Combined SCR –
A novel approach for NOx and PM aftertreatment

M. Müller[1], S. Schraml , P. Broll, H. Bülte,
DEUTZ AG, Ottostr. 1, 51149 Cologne, Germany
H. Harndorf,
University of Rostock, Albert-Einstein-Str. 2 , 18059 Rostock, Germany

To meet the requirements of future emission legislation engine manufacturers will have to offer a complete system consisting of an advanced diesel engine and an aftertreatment unit. Future exhaust aftertreatment systems will most probably contain a selective catalytic reduction catalyst (SCR) as well as a diesel particulate filter (DPF) to cope with stringent NOx and PM emission limits. For off-road applications, DEUTZ has the ambition to couple all active aftertreatment components directly to the engine in order to minimize the number of variants and thus to lower application efforts. In compliance with the EU Stage 4 and US Tier 4 emission limits, DEUTZ investigates a novel approach with the target to realize a compact and cost optimised emission control system.

The exhaust aftertreatment concept, which is named "Combined SCR", essentially consists of a burner-vaporiser unit, a V_2O_5 -coated SCR-catalyst and a coated diesel particulate filter (cDPF). The employment of the burner-vaporiser unit on the one hand enables to exceed an exhaust gas temperature which upstream of the SCR-catalyst is greater than 300℃ within the entire engine operation map. On the other hand, the vaporization enthalpy for additionally injected diesel fuel is provided. The diesel vapour is homogeneously mixed with engine exhaust gas, which allows excellent transport of chemically bound energy within the exhaust system and thus lowers engineering efforts for different applications.

A specific element of the concept is that the SCR-catalyst also serves as an oxidation catalyst for the diesel vapour during thermal DPF regeneration. The described compact system configuration allows not only to reduce nitrogen oxides (NOx) but also to generate heat by at least partial oxidation of hydrocarbons. The target temperature of approximately 600℃ upstream the DPF is reached in three steps. The first temperature increase of the exhaust gas will be achieved by the burner, which has a constant thermal power. This heat release ensures light-off temperature for the subsequent catalytic process and fuel vaporization. In the second stage around 30-60% of the chemically bound energy is released from partial oxidation of the hydrocarbons on the SCR catalyst.

[1] *corresponding author, Email: mueller.ma@deutz.com*

This in particular is a special feature of the hydrocarbons from the DEUTZ burner-vaporizer unit. The remaining chemical energy, in a great portion bound to carbon monoxide, is preferably released downstream the SCR on the cDPF. By extended test bench investigations it has been shown that there is no degradation neither on SCR nor on heat-up performance observed. In the figure below, a typical setup is shown for integrating the combined SCR system to a complete Tier4 exhaust aftertreatment system.

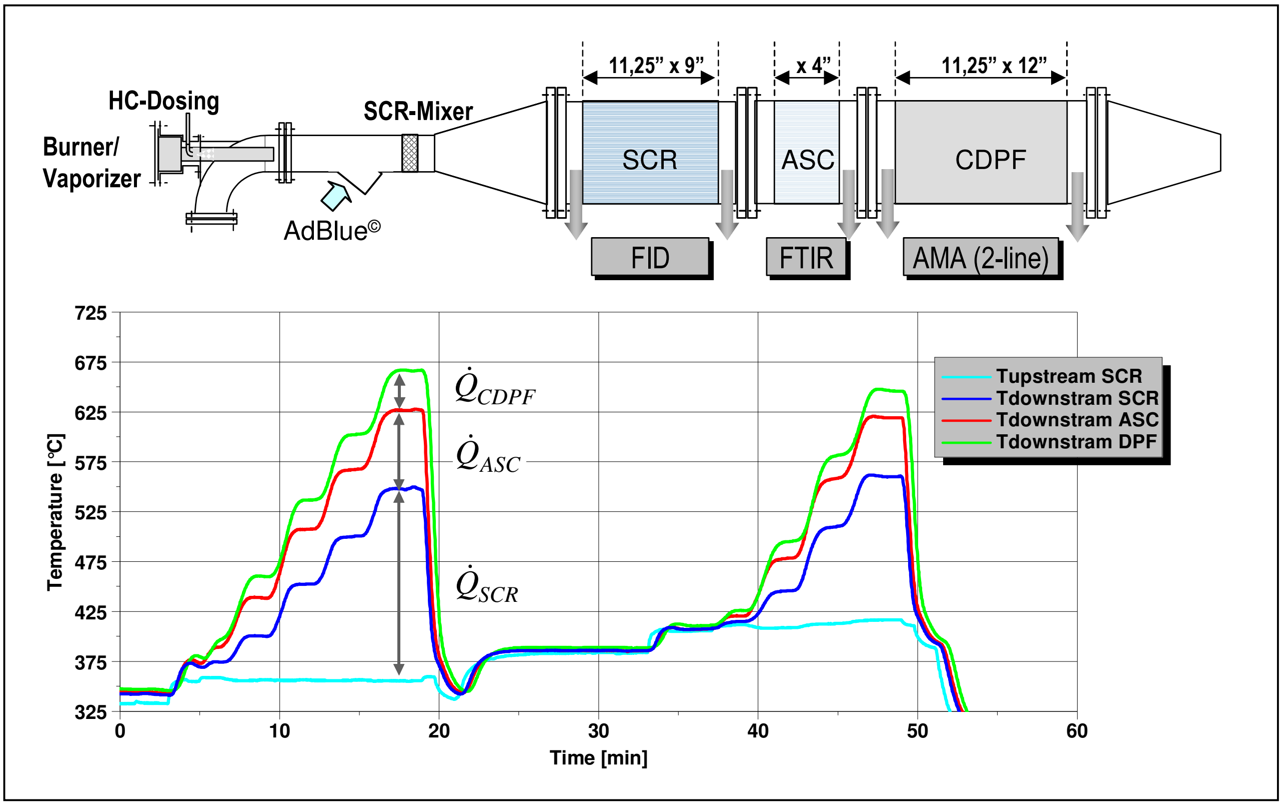
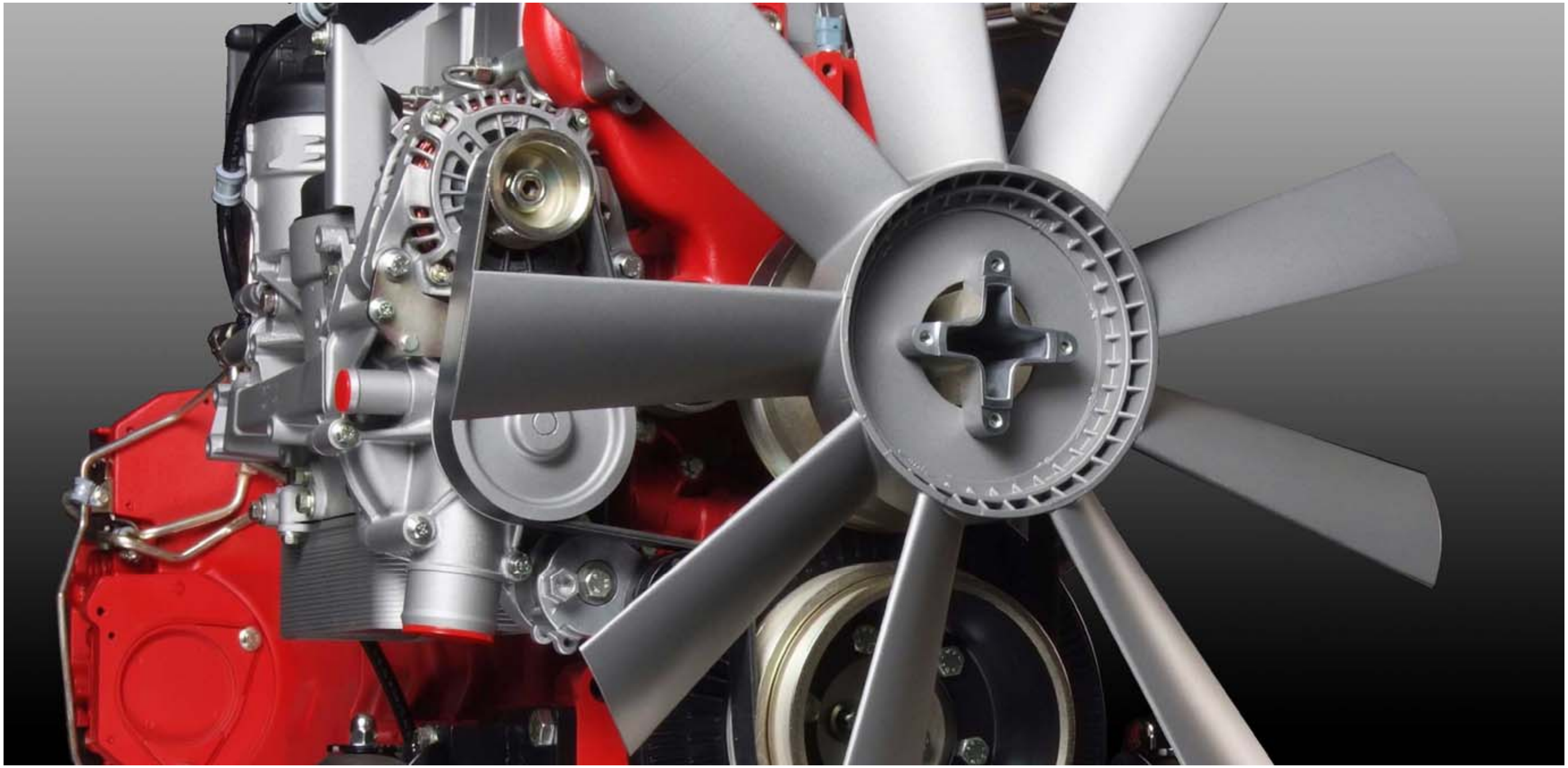


Figure 1: Experimental test setup

As the burner/vaporizer unit ensures sufficiently high exhaust temperatures for all given operation conditions, one of the main benefits of this system configuration is the applicability for a broad variety of applications with no restrictions and without the need for an additional heat mode calibration. Further, the SCR catalyst in front of the DPF allows high NO_x conversion rates even for cold cycles and the application of vanadium-based technologies which – in contrast to zeolite SCR systems – gained a high maturity level and offers high NO_x conversion rates at moderate costs. Especially cold cycle SCR performance is one of the key aspects for forthcoming emission legislations as the NO_x certification values have to be met for very challenging certification cycles. As a consequence, the lack of the passive regeneration feature against the well known SCRT configuration, which will be broadly used for Euro 6 on-road applications, can at least be partly compensated by an advanced engine calibration. Further features and experimental results of the combined SCR approach will be presented in more detail within this presentation.



Combined SCR – A novel approach for Nox and PM aftertreatment

13. ETH-Conference on Combustion Generated Nanoparticles (22.-24.06.2009)

M.Müller, Dr. H.Bülte, Dr. S.Schraml, Dr. P.Broll, DEUTZ AG, Cologne
Prof. Dr. H.Harndorf, University of Rostock

DEUTZ

Content

Introduction

The engine company. DEUTZ

DEUTZ manufactures engines for different applications in a power range of 9 – 500 kW…

Construction

Infrastructure

Agriculture

Nutrition

Commercial

Daily demand

Introduction

The engine company. DEUTZ

- Totally different market requests for the different applications concerning:
  - Technology
  - Performance
  - Load profiles
  - Maintenance

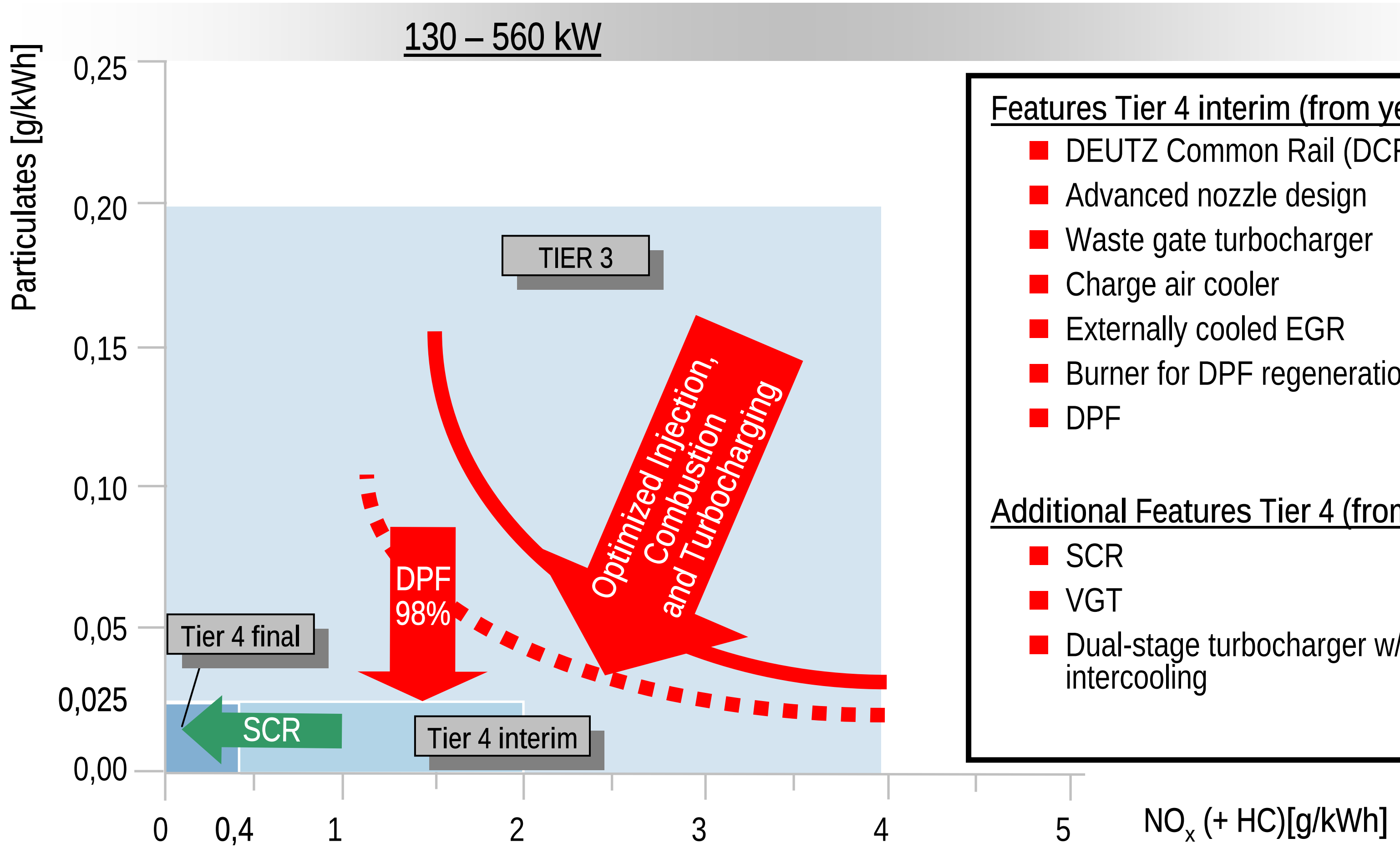
  } High number of variants of one engine

- Future exhaust aftertreatment systems will most probably comprise selective catalytic reduction (SCR) as well as wall-flow diesel particulate filters (DPF) to cope with stringent NOx and PM emission limits

- DEUTZ will offer a complete system consisting of the diesel engine and the aftertreatment unit with the target to realize a compact and cost optimised system to meet the emission standards
  - Minimized application efforts
  - Maximized customer value

The engine company. DEUTZ

DEUTZ strategy for forthcoming emission legislation



Features Tier 4 interim (from year 2011)

- DEUTZ Common Rail (DCR®) 2000 bar
- Advanced nozzle design
- Waste gate turbocharger
- Charge air cooler
- Externally cooled EGR
- Burner for DPF regeneration
- DPF

Additional Features Tier 4 (from year 2014)

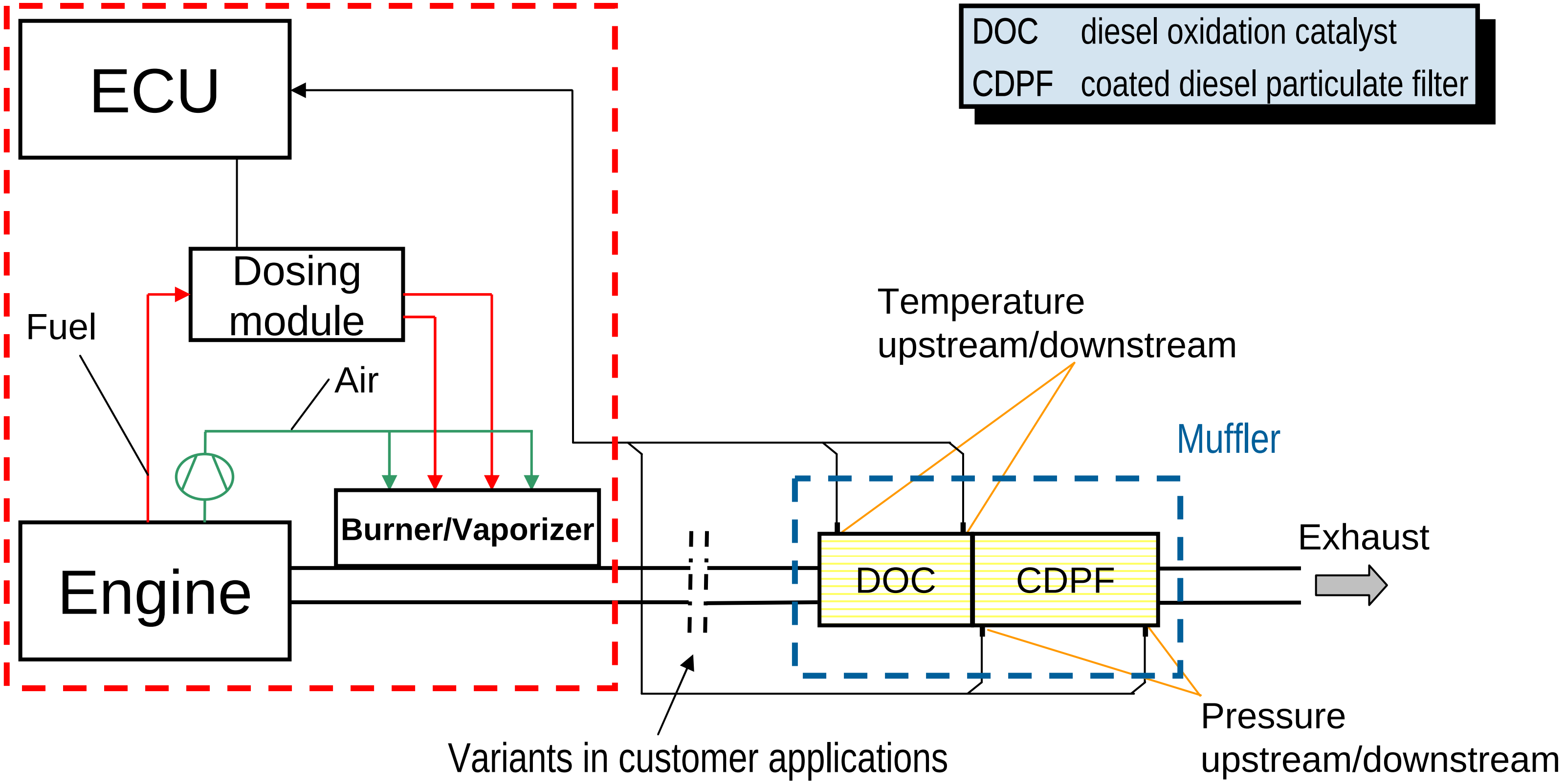
- SCR
- VGT
- Dual-stage turbocharger w/ and w/o intercooling

The engine company. DEUTZ

DEUTZ strategy for Tier 4 interim

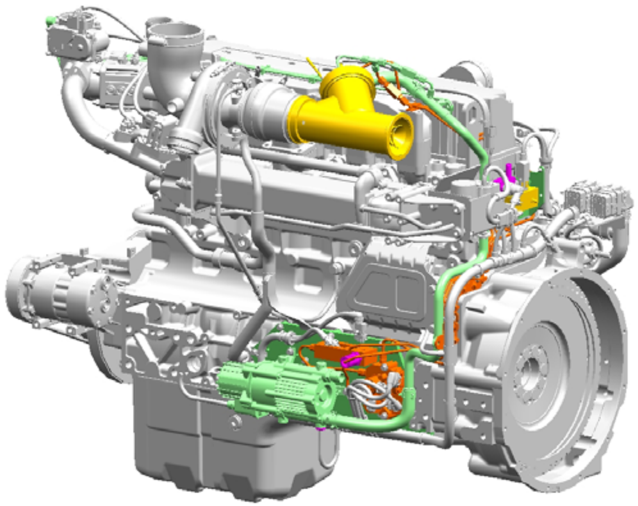
- Active components closed coupled to the engine
- Space consuming components (catalyst, muffler, acoustics, etc…) located in the machinery

DOC	diesel oxidation catalyst
CDPF	coated diesel particulate filter



DEUTZ strategy for Tier 4 interim

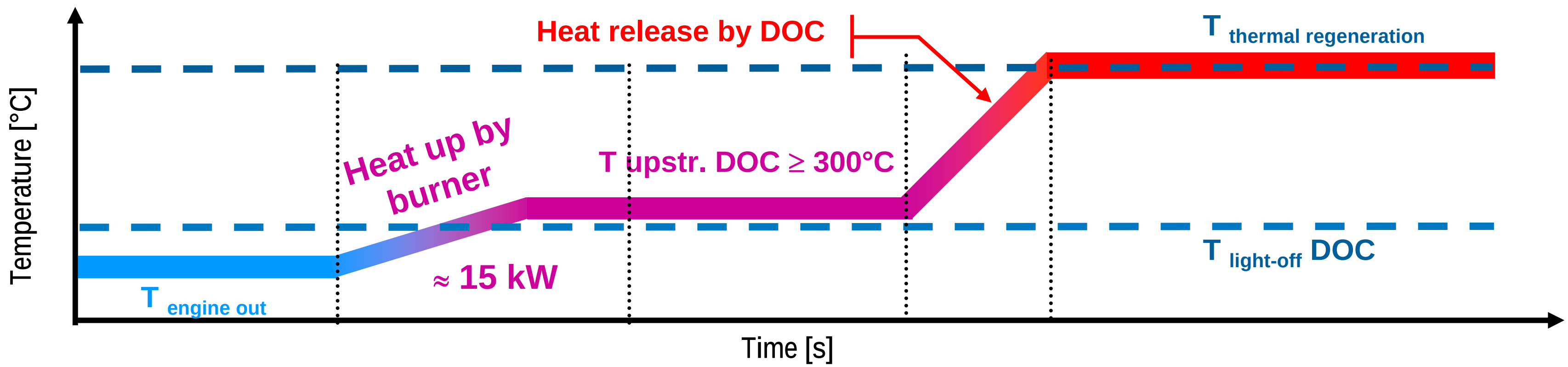
- TCD2013 L06 4V Tier4 interim



Key facts of the burner / vaporizer unit:

- 15 kW power
- Engine independent preheating of catalyst
- Exhaust gas temperature ≥ 300 °C
- Provides vaporisation enthalpy
- Additional HC doser included
- Homogeneous dispersion of the vaporized diesel fuel on the catalyst surface

- Heat mode for DPF-regeneration

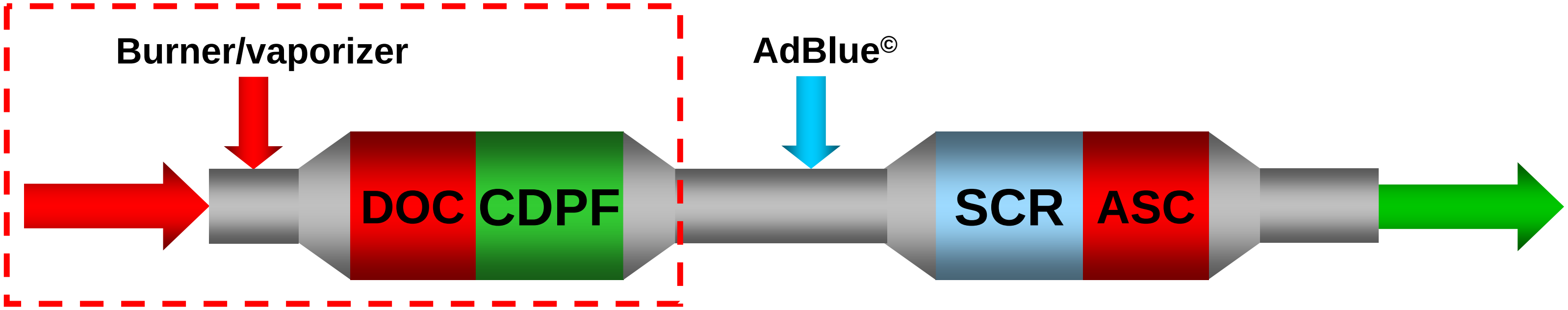


System - concepts for off-road emission regulations

The engine company. DEUTZ

System concepts for Tier 4 final

- 1st concept: EAT-system consisting of DPF + SCR (SCRT© -configuration)
- Add-on system to Tier4 interim setup



DOC	diesel oxidation catalyst
CDPF	coated diesel particulate filter
SCR	selective catalytic reduction cat.
ASC	ammonia slip catalyst

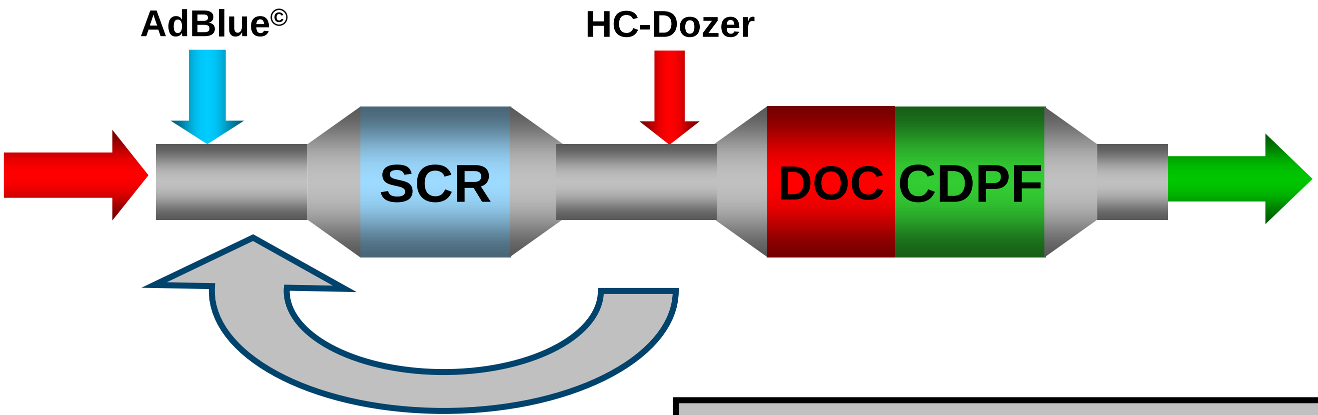
- Pros and cons:
  - \+ Passive DPF-regeneration feasible
  - \+ Application of the Tier4 interim muffler feasible
  - \- AdBlue© - dosing upstream DOC not possible (NH_3 oxidation)
  - \- AdBlue© - doser cannot be closed coupled to the engine
  - \- High application efforts
  - \- High precious metal quantity

System - concepts for off-road emission regulations

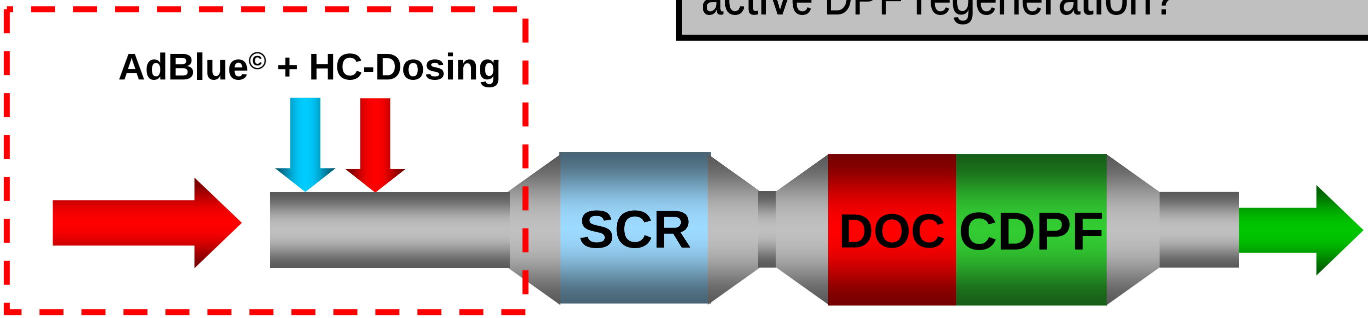
The engine company. DEUTZ

Alternative options for Tier 4 final

- 2nd concept: SCR-system upstream DOC and DPF
  - Scope: All active components (HC and AdBlue© dosing unit) coupled close at the engine



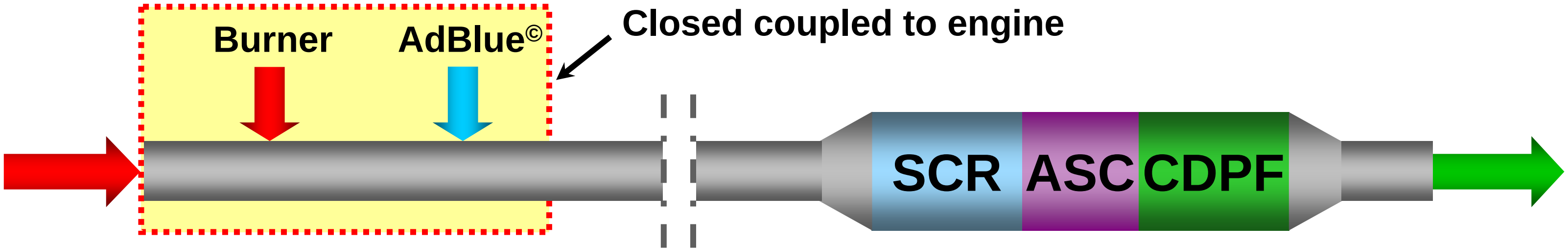
Does the HC-dosing damage the SCR coating during an active DPF regeneration?



A novel approach - Combined SCR

The engine company. DEUTZ

Benefit of the Combined SCR system

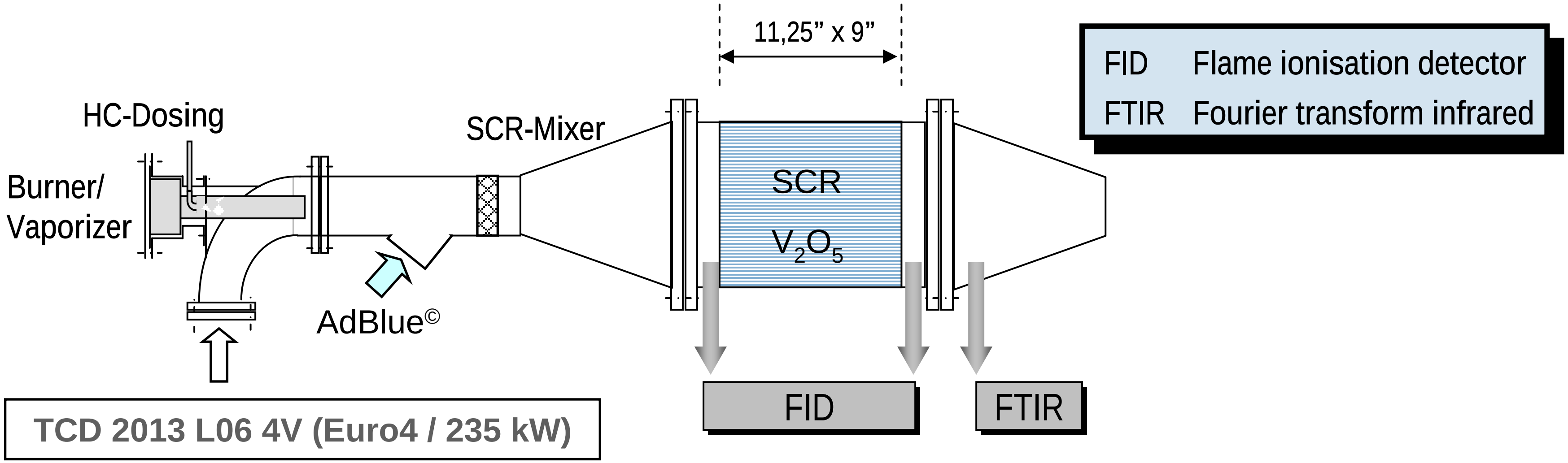


+ All active components can be mounted at the engine
+ Hydrocarbons partially oxidised on the catalytic coating of the SCR – catalyst (V_2O_5)
+ Heat release for the DPF – regeneration is partially generated by the SCR - coating
+ NOx – conversion up to 95 % (steady state) in dependency of the engine operating point
+ 100 % soot reduction by the DPF (wall-flow)
+ The burner guarantees an exhaust gas temperature ≥ 300 °C within the whole engine map
+ Probably only one muffler required like TIER4 interim
+ Cost benefit due to saving of precious metal

– No NO_2 formation for passive regeneration (CRT)

Experimental setup

The engine company. DEUTZ

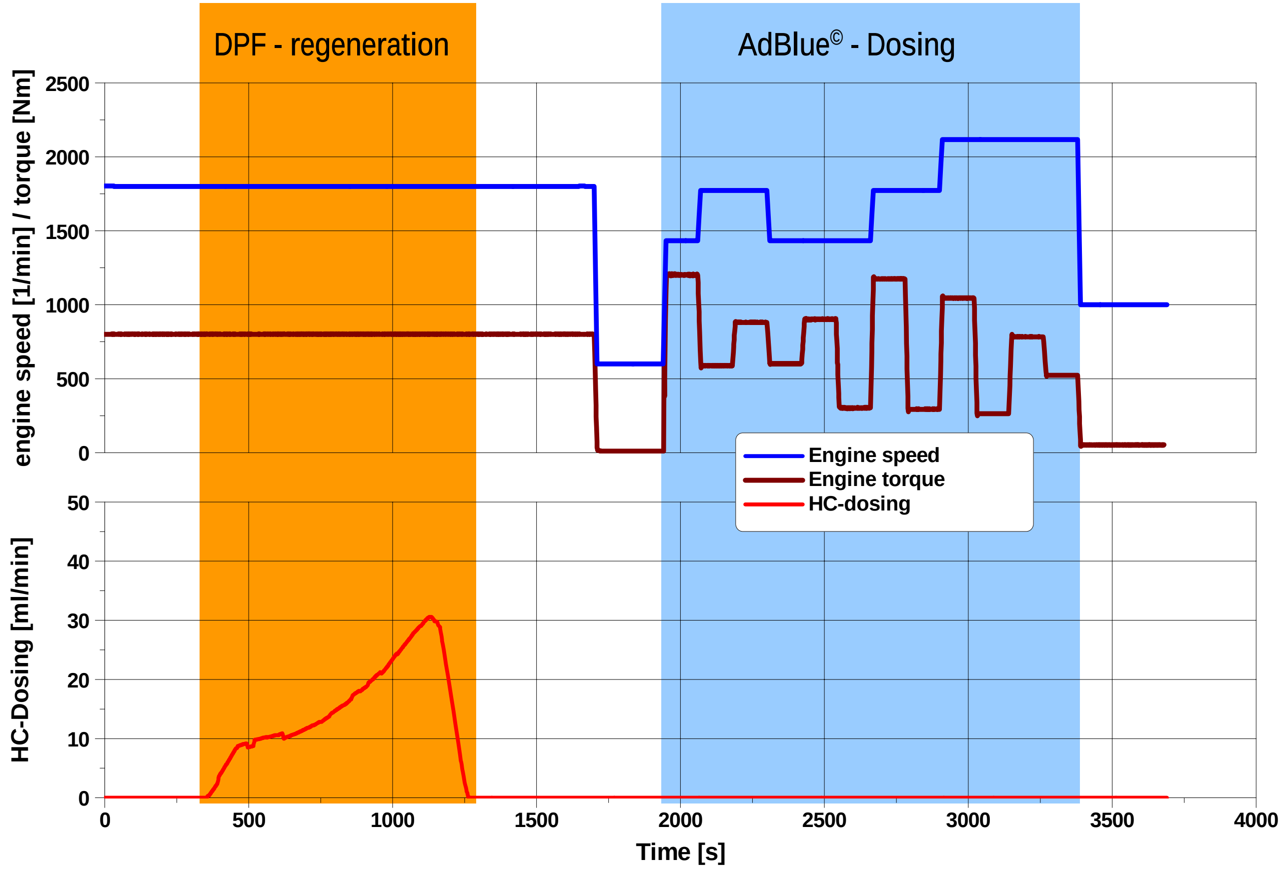


- Oxidation behaviour of the hydrocarbons (HC) on the vanadium-based SCR-coating?
- Main focus:
  - Does HC-dosing and oxidation damage the SCR - coating?
  - Which exothermic is produced on the catalytic coating?
  - How is the temperature distribution in the catalyst?
  - Does the catalyst oxidise the dosed diesel fuel completely? HC/CO-slip?
  - How does the system work at low temperatures ?

Test results

Alternating admission of diesel fuel and NH_3 to the SCR - coating

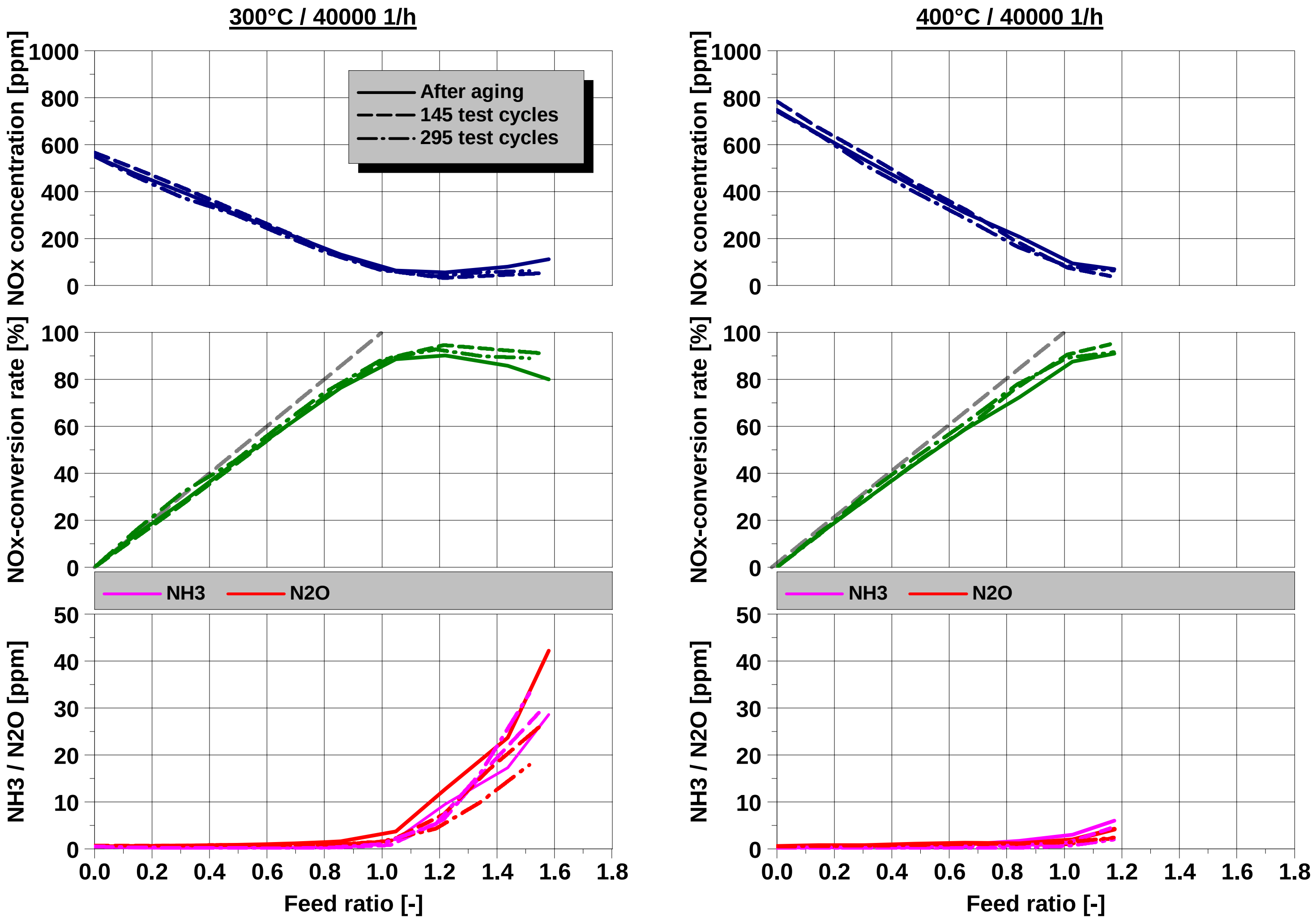
- Test cycle: Combination of a DPF-regeneration + ESC test cycle, duration: 62 min / cycle
- 295 test cycles were accomplished



Test results

The engine company. DEUTZ

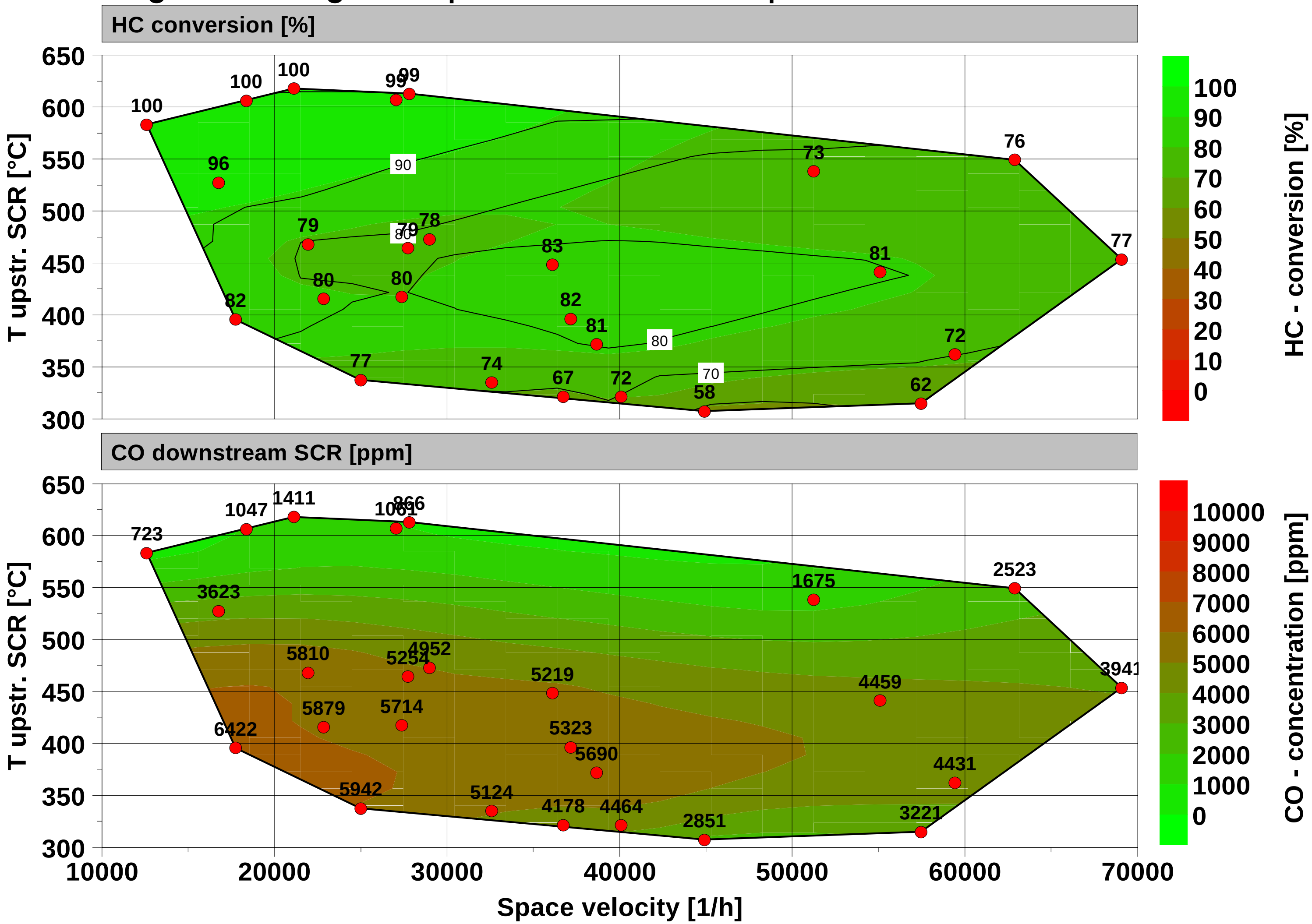
SCR performance after 295 test cycles



Test results

The engine company. DEUTZ

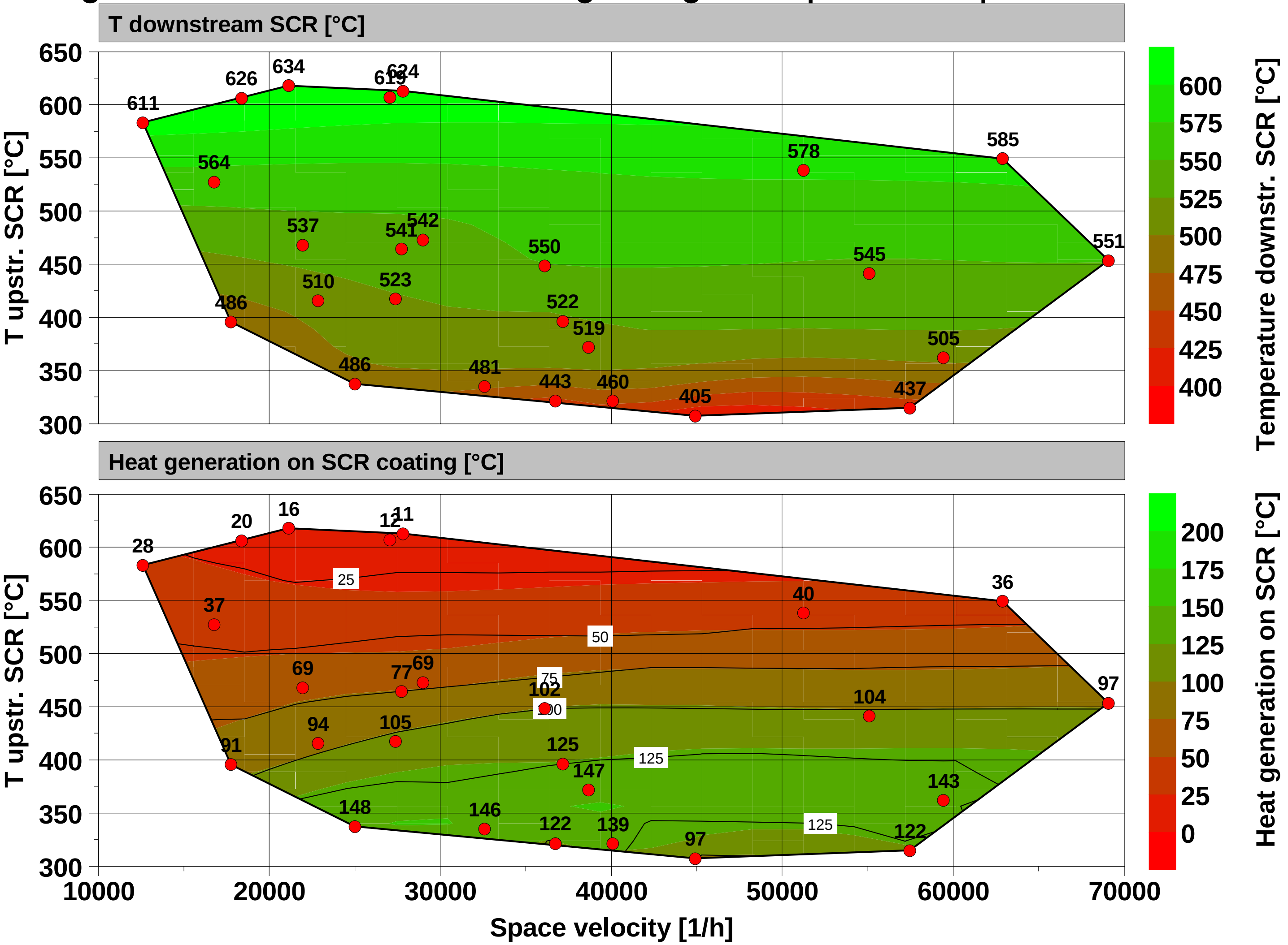
HC-dosage for a target temperature of 630°C upstream DPF



Test results

The engine company. DEUTZ

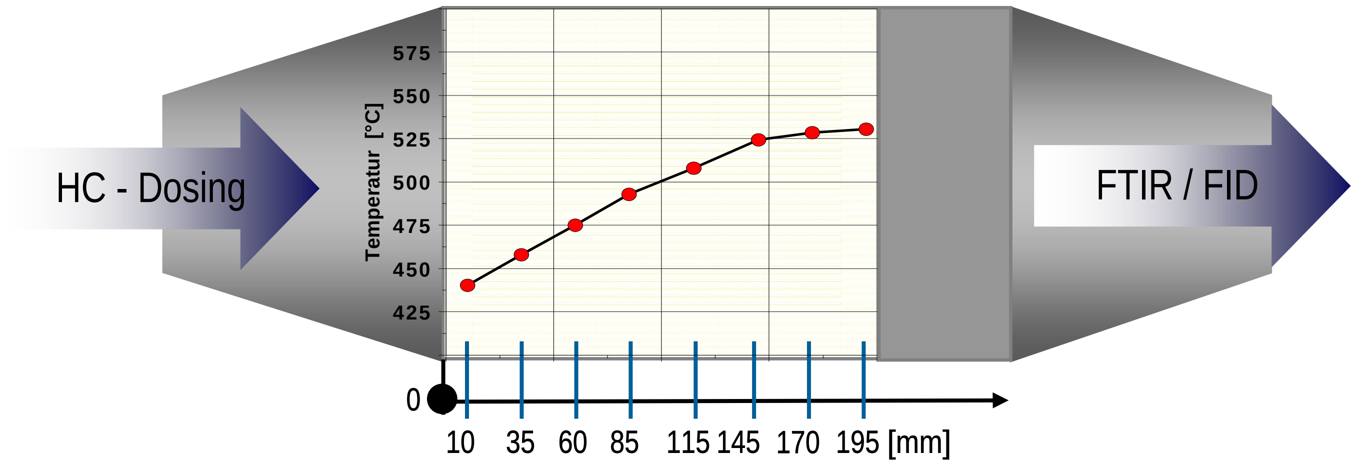
Heat generation on the SCR coating / Target temperature upstream DPF of 630°C



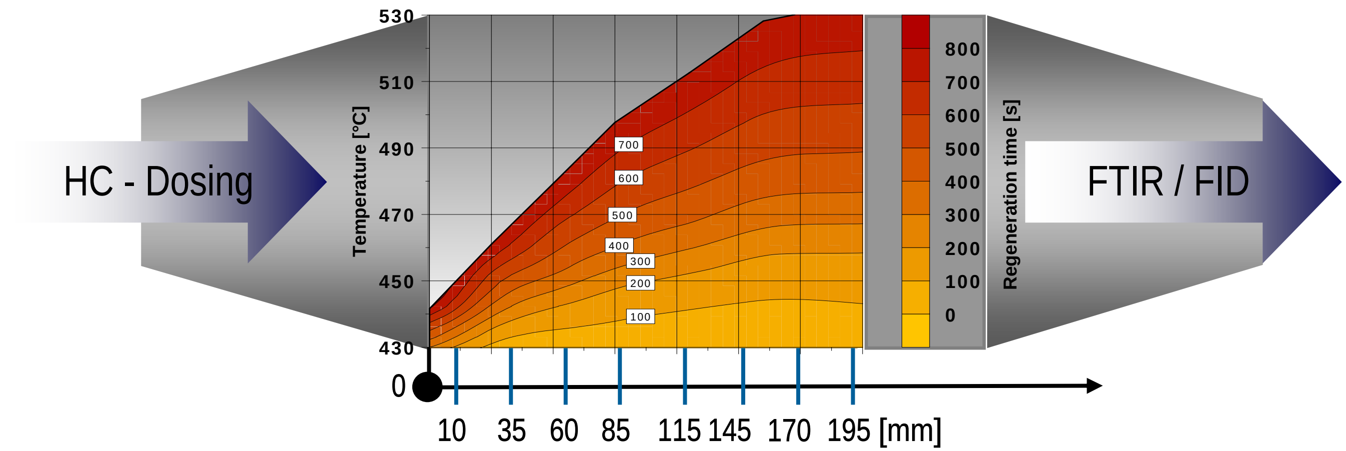
Test results

The engine company. DEUTZ

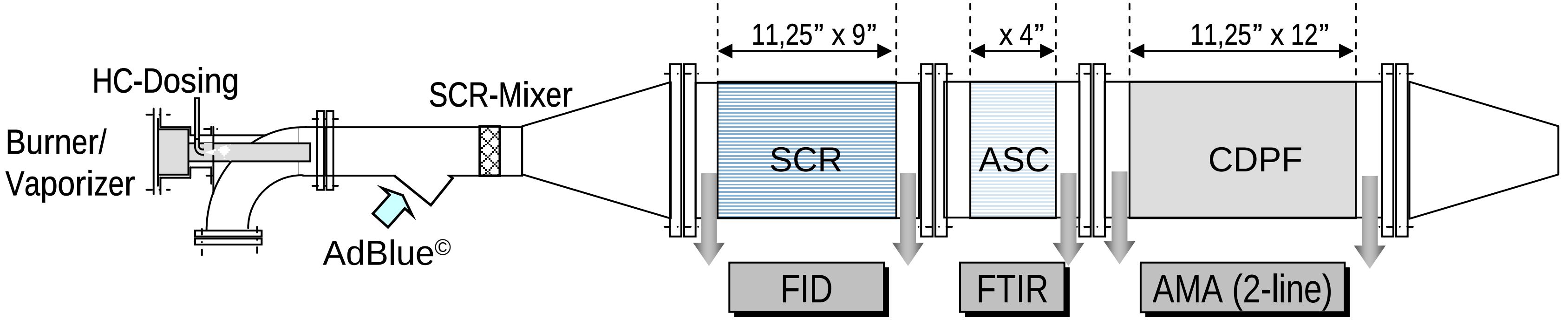
- Axial temperature distribution during the DPF-regeneration at peak HC-dosage



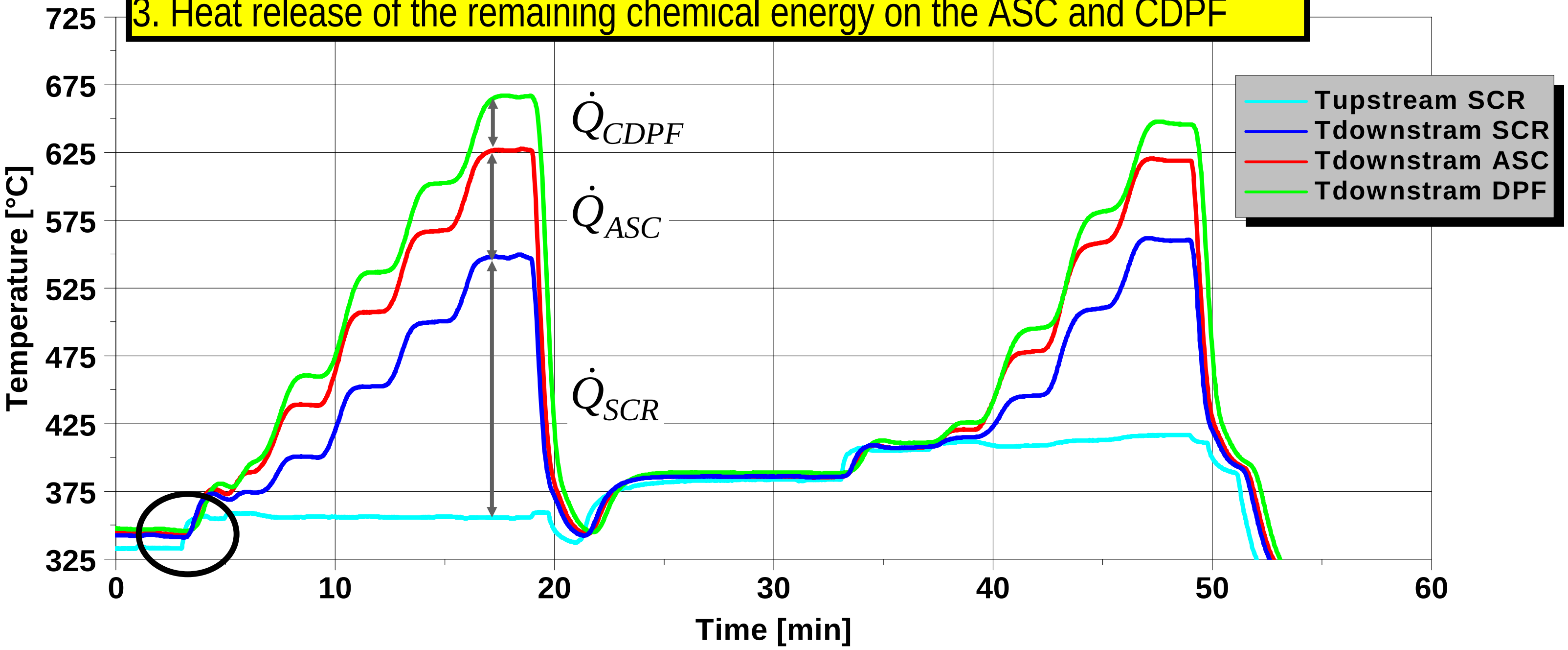
- Axial temperature distribution during DPF regeneration (test cycle)



Heat-up performance of the Combined SCR system at max. space velocity of 60000 1/h



3. Heat release of the remaining chemical energy on the ASC and CDPF



Summary and outlook

The engine company. DEUTZ

- HC-oxidation on the SCR coating
  - The vanadium-based SCR - coating (V_2O_5) shows oxidising characteristic and serves as an oxidation catalyst for the diesel vapour during DPF regeneration
    - The precious metal loadings on the ammonia slip catalyst and the coated DPF can be reduced
  - The formation of CO is a favourable feature
    - The high quantities of CO almost completely oxidised on the ASC + CDPF.
    - The SCR-coating is thereby protected from excessive temperatures

- SCR performance
  - No substantial degradation for…
    - NOx - conversion
    - NH_3-Slip
    - Secondary emission (N_2O)

Summary and outlook

- Temperature distribution
  - Axially homogeneous heat release rate (locally moderate thermal stress)
  - An incomplete heat release can be excluded. The decrease of the temperature gradient at the end of the SCR - catalyst describes a sufficient dimensioning of the catalyst volume
  - No axial „Shifting “of the reaction zone, stable over 295 test cycles ≈ 2500 engine operation hours

- Heat mode for the DPF regeneration in three steps
  - 1. Heat release by the burner/vaporiser unit
  - 2. Heat release from partial oxidising of the hydrocarbons on the SCR coating
  - 3. Heat release of the remaining chemical energy on the ASC and CDPF

- Outlook
  - System development based on this concept
  - System integration to muffler design
  - Comprehensive study of the global reactions