Dual Layer Coated High Porous SiC for SCR Integration into DPF

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Outline

- Motivation for this development
- The high porous SiC substrate
- The first coating layer for improvement of mechanical strength
- The second functional layer: SCR catalyst
- Analysis of coated lab samples
- SCR efficiency in lab scale test
- Engine bench test data
- Summary

Need for future diesel exhaust emission systems: Euro VI/Tier 4 final and beyond

Reduction of space and costs

CO_2 reduction via the exhaust system

- Weight
- Back pressure
- Regeneration strategy – efficient control of temperature – optimal use of fuel – lower fuel comsumption

→ **Integration of $DeNO_X$ (SCR) functionality into DPF**

Literature:

SAE 2011-01-1312 → reduced packaging by SCR-DPF / SCR
SAE 2011-01-1140 → Cu zeolite on Cordierite DPF
SAE 2013-01-0840 → high porous SiC

Design of a high porous DPF substrate for SCR integration

- High porosity level (> 60%)
- High spec. Surface area

- Good mechanical strength
- Reasonable soot load limit (> 5g/l)
- Specific weight high enough
  → sufficient heat capacity

- High filtration efficiency

High wash coat loading for high NO_X conversion

Robustness and protection of catalyst

PN efficiency requirements

SiC with 65% porosity

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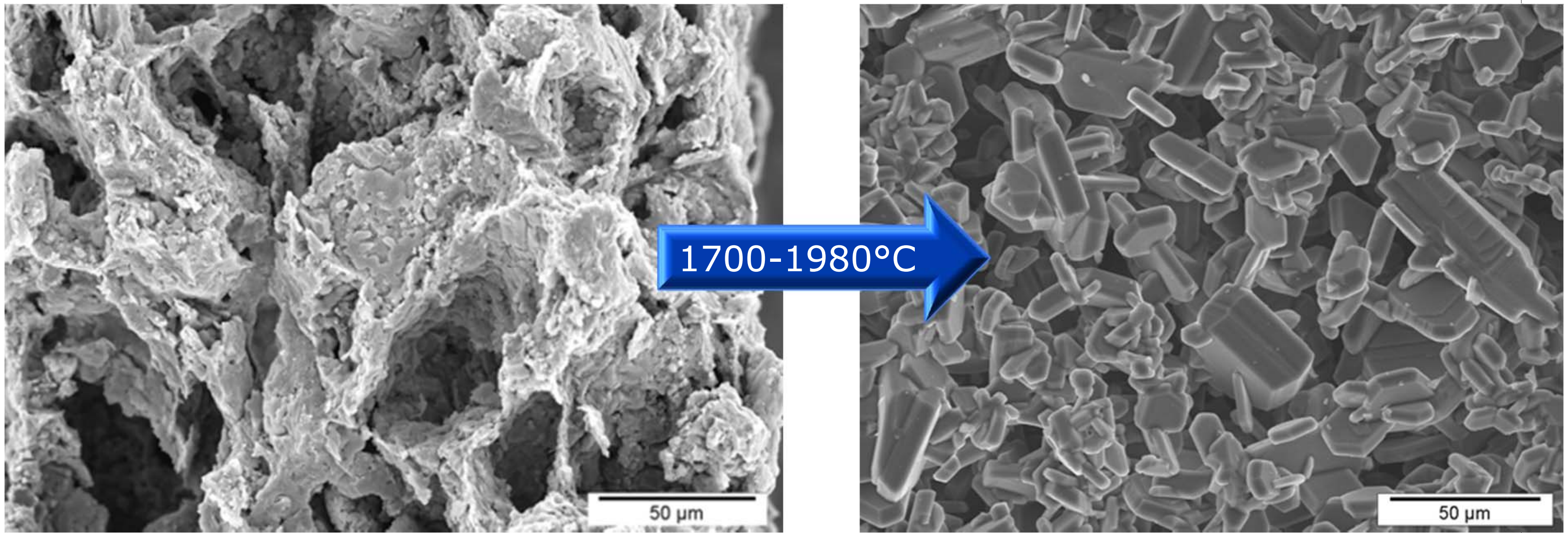
The high porous SiC substrate



SAE 2010-01-0539 | WO 2013/076045A1

CTE (RT – 800°C), 1/K	4.7
Therm. heat cond. 400°C, W/mK	2.2
Spec. heat capacity 400°C, J/gK	1.032
Bending strength, MPa	2.8
Maximum operating temperature, °C	1400

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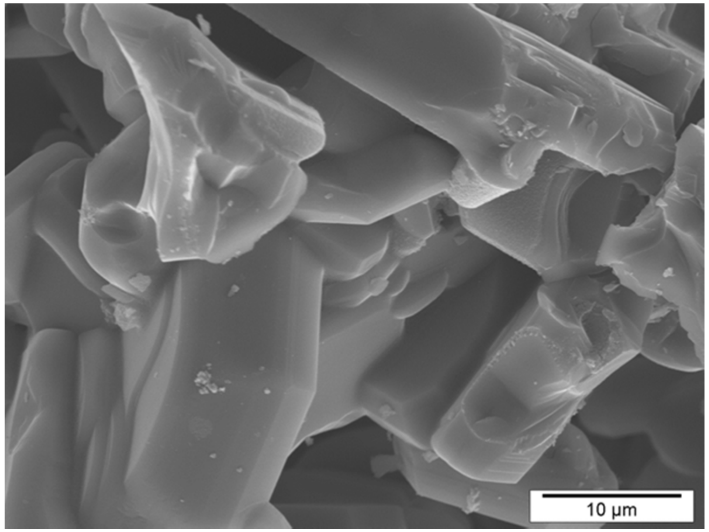
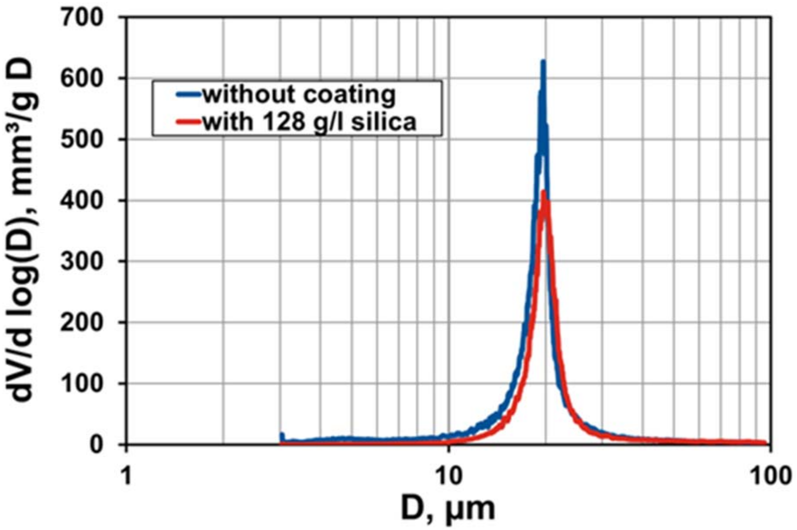
Performance of blank filters due to filtration and back pressure

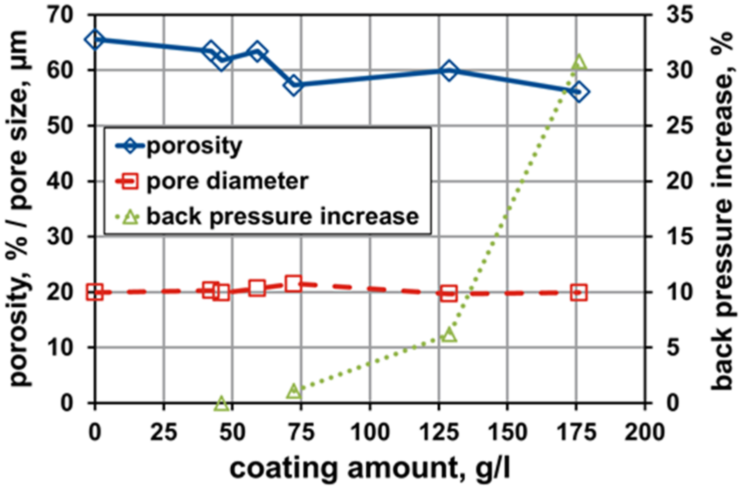
			PN efficiency		Back pressure @ 200kg/h, 450°C	
200 cpsi – 5.66“x8“			**fresh**	**3 ESC**	**fresh**	**5g/l**
58%	15-18µm	400µm	>98%	>99.9%	3.3kPa	10.1kPa
60%	15-18µm	400µm	>93%	>98%	3.1kPa	9.5kPa
65%	20-22µm	400µm	>80%	>95%	2.9kPa	9.0kPa

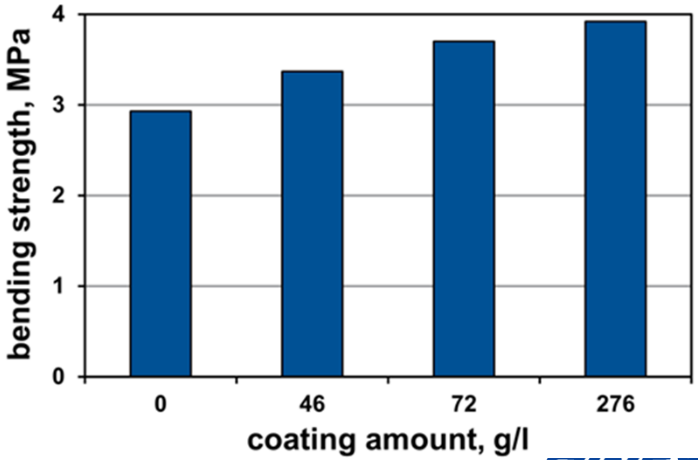
			PN efficiency		Back pressure @ 200kg/h, 450°C	
300 cpsi – 5.66“x8“			**fresh**	**3 ESC**	**fresh**	**5g/l**
58%	14-16µm	300µm	>92%	>99.9%	3.7kPa	8.8kPa
60%	14-16µm	300µm	>92%	>98%	3.5kPa	8.2kPa

First coating layer for improvement of mechanical strength









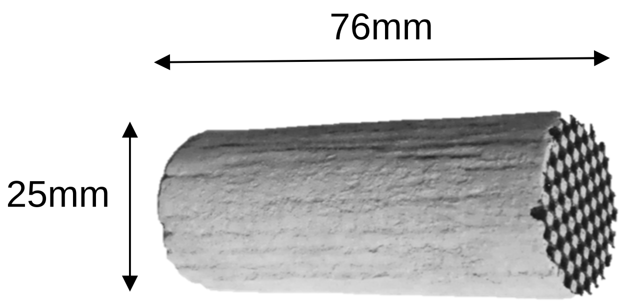
Second coating layer for SCR functionality
SCR catalyst candidates

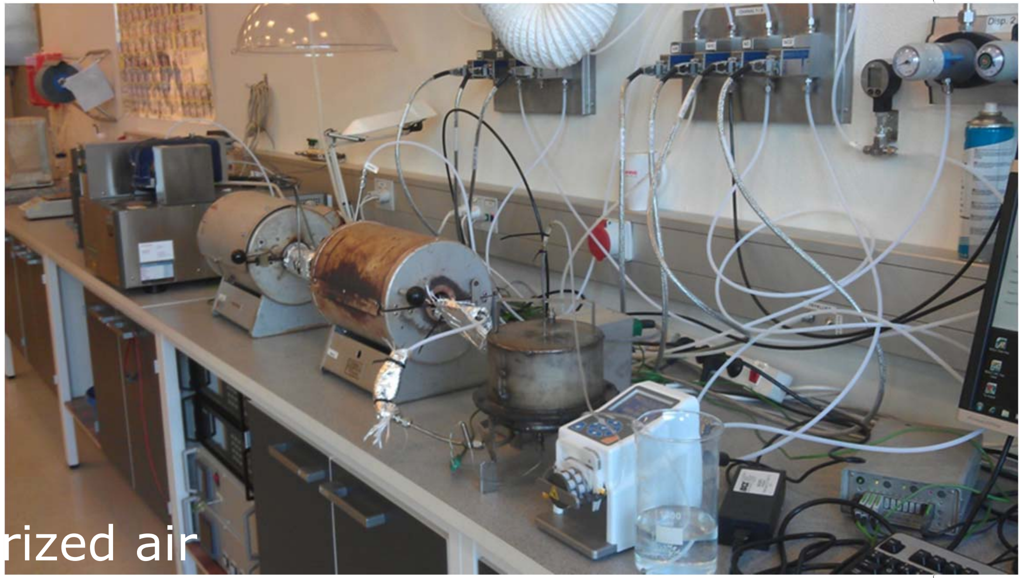
	Vanadia-based (V_2O_5 / WO_3-TiO_2)	**Cu-Zeolite** (Cu-ZSM-5)	**Fe-Zeolite** (Fe-β)	**Mixed metal oxide** (CeO_2-ZrO_2 based)
Function of every single compound	V_2O_5: SCR active center WO_3: promoter TiO_2: support	Cu: NO oxidation to NO_2 ZSM-5: host, SCR reaction, NH_3 storage	Fe: NO oxidation to NO_2 Beta: host, SCR reaction, NH_3 storage	CeO_2: SCR active center, O_2 storage ZrO_2: thermal stabilizer, NH_3 storage
SCR activity	High (dependent on V_2O_5 content, best: ~ 3 wt%)	High at low temperatures steadily decreasing beyond 350°C	High (at high temperatures up to 600°C, above NH_3 over-consumption) Low (< 300°C)	High (variable temperature window dependent on Ce/Zr ratio, dopants, surface area + water content)
SCR temperature interval	T_{50}: 200°C ≥ 90%: 300°C – 500°C	T_{50}: 180°C ≥ 90%: 250°C – 400°C	T_{50}: 300°C ≥ 90%: 400°C – 650°C	T_{50}: ~ 250°C or lower ≥ 90%: ~300°C – 500/550°C dependent on Ce/Zr ratio + dopants
NH_3 storage	Low	High	High	Medium
N_2O formation	Increasing formation at >400°C (at 10 ppm NH_3 slip)	High formation tendency even at low temperatures	No formation Reduces N_2O to N_2 above 400°C	Low formation tendency
Toxicity	V_2O_5 volatility (>690°C)	Concerns due to $CuSO_4$ creation	No	No/low

Lab sample specifications

Sample ID	First layer	Second layer
#FeZ01	—	Fe-β-zeolite, 120g/l
#FeZ02	—	Fe-β-zeolite, 60g/l
#FeZ03	SiO_2, 60g/l	Fe-β-zeolite, 65g/l
#CeZr01	$CeO_2/ZrO_2/Nb_2O_5$ nano slurry, 160g/l	—
#CeZr02	$CeO_2/ZrO_2/Nb_2O_5$, 130g/l	—
#CeZrFeZ01	—	$CeO_2/ZrO_2/Nb_2O_5$, 50g/l + Fe-β-zeolite, 50g/l
#CeZrFeZ02	SiO_2, 60g/l	$CeO_2/ZrO_2/Nb_2O_5$, 50g/l + Fe-β-zeolite, 40g/l
#CeZrFeZ03	$CeO_2/ZrO_2/Nd_2O_3/Pr_6O_{11}$ nano slurry, 55g/l	Fe-β-zeolite, 55g/l

Test of lab samples





- Main gas flow: pressurized air
- NO concentration: 250/500 ppm
- NO_2 concentration: 250/0 ppm
- NH_3 concentration: 500 ppm
- Water content: 10 %
- Space velocity: 31,000/h (normalized 20°C, 1013 hPa)
- (50,000/h @ 200 °C – 75,000/h @ 450 °C)
- Temperature range: 200 – 450 °C

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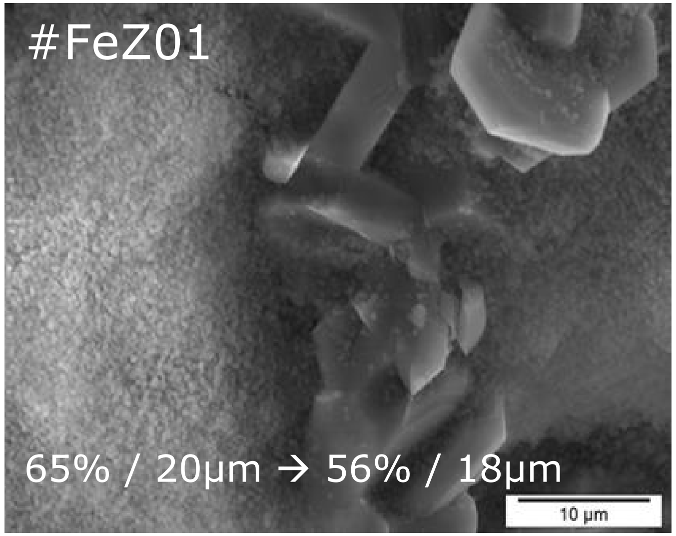
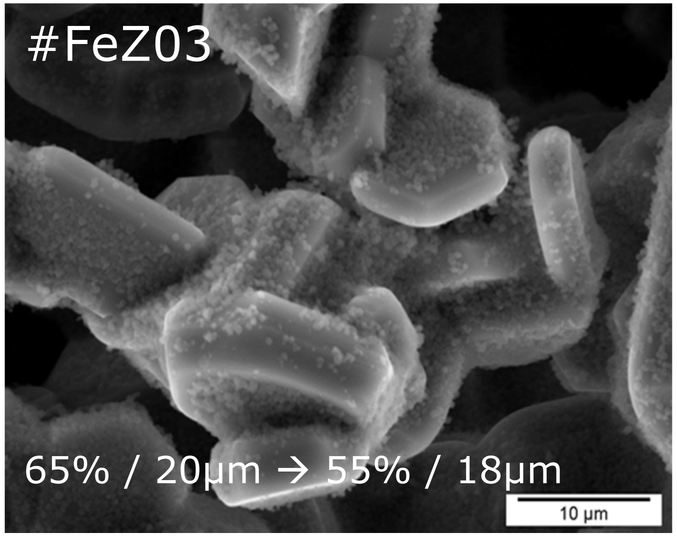
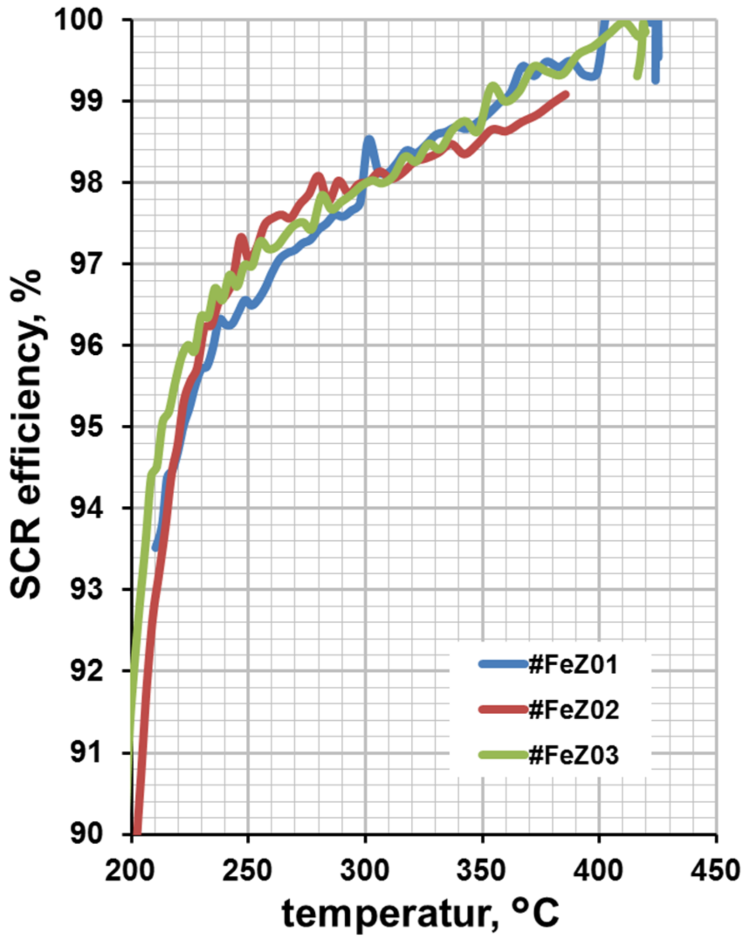
Fe-β zeolite







NO_2 / NO_X ratio was adjusted to 50 %

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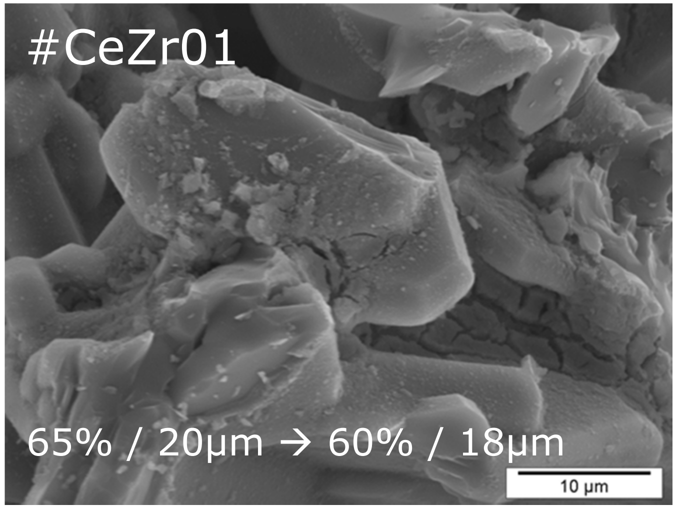
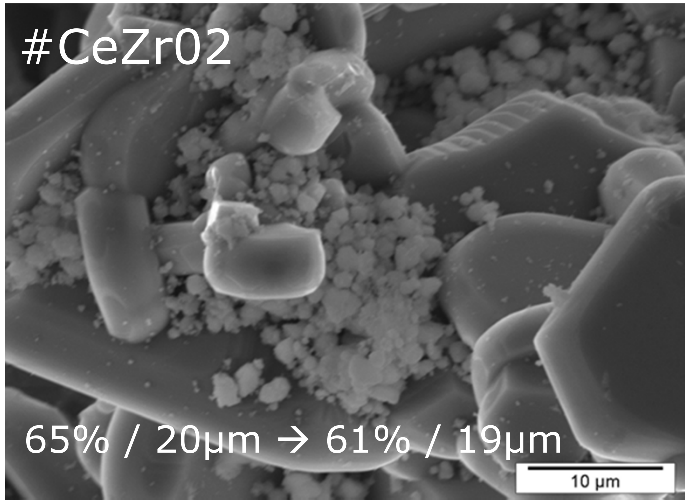
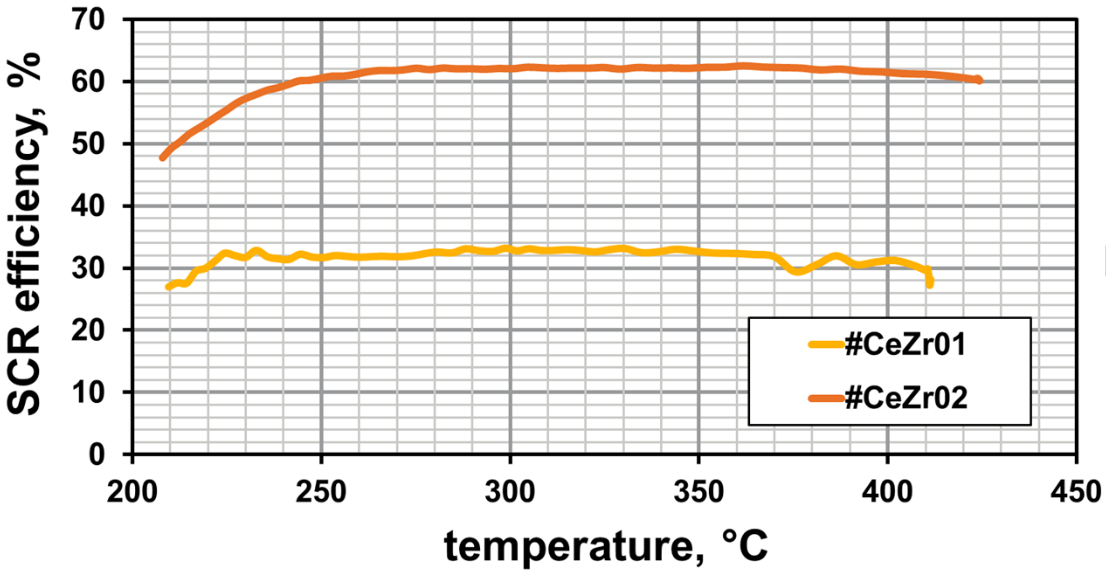
CeO_2-ZrO_2 based mixed metal oxides

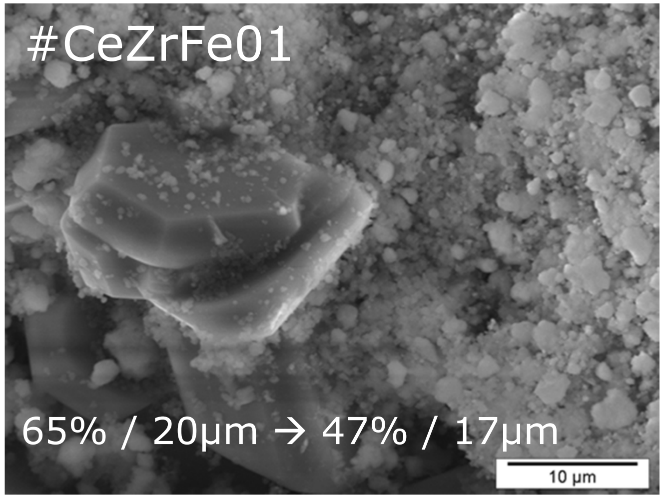


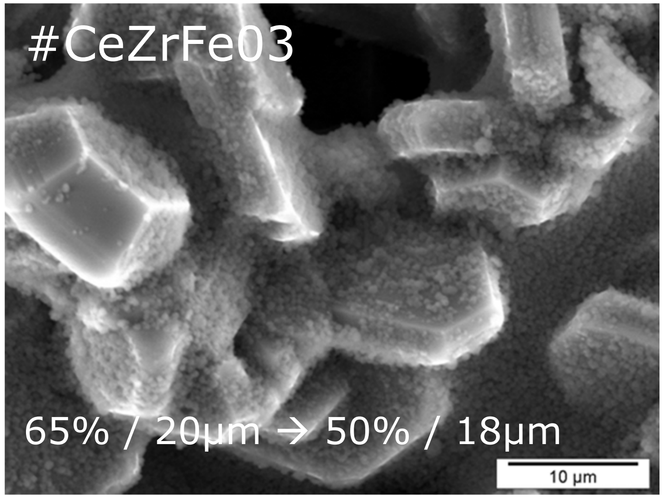


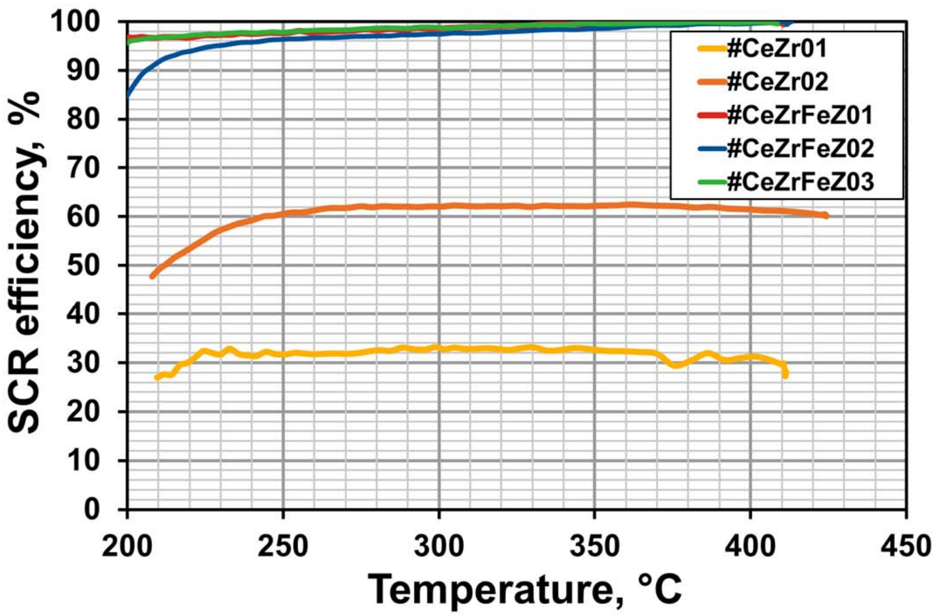


NO_2 / NO_X ratio was adjusted to 50 %

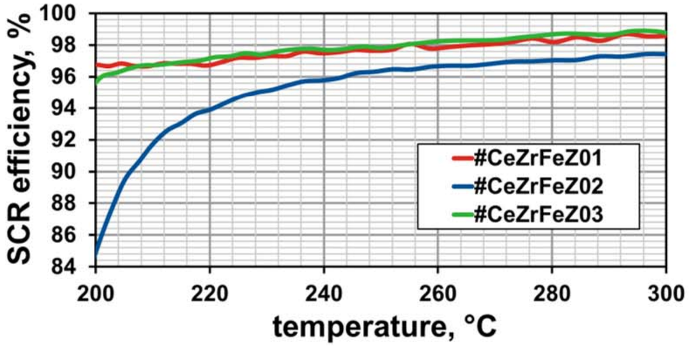
The combinations
Fe-β-zeolite with CeO_2-ZrO_2 mixed metal oxides



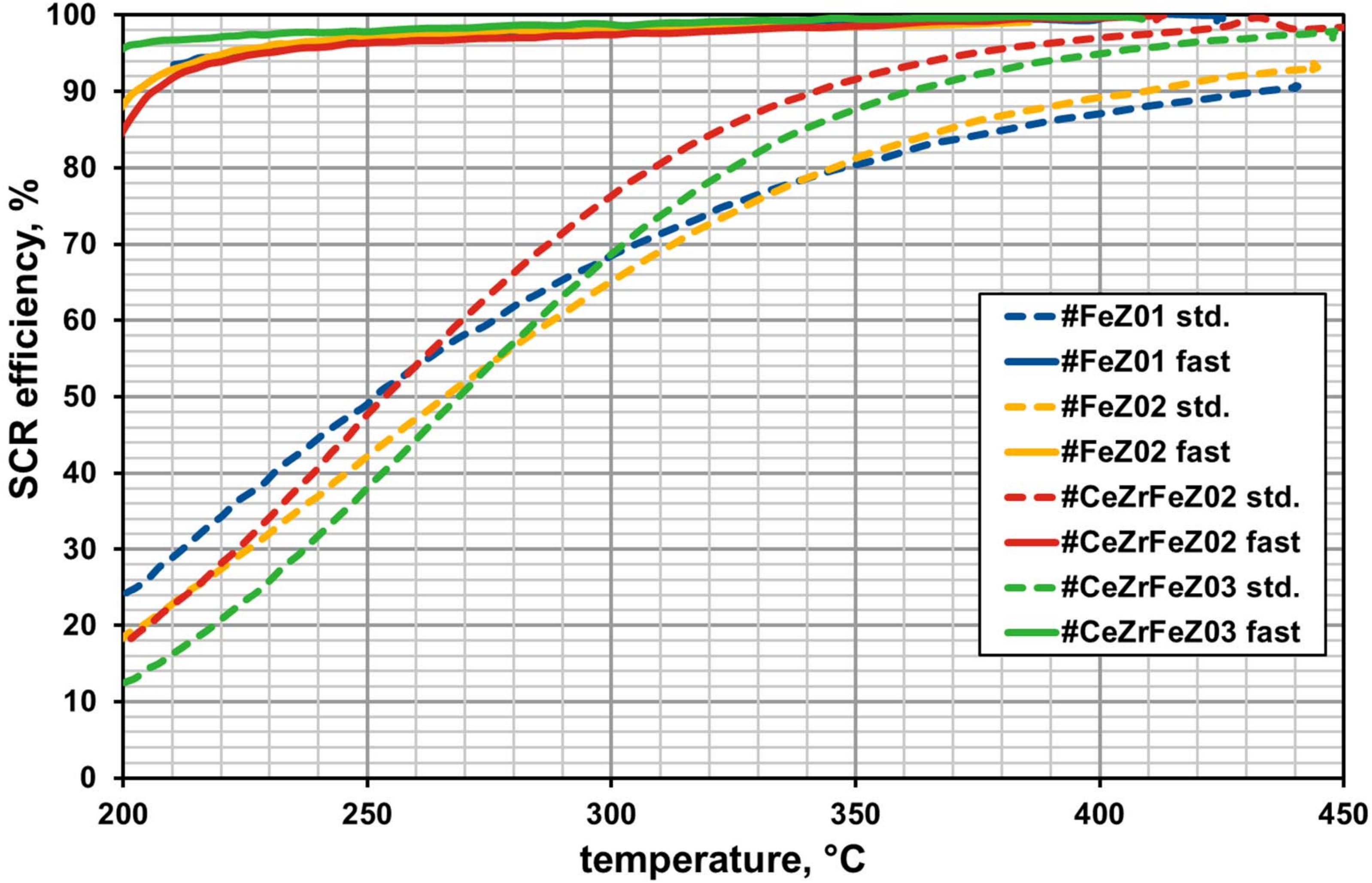




NO_2 / NO_X ratio was adjusted to 50 %

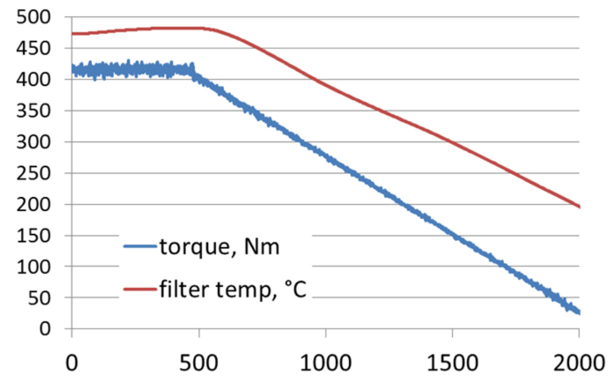


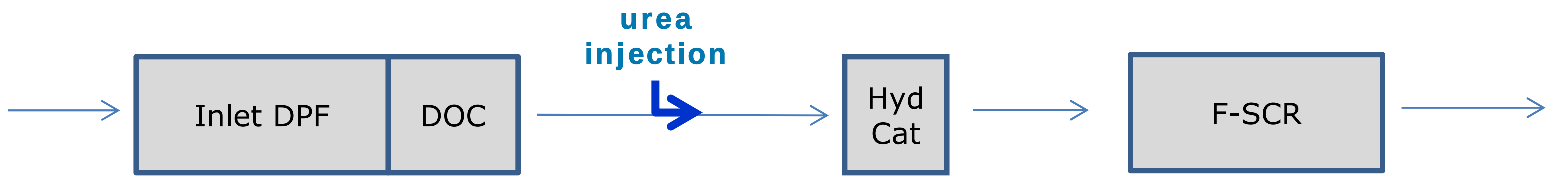
NO_X conversion under standard SCR conditions compared to fast SCR

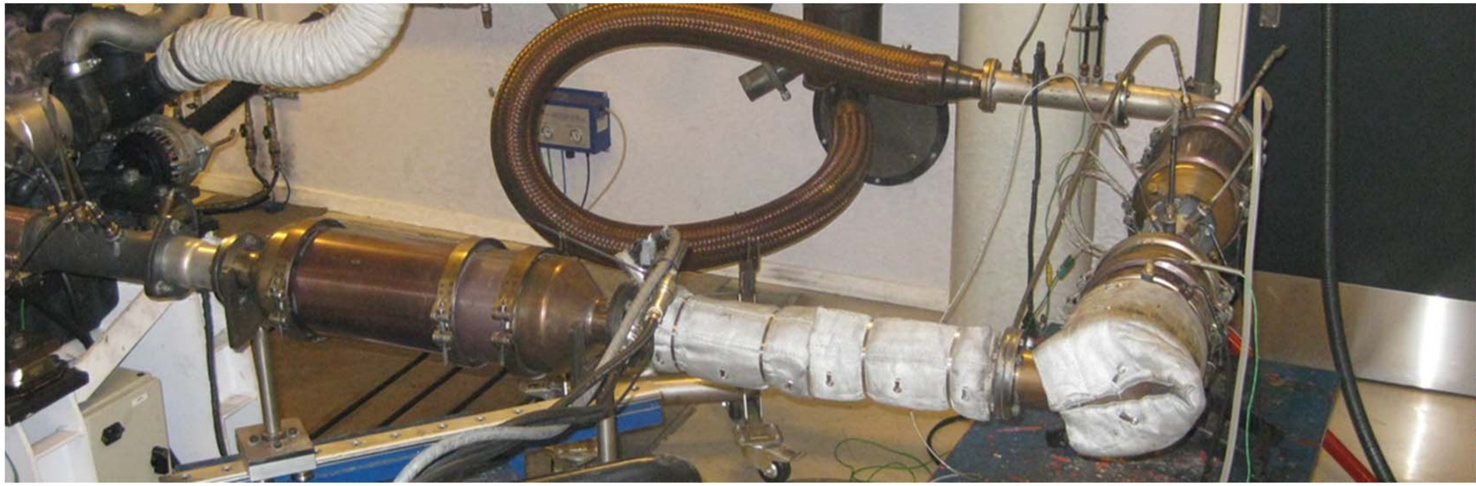


Engine bench test setup

- OM 904 engine, 4.25L – 4 Cyl. - 129 kW
- Dynamometer: Horiba T250
- Gas analyzer: Horiba MEXA6000-FT
- AdBlue dosing: Emitec Airless urea doser
- An uncoated DPF was mounted upstream to take the soot out of exhaust mass flow







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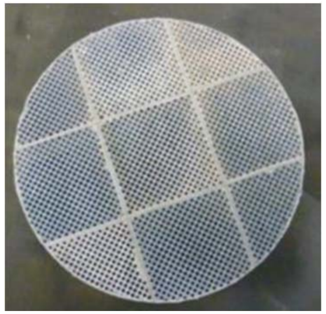
Filters with SCR coatings for engine bench tests

	#FeZ01-DPF	#FeZ03-DPF	#CeZrFeZ01-DPF	#CeZrFeZ03-DPF - layered
PN efficiency, fresh	>99.8%	>99.8%	>99.8%	>99.8%
Back pressure cold flow @ 600m³/h	6.8kPa	6.9kPa	6.2kPa	6.0kPa
Back pressure @ 140kg/h 480°C	3.4kPa	3.5kPa	3.3kPa	3.1kPa



60g/l SiO_2
60g/l Fe-β-Z

60g/l $CeO_2/ZrO_2/Nb_2O_5$
60g/l Fe-β-Z

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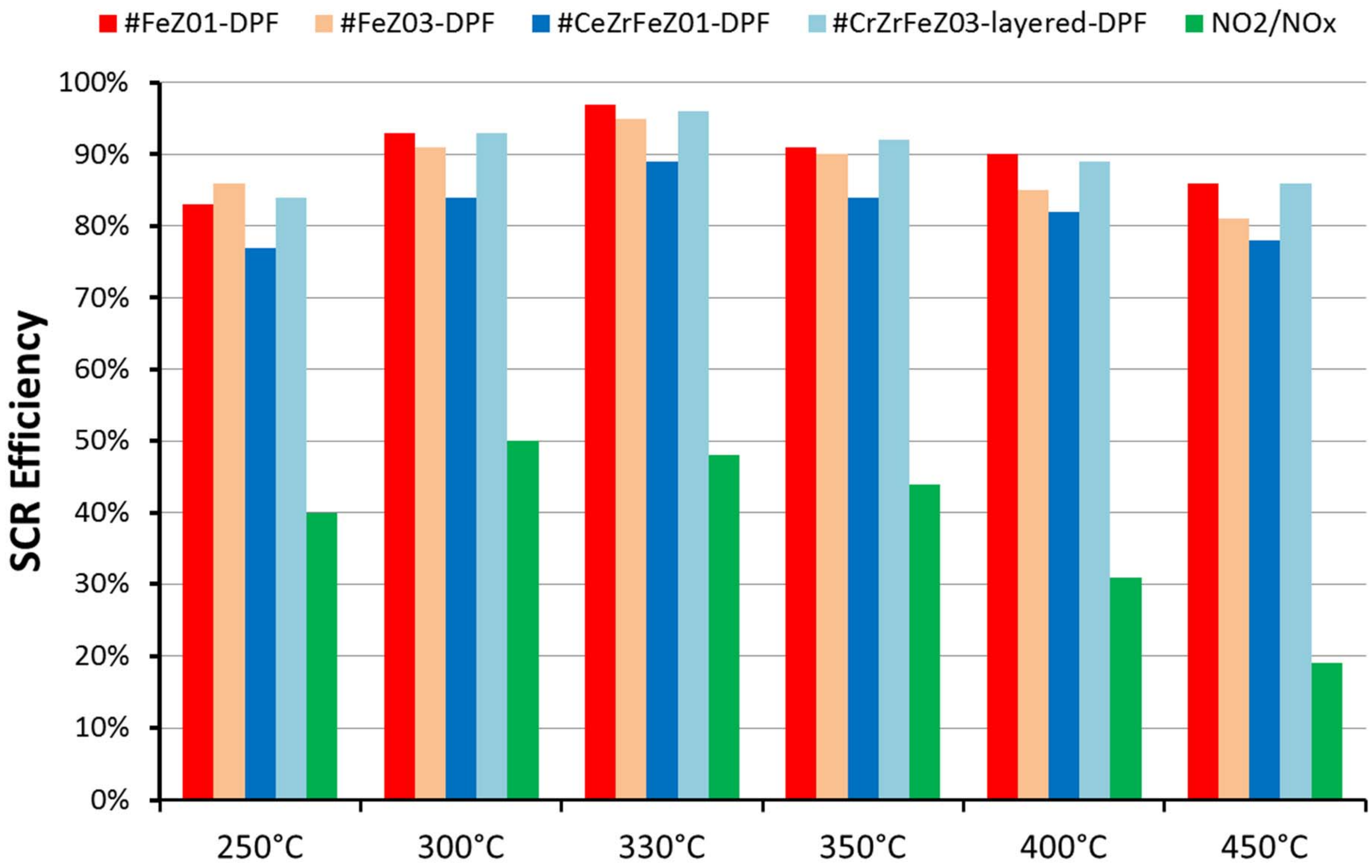
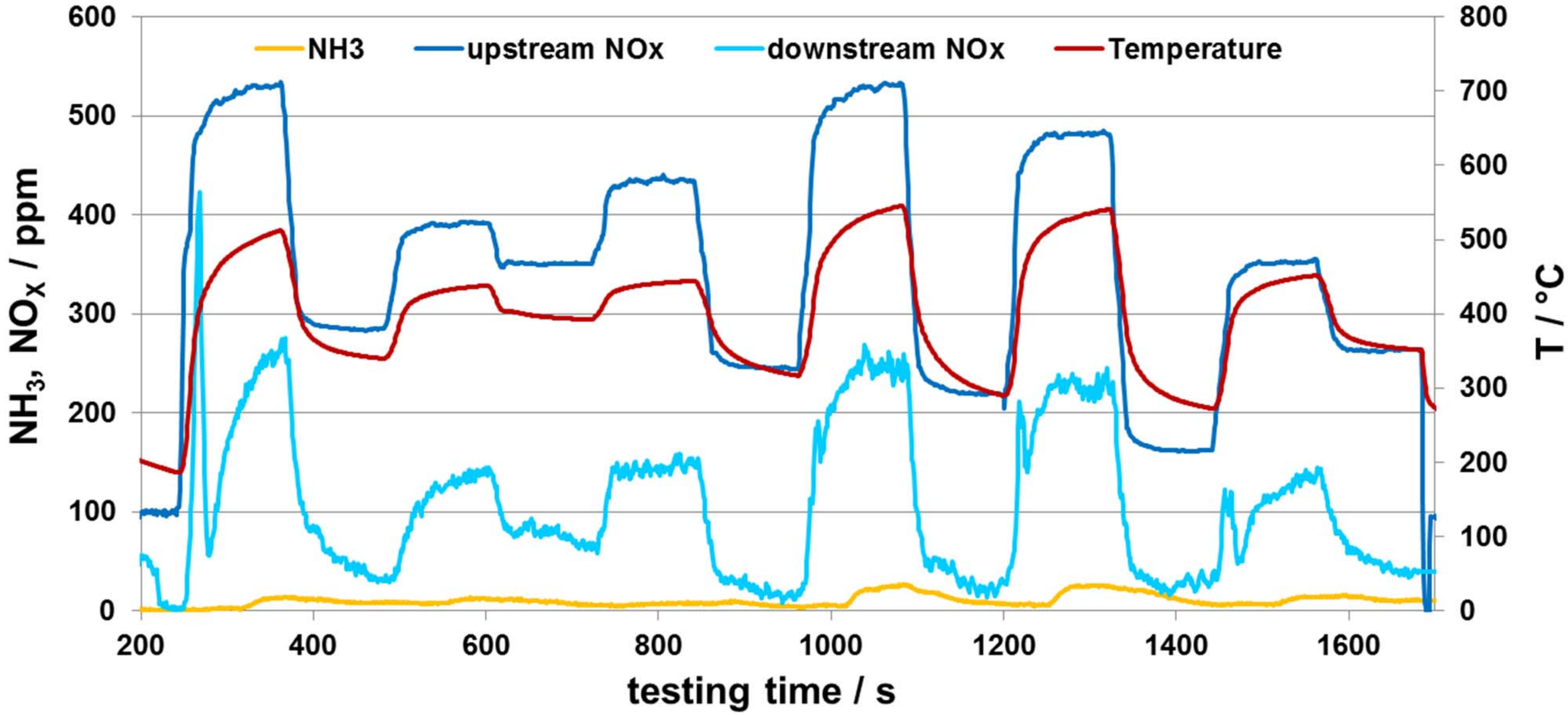
SCR efficiency for all the test filters



Performance of#CeZrFeZ03-DPF_layered during ESC



- SCR performance over cycle: **70.0 %**
- Filtration performance over cycle: **99.6 %**

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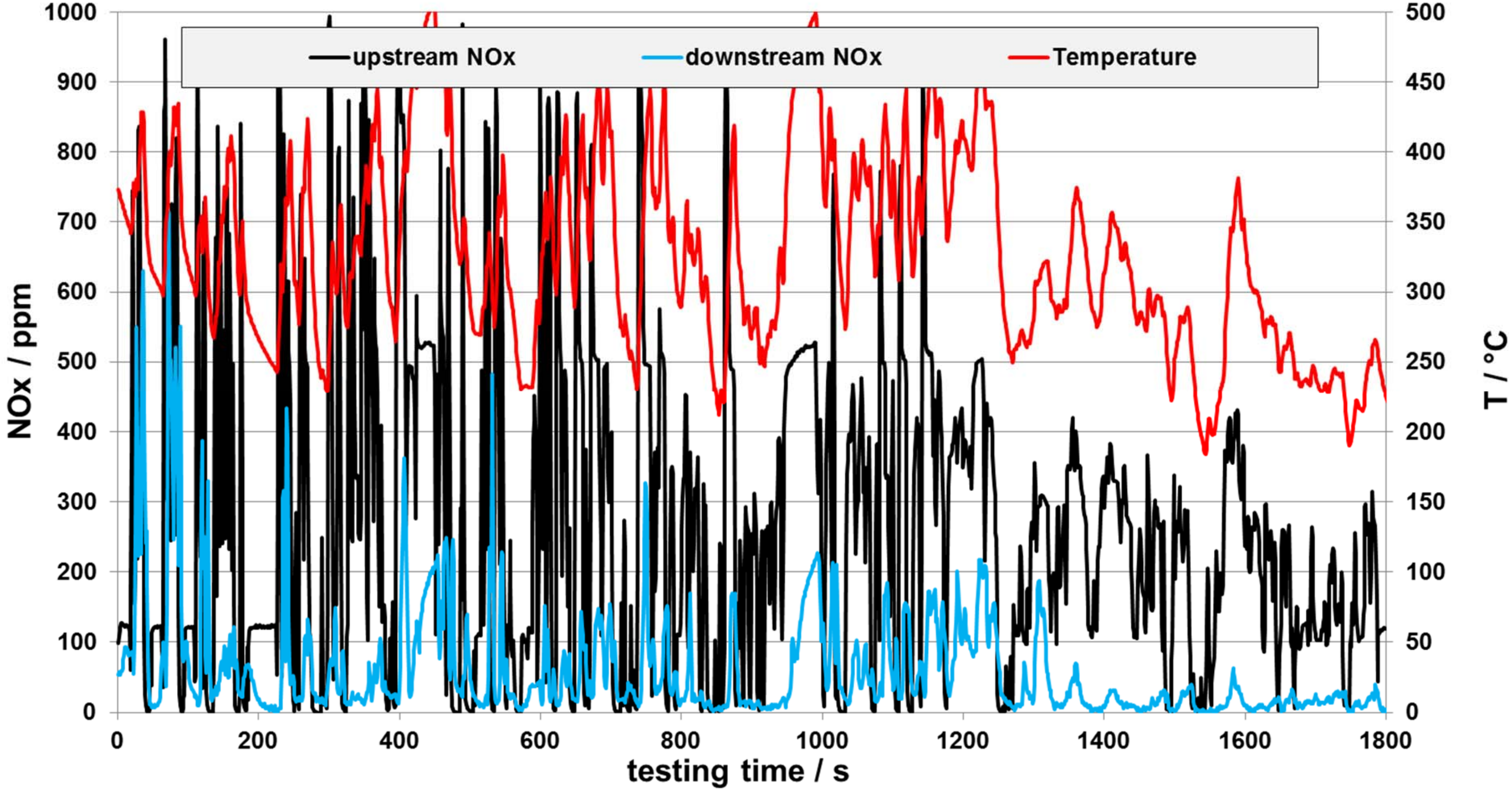
Performance of#CeZrFeZ03-DPF_layered during ETC



- SCR performance over cycle: **76.3 %**
- Filtration performance over cycle: **99.7 %**

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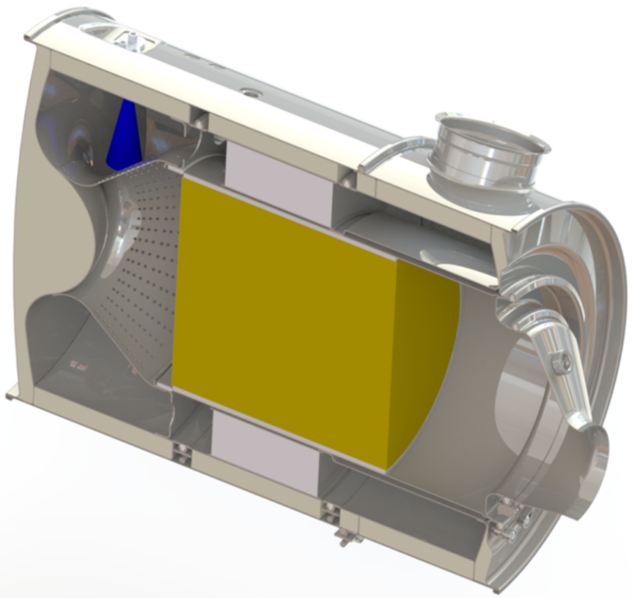
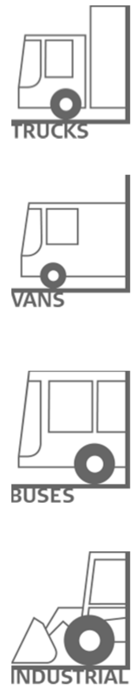
Summary and conclusions

- A high porous SiC with a dual layer coating was presented
  - Enhancing mechanical strength
  - High SCR performance at low catalyst loadings
- Catalyst solutions based on a Fe-β-zeolite and mixed metal oxides (doped ceria/zirconia) have been developed
- Lab scale and engine bench test show a high SCR efficiency between 80 % and 95 % for the zeolite and zeolite/mixed metal oxide solutions
- High porosity of 65 % combined with the initial layer is the optimum substrate for the used catalysts
- The developed SCR coated DPF is a very promising candidate for future Euro VI systems with reduced packaging size

Thank You for your Attention!



For more details see: SAE2014-01-1484



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