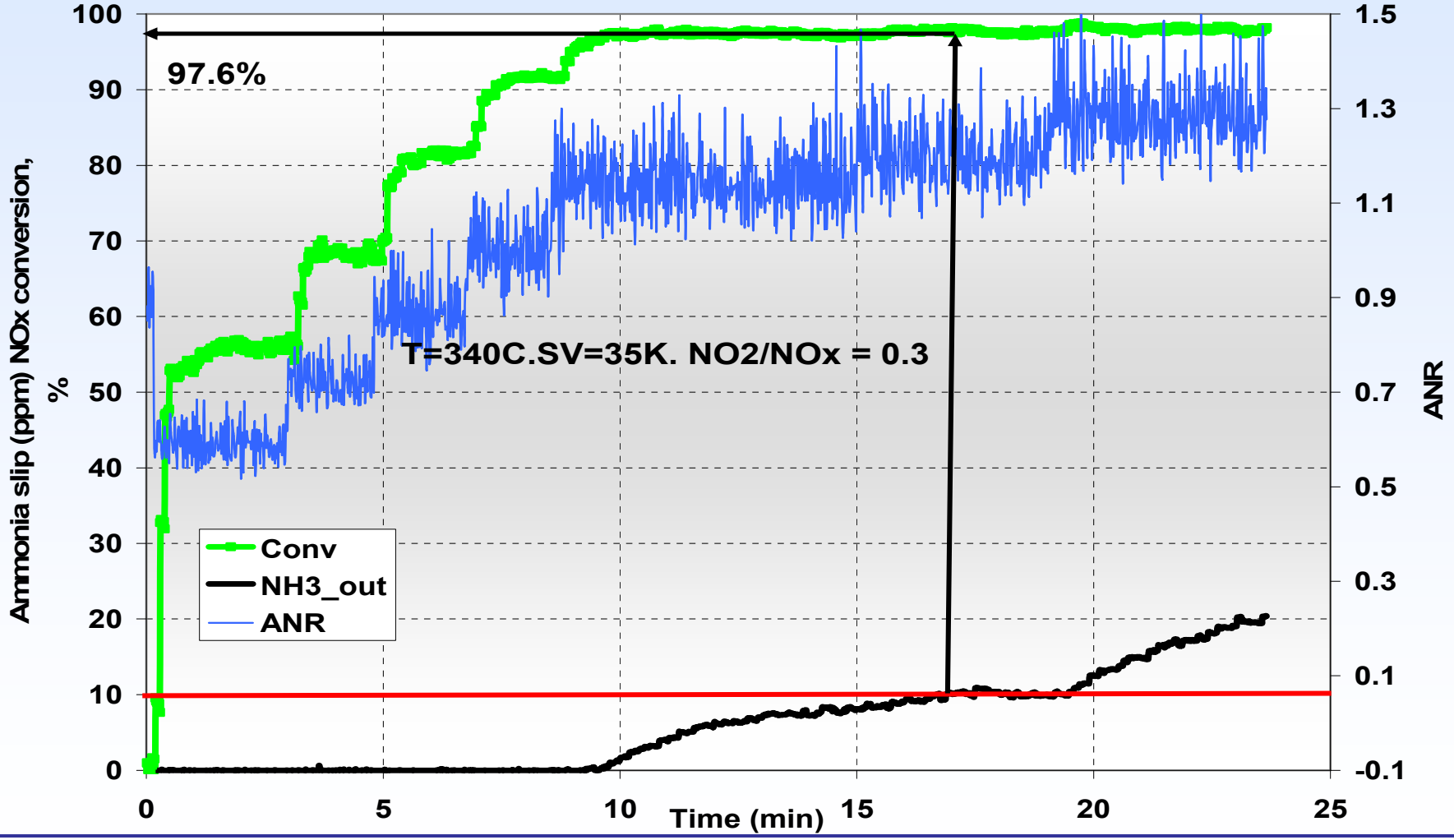
Set up enables to control:

- temperature,
- flow rate,
- injection stoichiometry
- NO/NO_2 ratio

Example of a Test on soot loaded SCR-DPF

(340°C; 35Khr^{-1}; NO_2/NO_x = 0.3, 4.9 g/L soot)

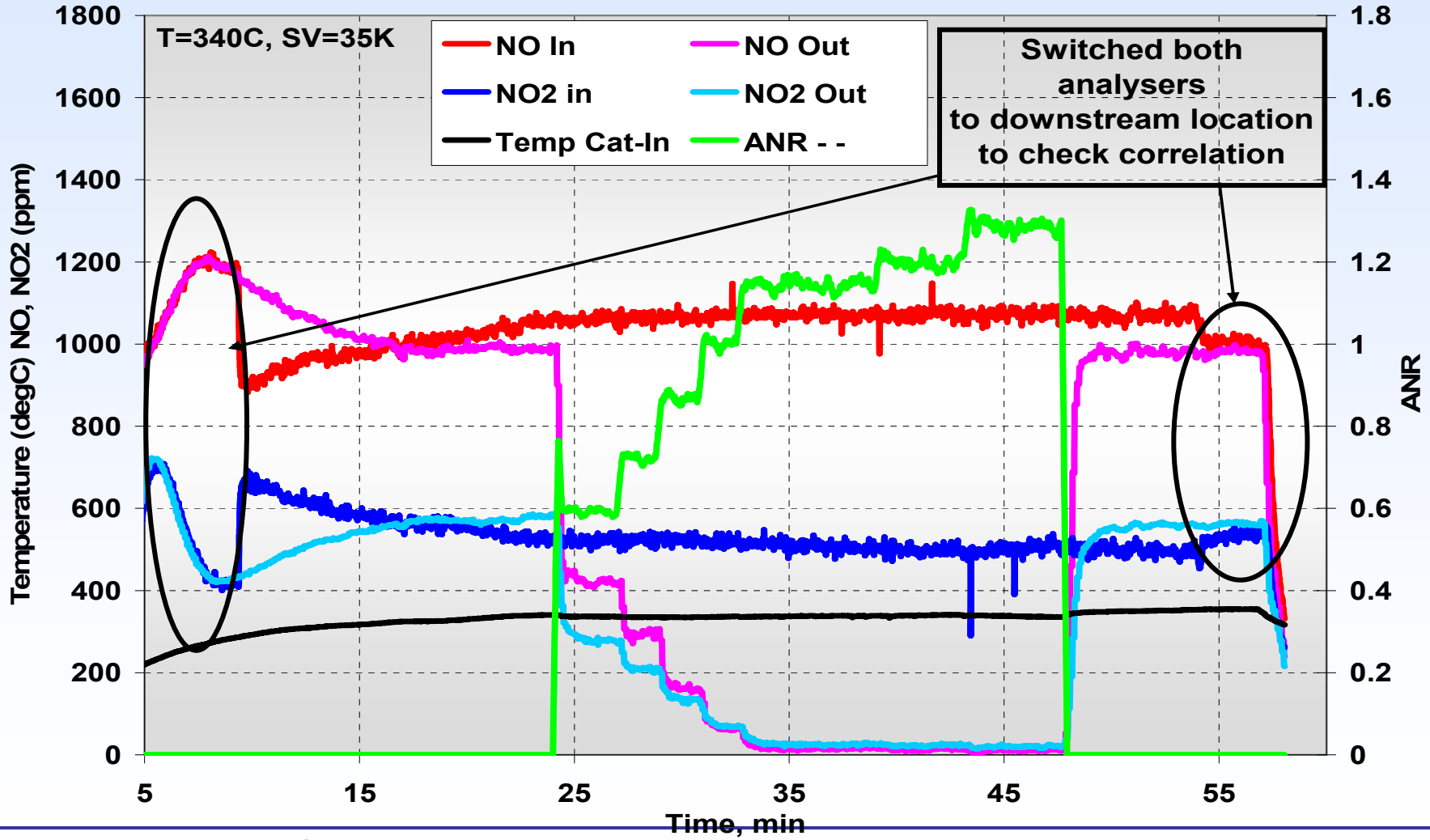
NO_x conversion; Ammonia slip; ANR



Details of a test on soot loaded SCR-DPF

(340°C; 35Khr^{-1}; NO_2/NO_x = 0.3, 4.9 g/L soot)

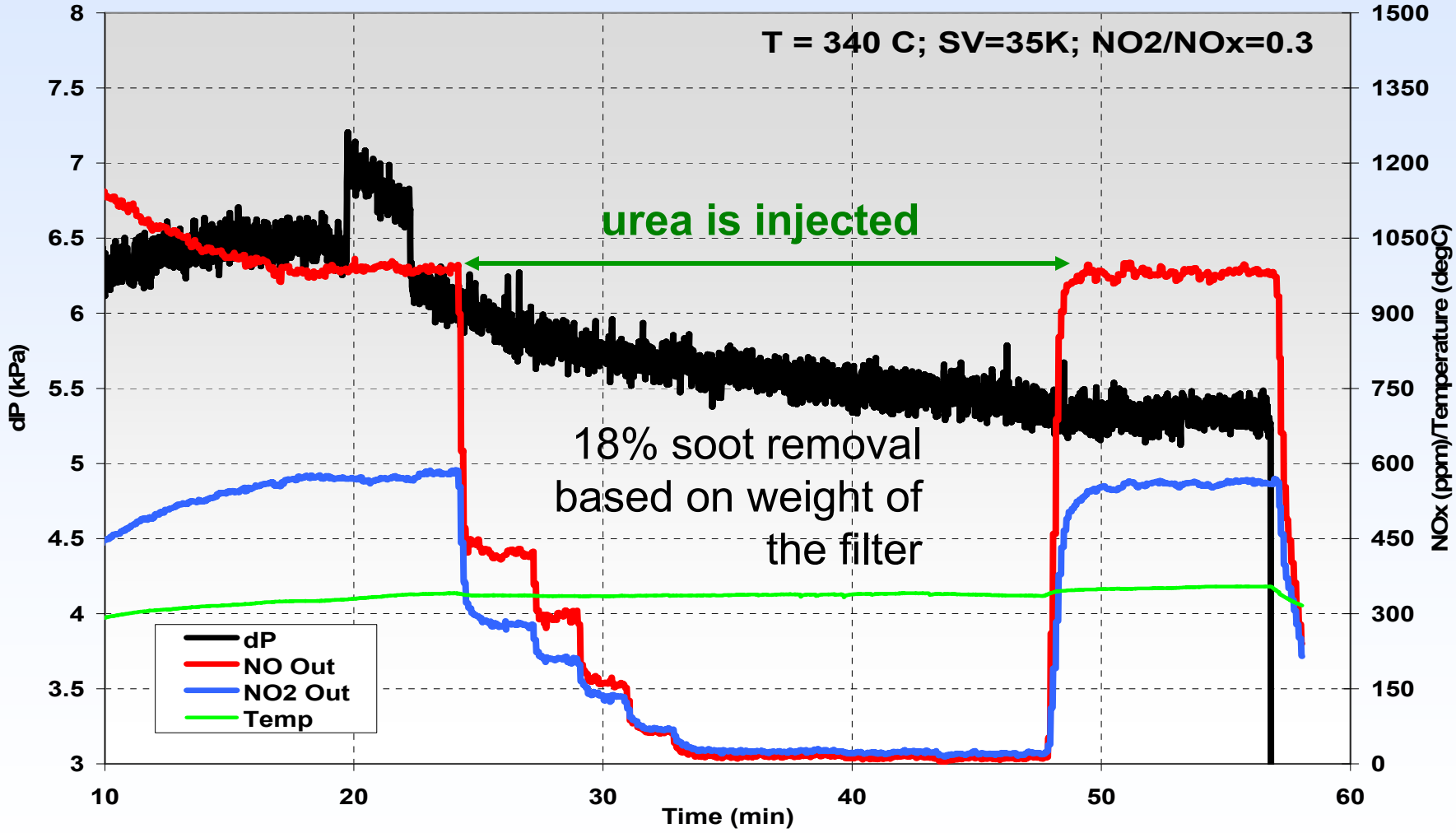
NO, NO_2 – inlet and outlet; ANR



Details of a test on soot loaded SCR-DPF (@ Eminox)

(340ºC; 35Khr^{-1}; NO_2/NO_x = 0.3, 4.9 g/L soot)

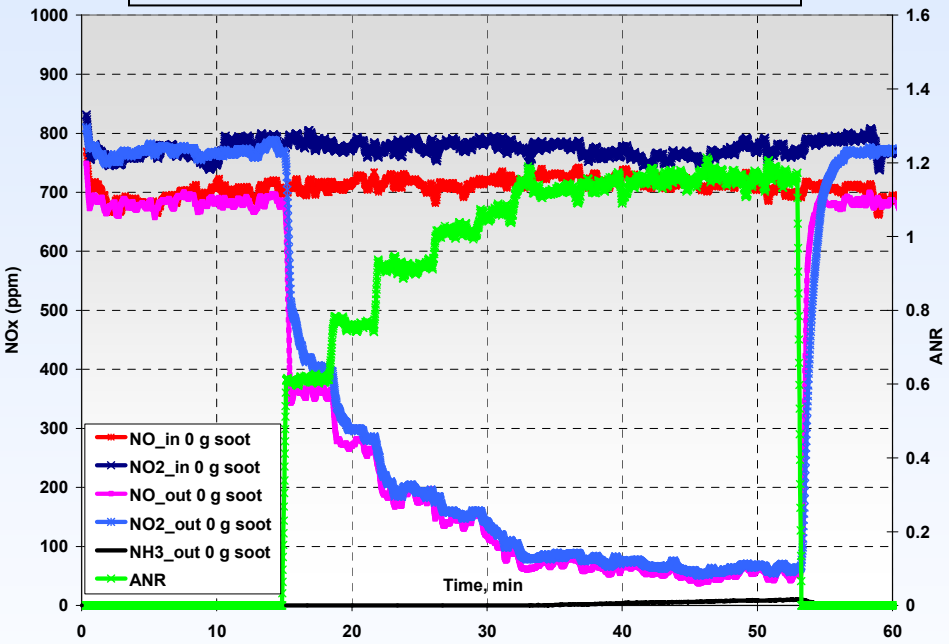
NO,NO_2 outlet; Backpressure



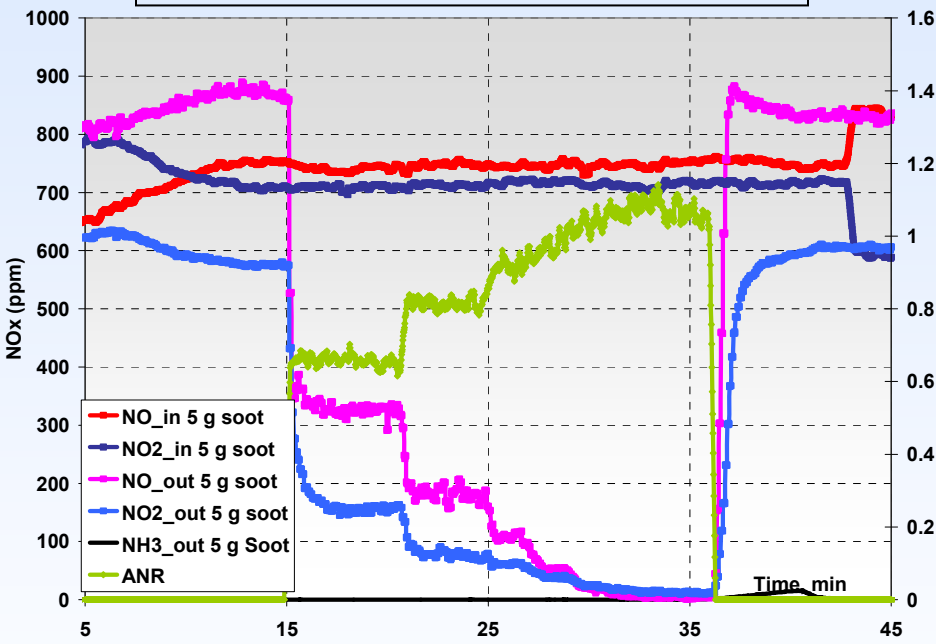
SCR activity with and without soot

No effect of soot was observed

T = 310 °C, SV=32K hr^{-1}, NO_2/NO_x = 0.5, **0 g soot**



T = 310 °C, SV=32K hr^{-1}, NO_2/NO_x = 0.5, **5.3 g soot**

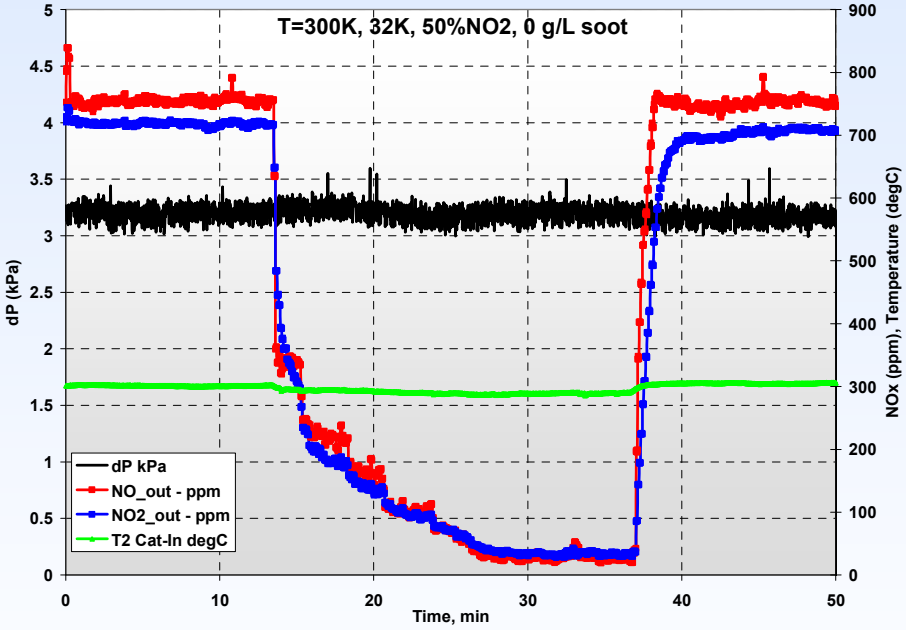


NO_2 to NO conversion due to soot oxidation did not affect SCR performance – the same high (>97%) NO_x conversion at 10 ppm NH_3 was observed during the tests

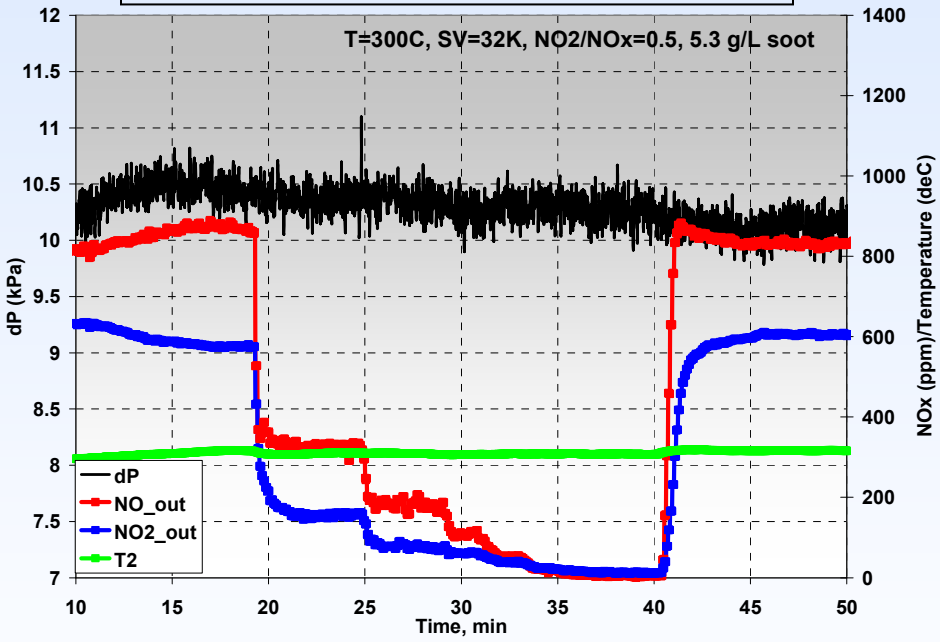
SCR activity with and without soot

Monitoring Back Pressure

T = 310 °C, SV=32K hr^{-1}, NO_2/NO_x = 0.5, **0 g soot**



T = 310 °C, SV=32K hr^{-1}, NO_2/NO_x = 0.5, **5.3 g soot**

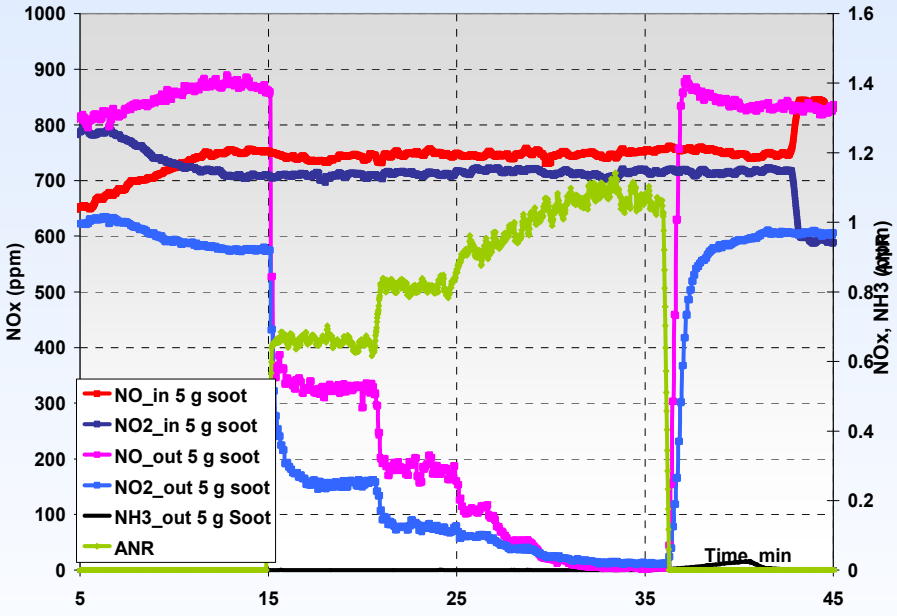


Soot oxidation was relatively low at these conditions – BP lowered about 0.5 kPa BP during 45 min of the test.

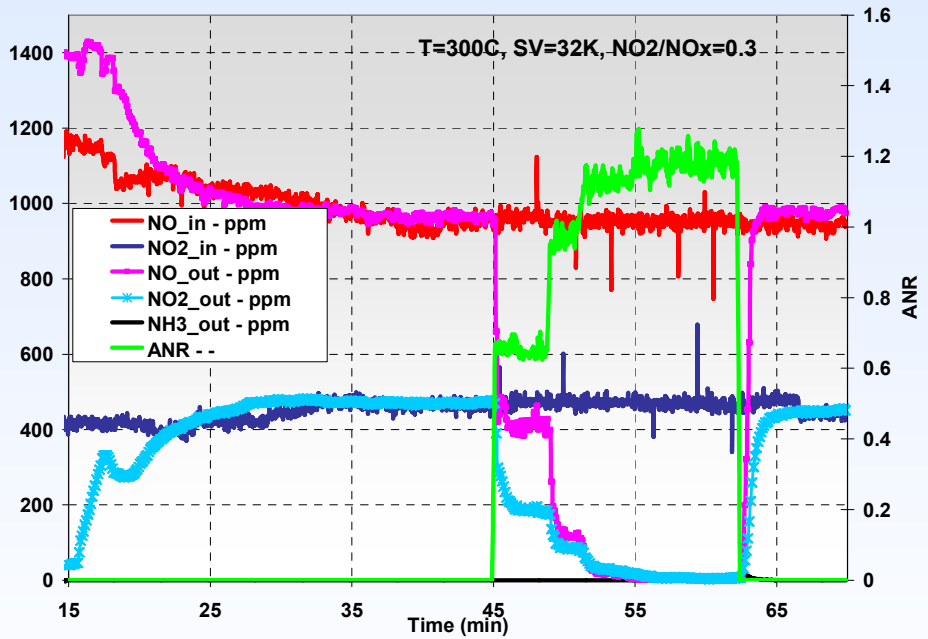
Evaluating effect of NO_2/NO_x ratio

SCR performance was not influenced by NO_2/NO_x ratio at 300°C

T = 310 °C, SV=32K hr^{-1}, **NO_2/NO_x = 0.5,** 5.3 g soot



T = 300 °C, SV=32K hr^{-1}, **NO_2/NO_x = 0.3,** 4.6 g soot

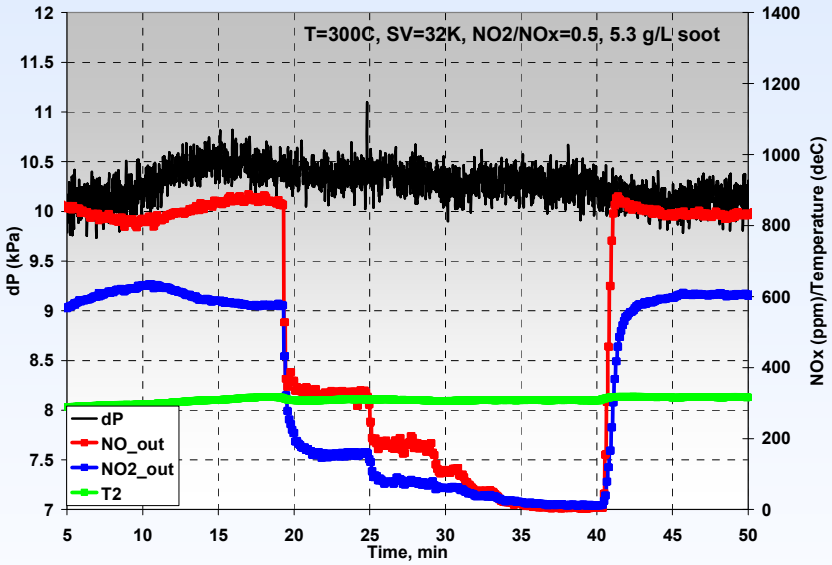


Competition for NO_2 between soot oxidation reaction and SCR reaction did not affect SCR performance – the same high NO_x conversion (>98% at 10 ppm ammonia slip) was observed during the tests

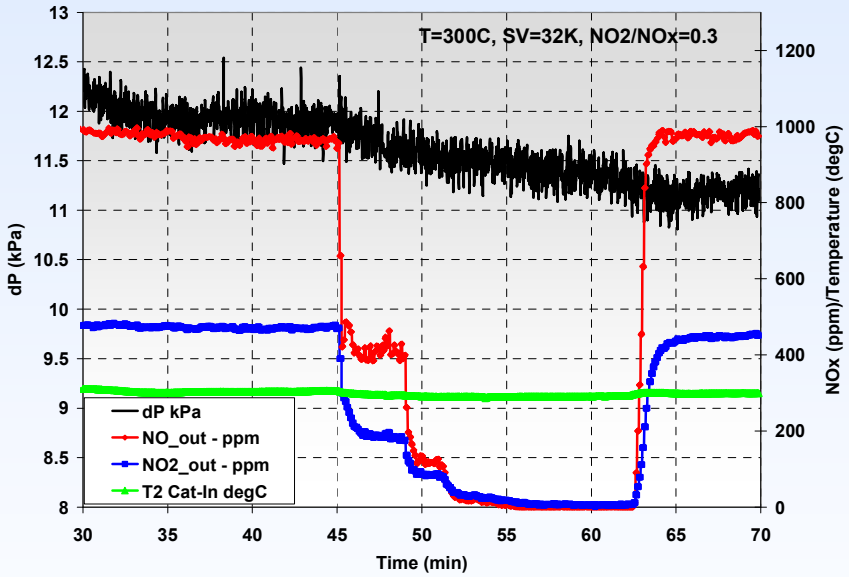
Evaluating effect of NO_2/NO_x ratio

Soot oxidation – no clear effect

T = 310 °C, SV=32K hr^{-1},
NO_2/NO_x = 0.5, 5.3 g soot
50' test: % soot removal – n/a



T = 300 °C, SV=32K hr^{-1},
NO_2/NO_x = 0.3, 4.6 g soot
70' test: 33.3% soot removal

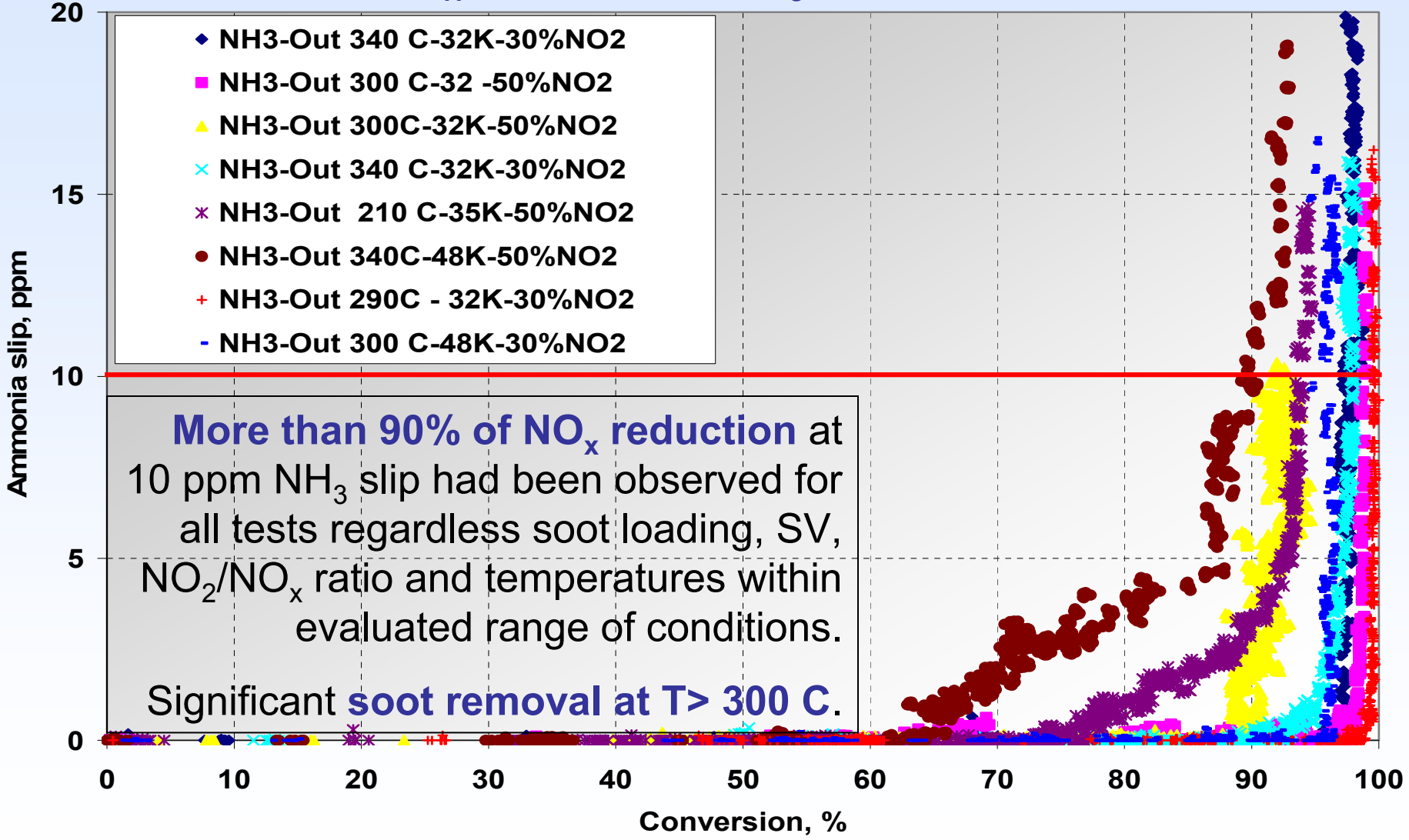


Based on BP measurements no difference in soot oxidation had been observed at 300 C for both tests.

Based on weight of the filter 33.3% soot was removed during 70 min of the test with 30% NO_2

Ammonia slip vs. NOx conversion for SCR-DPF

More than 90% NO_x @ 10 ppm NH_3 slip



More than 90% of NO_x reduction at 10 ppm NH_3 slip had been observed for all tests regardless soot loading, SV, NO_2/NO_x ratio and temperatures within evaluated range of conditions.

Significant **soot removal at T> 300 C**.

Summary of Observations

Simultaneous NO_x and Soot removal

- No negative effect of soot loading (up to 6 g/L) was observed on NO_x oxidation function of SCR-DPF
- SCR performance was not affected by concentration of NO_2 in feed gas (within 0.3-0.5 NO_2/NO_x range)
- Competition for NO_2 between SCR and passive soot oxidation did not affect rate of soot removal (within 0.3-0.5 NO_2/NO_x range)
- We did not observe slowing down in rate of soot oxidation due to urea injection.
- Soot removal was continued when NO_x reduction was higher than 90% and no NO_2 was available for soot oxidation

- Overall: simultaneous NO_x and soot removal had been confirmed.

People working on the project