International Symposium on Modelling
of exhaust-gas after-treatment

# Development of a SCR System for a Dual Line Exhaust by Using Two-Phase Flow CFD Calculations

Bernd Amon, Herbert Albert, Faurecia

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## CONTENT

- Motivation
- Analysis of the Basic Design of the Exhaust System
- Applied CFD Methods
- Test bed Verification
- Conclusions

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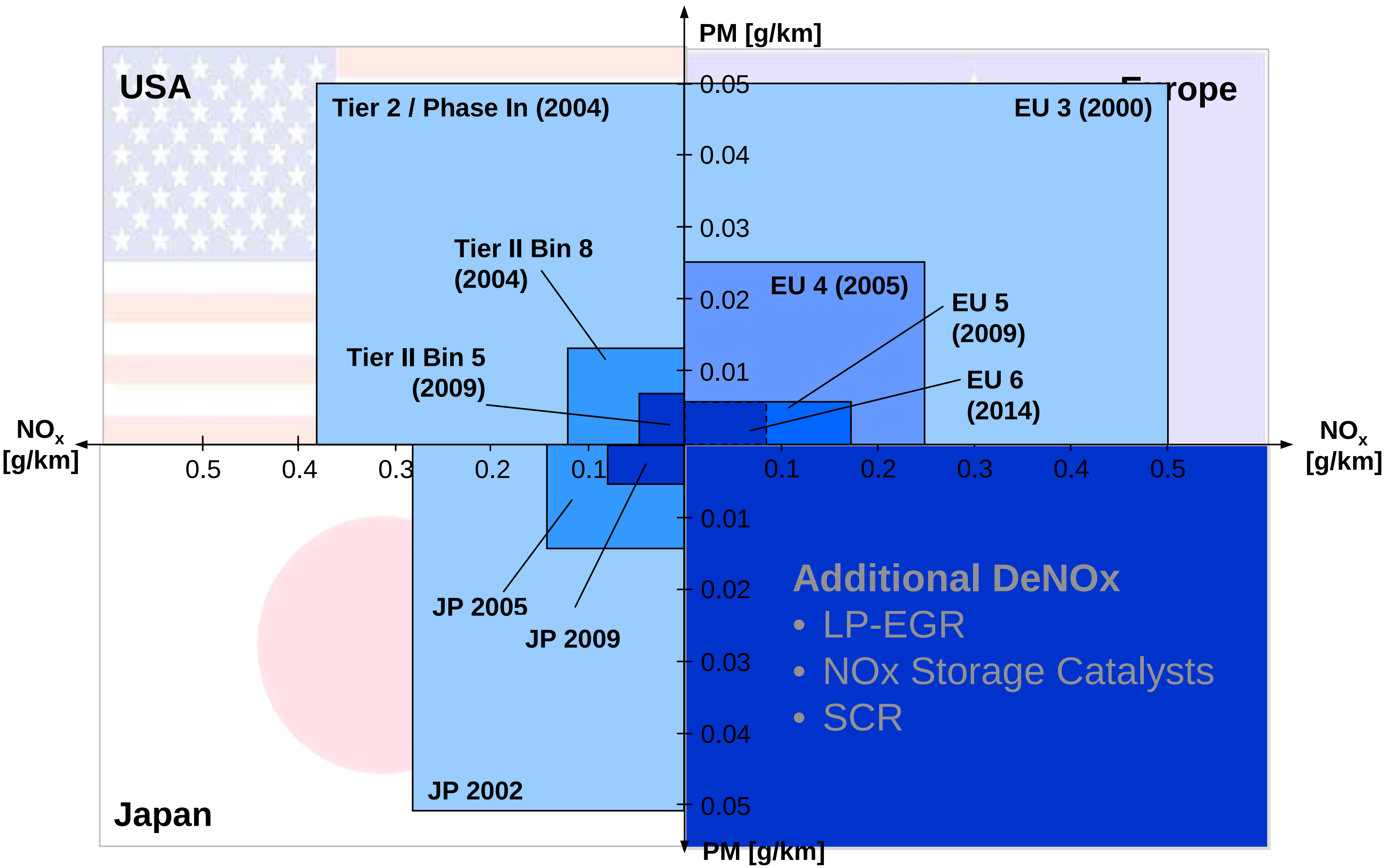
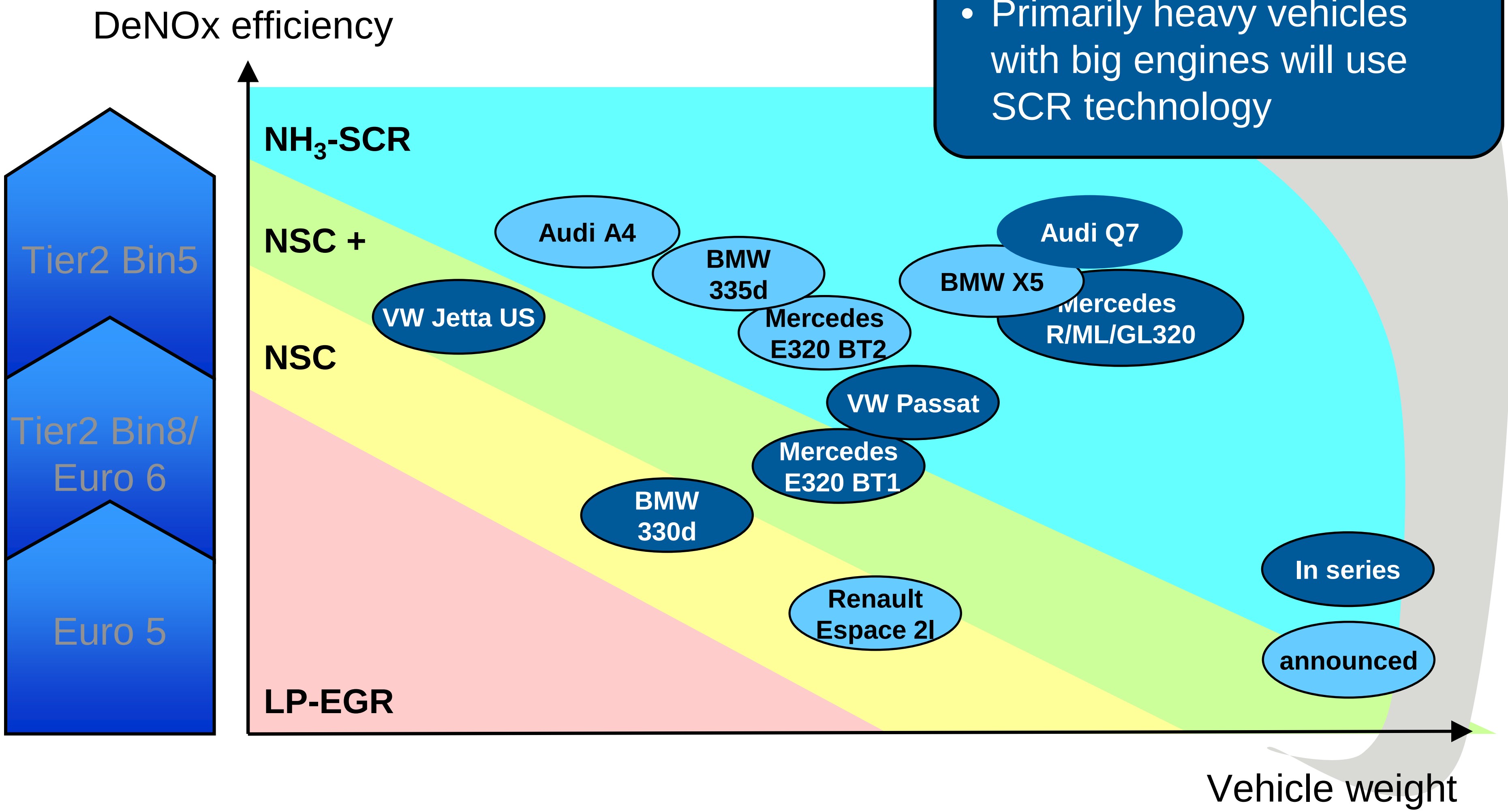
# EMISSION LIMITS – LDV DIESEL



## APPLICATION DeNOx - Technologies




- Primarily heavy vehicles with big engines will use SCR technology

# SCR SYSTEM

**Standard**

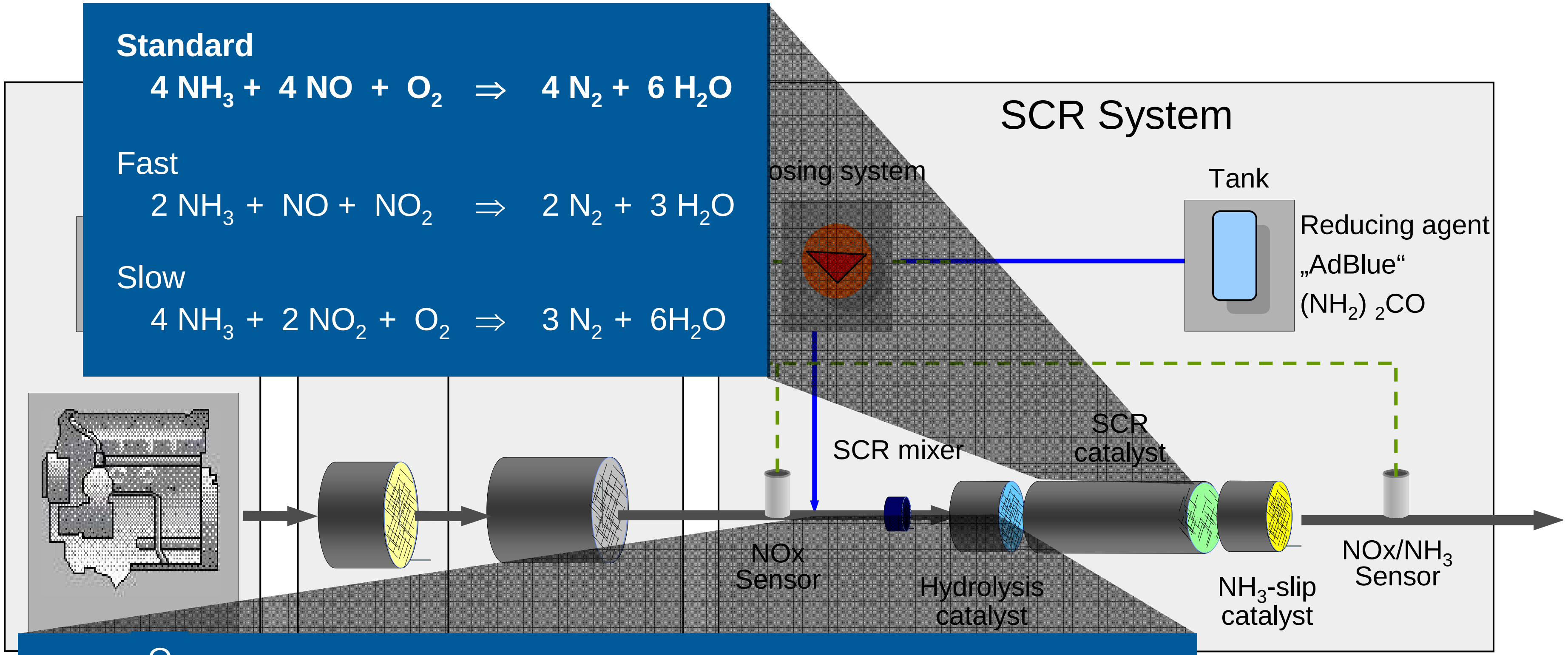
$$4\,NH_3 + 4\,NO + O_2 \Rightarrow 4\,N_2 + 6\,H_2O$$

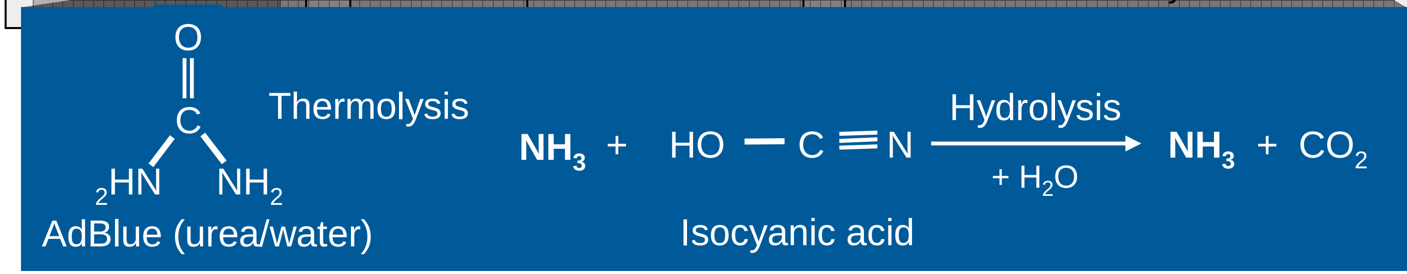
Fast

$$2\,NH_3 + NO + NO_2 \Rightarrow 2\,N_2 + 3\,H_2O$$

Slow

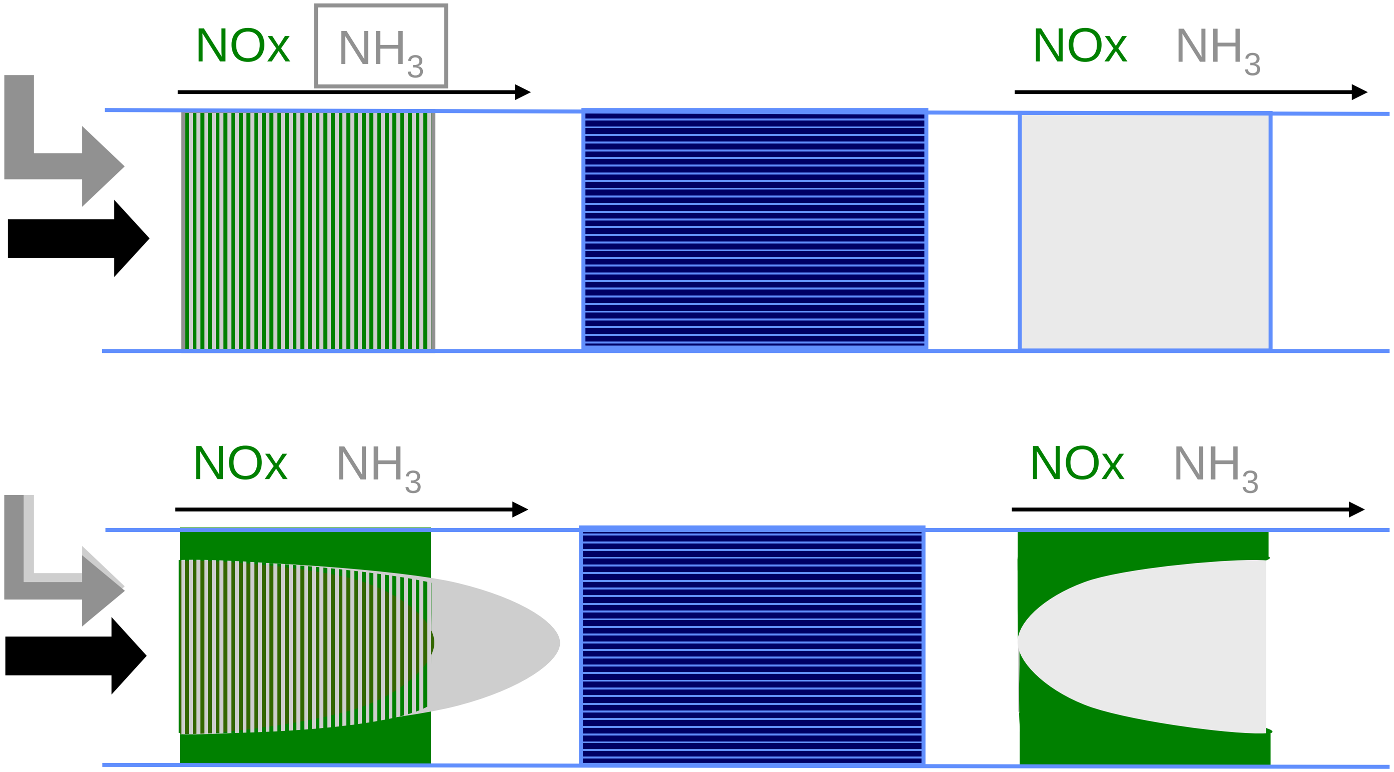
$$4\,NH_3 + 2\,NO_2 + O_2 \Rightarrow 3\,N_2 + 6H_2O$$



# UNIFORM DISTRIBUTION OF “AD BLUE”

- To receive a high reduction rate on NOx by the SCR catalyst a very good distribution of the reducing agent on the catalyst surface is necessary




- complete NOx-reduction (theor.)
- no $NH_3$-slip

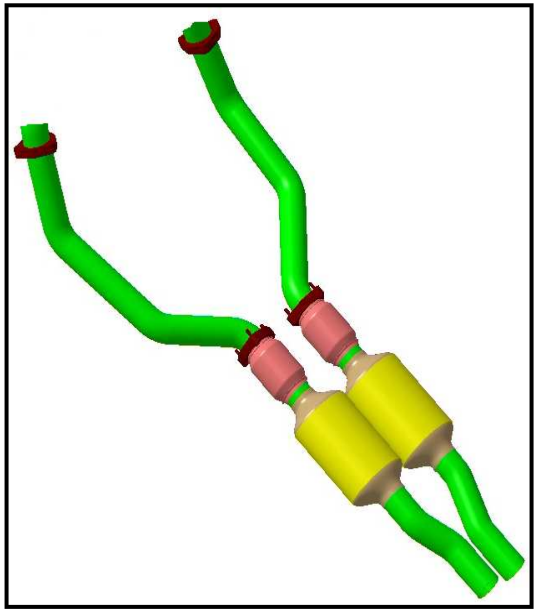
- $NH_3$-slip

or

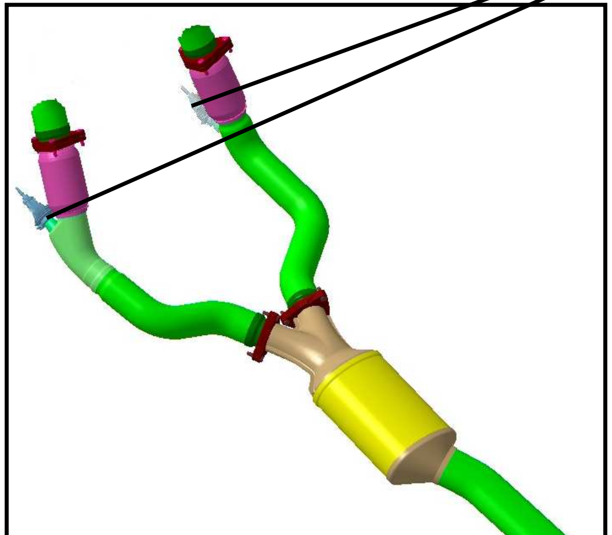
- lower NOx-reduction

## SCR FOR V-ENGINES
4 ltr - turbocharged

### Starting Design
- Dual pipe
- 2 SCR catalysts
- Flex pipe in front of catalyst
- No location for injection



### Optimized Packaging
- Location for injection optimized
- 1 SCR catalyst with optimized geometry
- Optimized outlet cone



**Basic design**

Find concept to use only **one** AdBlue injection

### Development Concept
- Lean – use simulation/ prediction
- Only final validation on engine test bench

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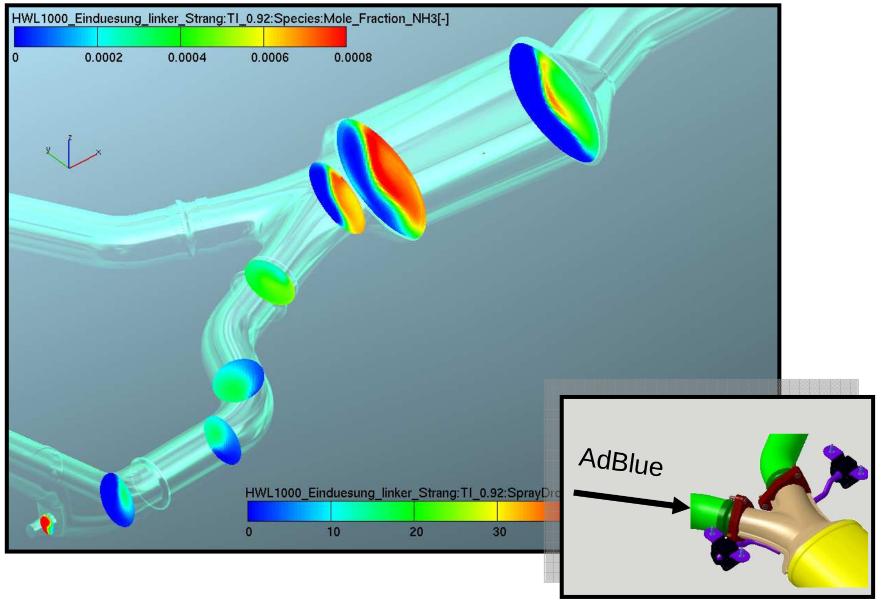
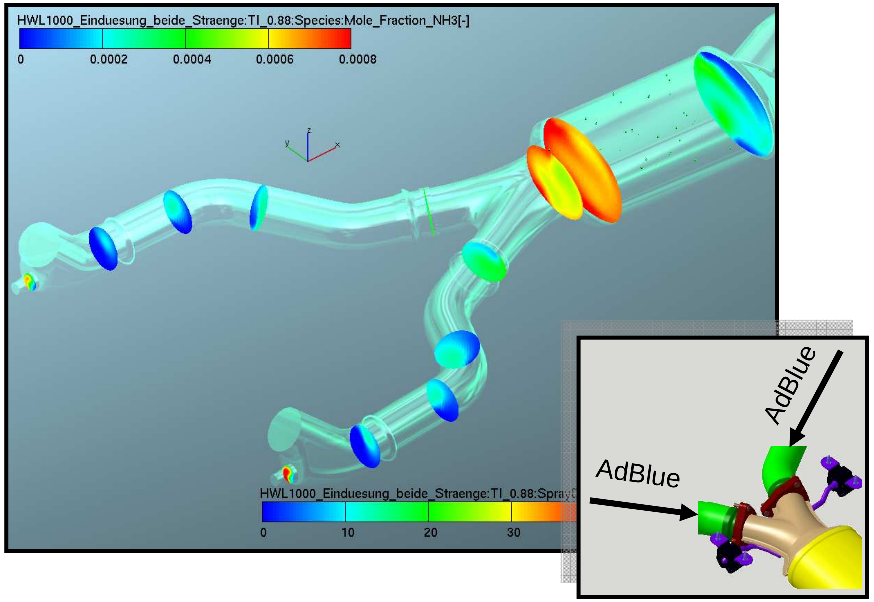
# ANALYSIS OF “BEST vs. WORST CASE”
## CFD Simulation - Results

### AdBlue injection in one pipe (basic 1)



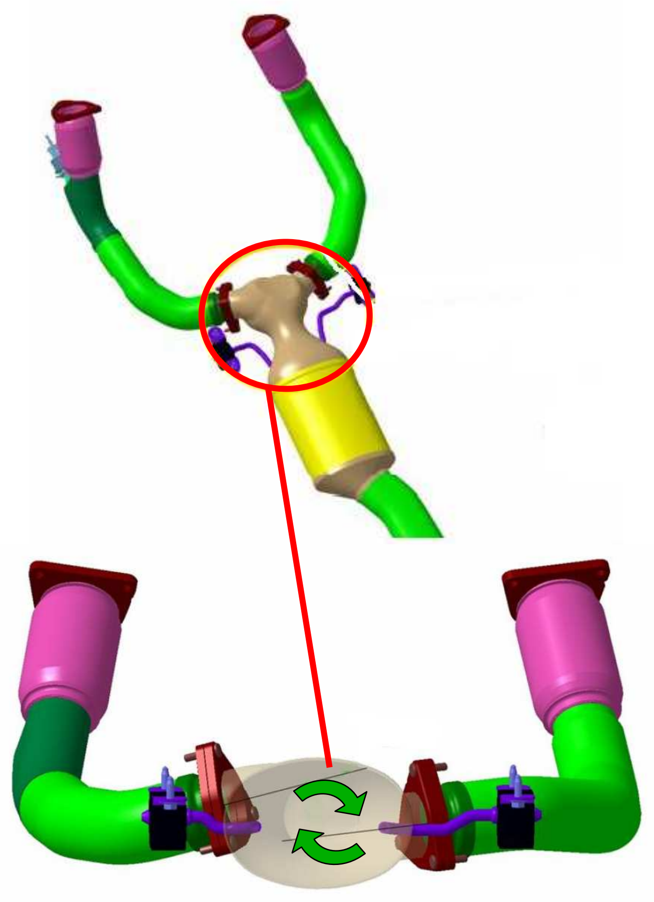

### AdBlue injection in two pipes (basic 2)



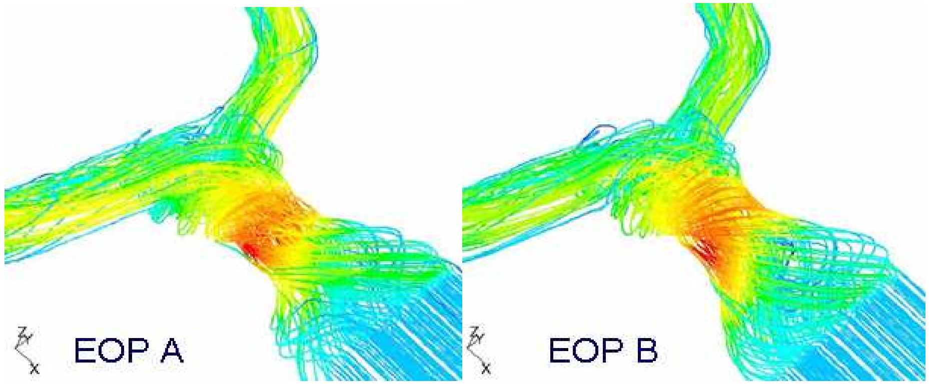

- With one AdBlue injection valve the ammonia distribution on the catalyst surface is not sufficient (left)
- With two AdBlue injection valves the CFD calculation shows a better uniformity of ammonia (right), but at higher costs

# DESIGN OPTIMIZATION AND VALIDATION

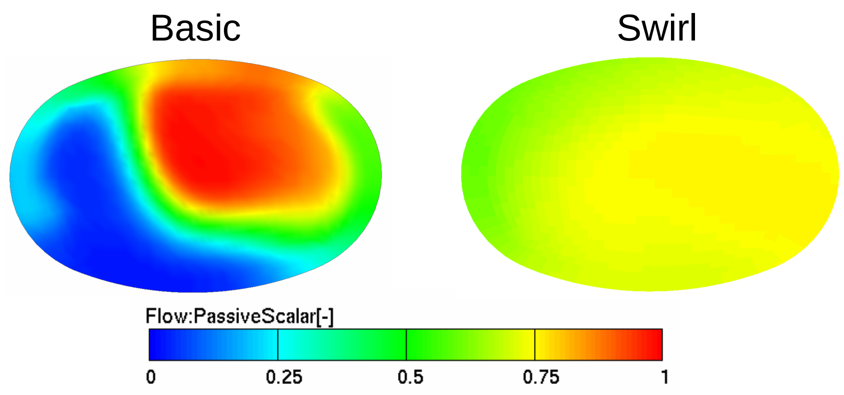
Swirl Cone Design



CFD-calculations (single-phase, steady state)




Distribution of passive scalar



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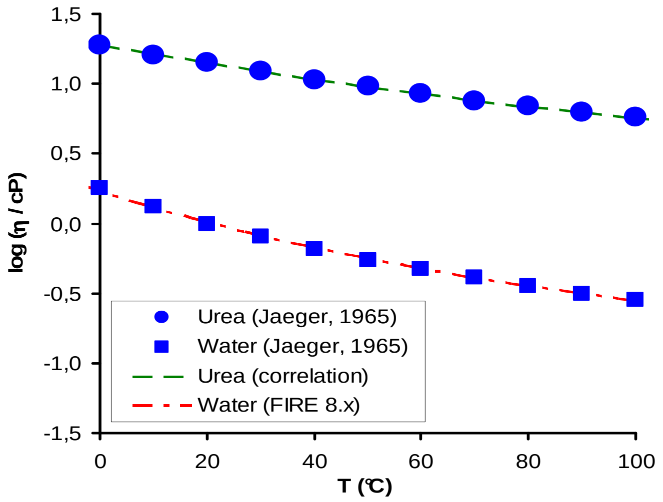
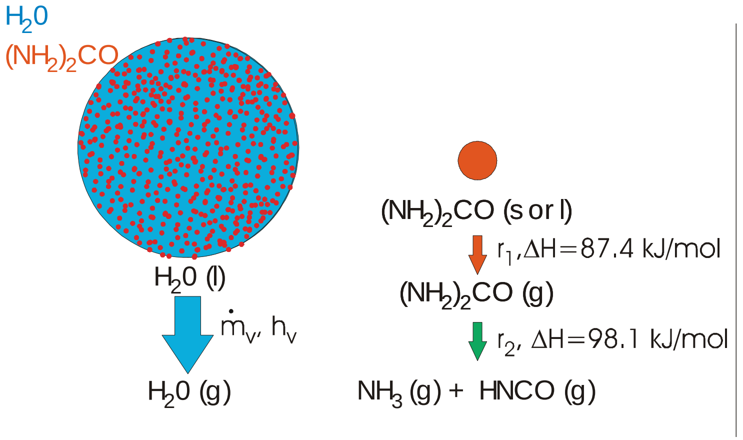
# CFD-SCR-SIMULATION

## Fluid Properties and Multi-component evaporation and thermoysis




FIRE®

Temperature and composition dependent modelling of

- liquid density, viscosity, specific heat
- solution vapour pressure

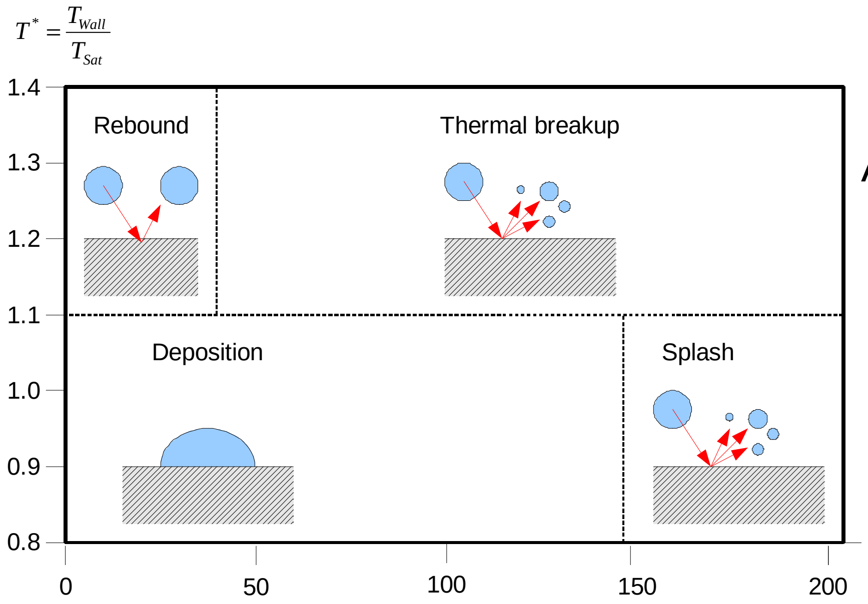
Properties for gaseous urea

- vapour heat capacity
- vapour dynamic viscosity

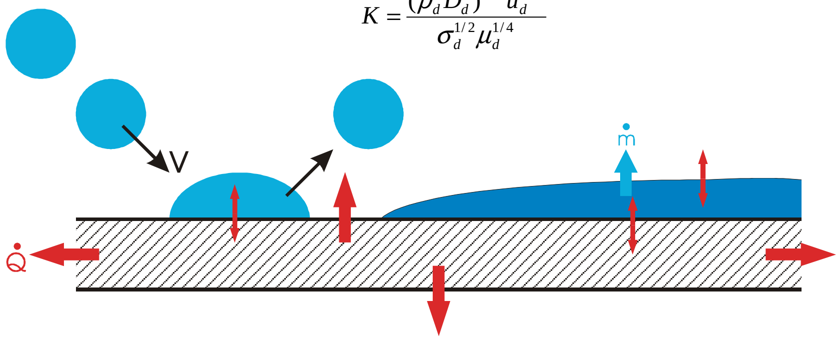
Spray / gas phase

- multi-component evaporation
- thermolysis
- hydrolysis

# CFD-SCR-SIMULATION
## Spray and Wallfilm modelling




$$K = \frac{(\rho_d D_d)^{3/4} u_d^{5/4}}{\sigma_d^{1/2} \mu_d^{1/4}}$$




FIRE®

Advanced Spray-Wall Modells

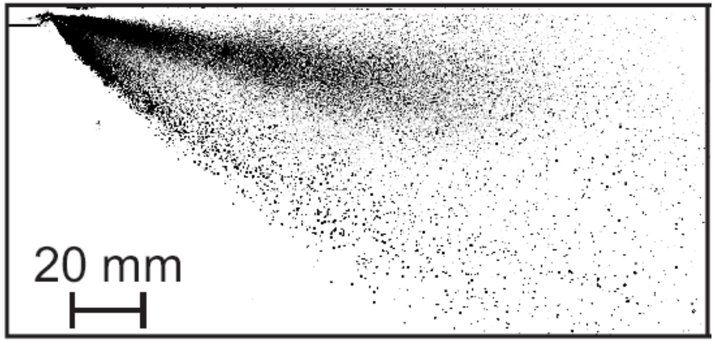
- Multicomponent wallfilm evaporation and thermolysis
- Modelling of heat transfer between droplets and wall (Wruck-Meingast)
- Wall temperatur dependent splashing model (Kuhnke with Birkhold Extension)
- Accounting for heat conduction in solid walls via lateral heat conduction


D. Kuhnke. Spray Wall Interaction Modelling by Dimensionless Data Analysis. PhD thesis, TU Darmstadt 2004.

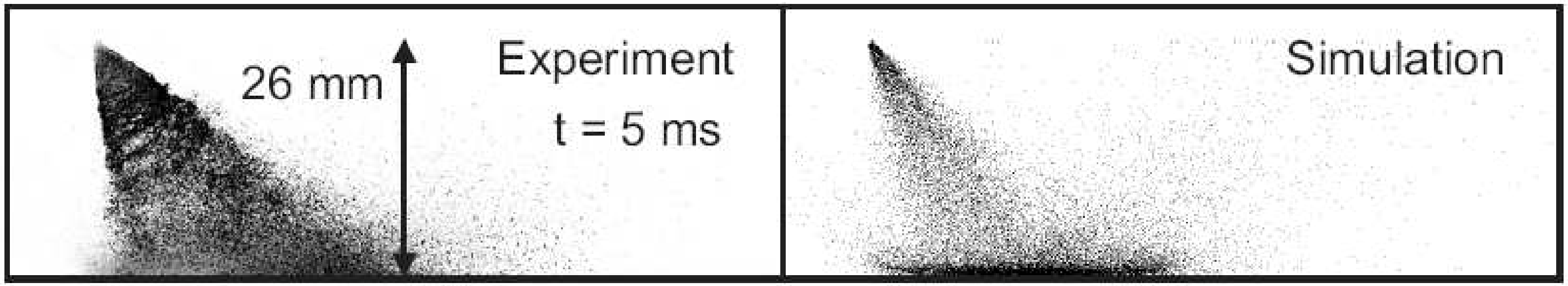
N. W. Wruck. Transientes Sieden von Tropfen beim Wandaufprall. PhD thesis, RWTH Aachen, 1998.

# CFD-SCR-SIMULATION
## Model validation

Lichtschnittvisualisierung




Simulation




Schwarzenberg, M. Untersuchung von Spraykonzepten zur Dosierung von Harnstoff-Wasser-Lösung beim Einsatz eines SCR-Verfahrens. Diplomarbeit, RWTH Aachen, 2005

F. Birkhold, U. Meingast, P. Wassermann, O. Deutschmann. Modeling and simulation of the injection of urea-water-solution for automotive SCR DeNOx-systems. Applied Catalyst B 70 (2007), 119-127

# CFD-SCR-SIMULATION
## Energy

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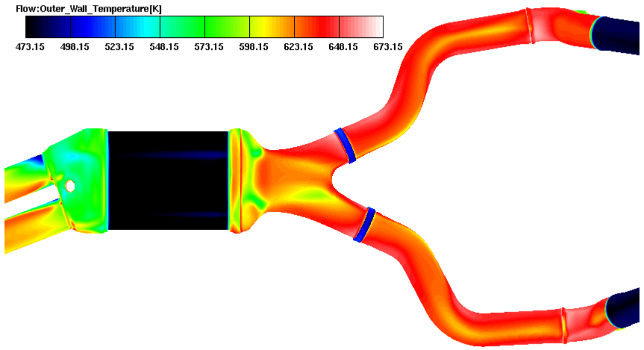
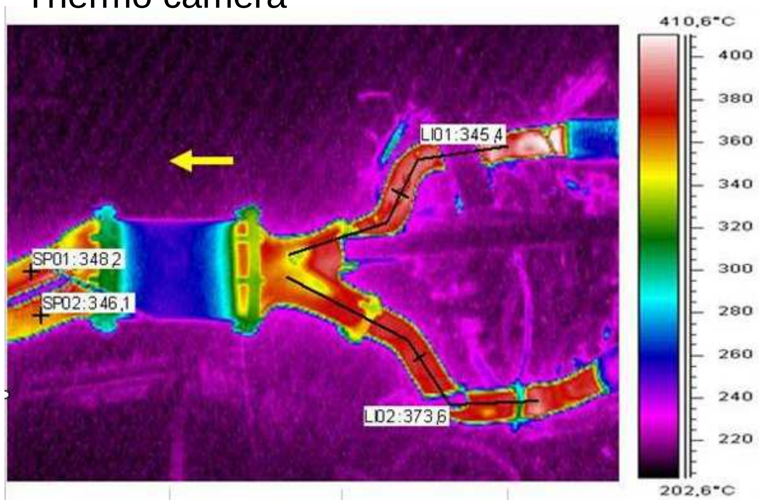
Simulation




Thermo camera




### Heat conductivity

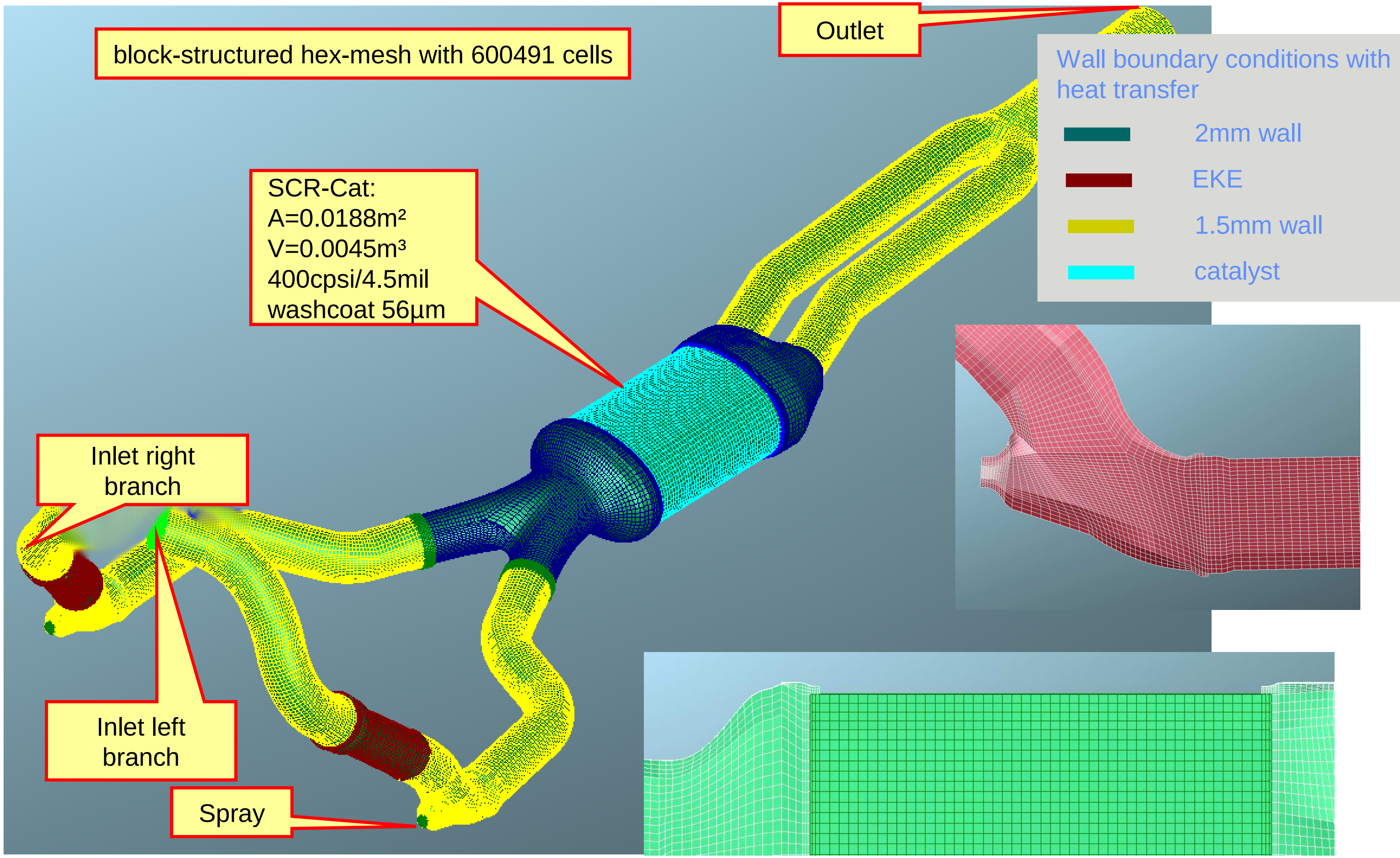
| | |
|---|---|
| Single wall tube | $s/\lambda = 6 \cdot 10^{-5}$ (m²K)/W |
| Decoupling element | $s/\lambda = 7.5 \cdot 10^{-2}$ (m²K)/W |
| Flange | $s/\lambda = 5 \cdot 10^{-2}$ (m²K)/W |
| Converter cover | $s/\lambda = 3.55 \cdot 10^{-2}$ (m²K)/W |
| Cones | $s/\lambda = 8 \cdot 10^{-5}$ (m²K)/W |

Heat transfer outside $\alpha_a = 10$ W/(m²K)

### Radiation

Emission coeff $\varepsilon = 0.5$ @ 30 °C

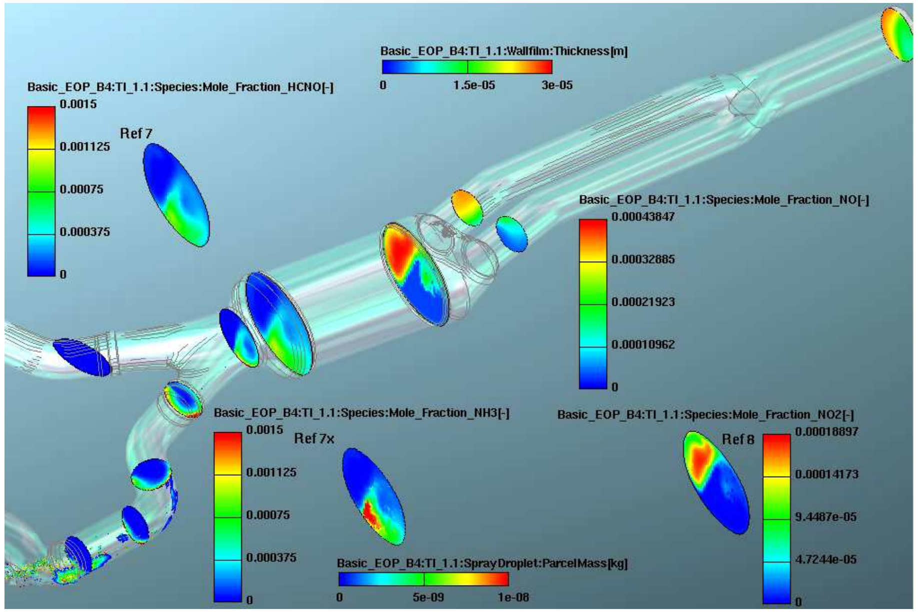
# CFD-SCR-SIMULATION
## Meshing

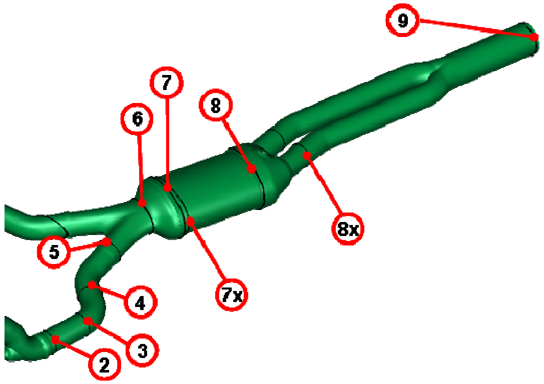


# CFD-SCR-SIMULATION
## Results

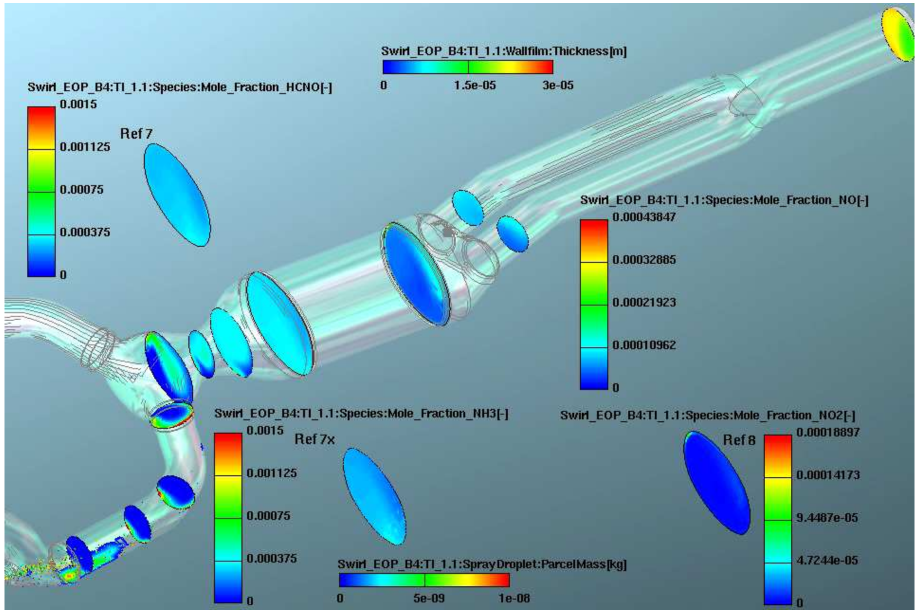
## OP B

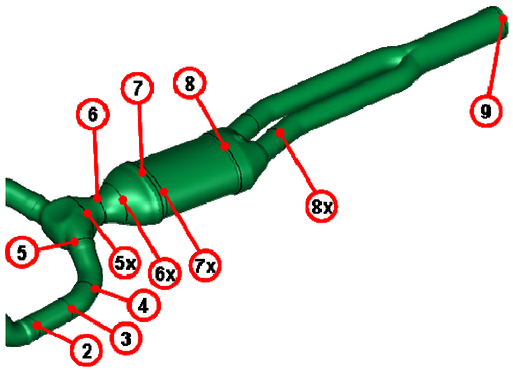
### Basic Design




### Swirl Design



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# ENGINE TEST BENCH INVESTIGATIONS

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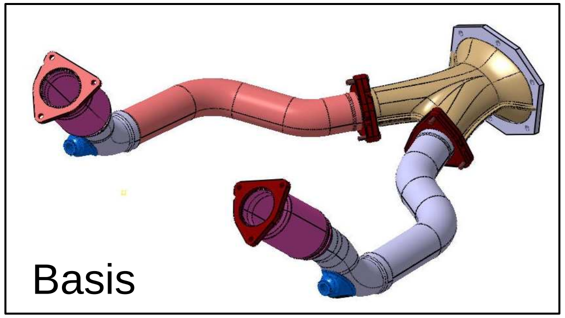
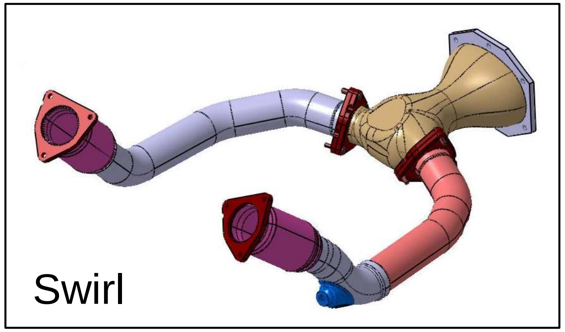
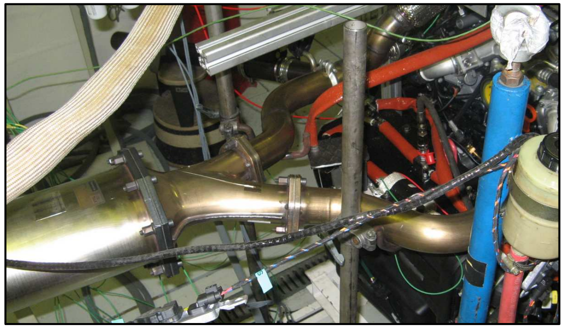


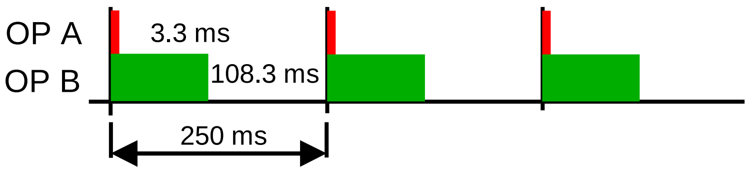



| | |
|---|---|
| Engine: | Diesel V8, 4.2 ltr, turbocharged |
| Max. power: | 240 kW @ 3750 rpm |
| Max torque: | 760 Nm @ 1800...2500 rpm |

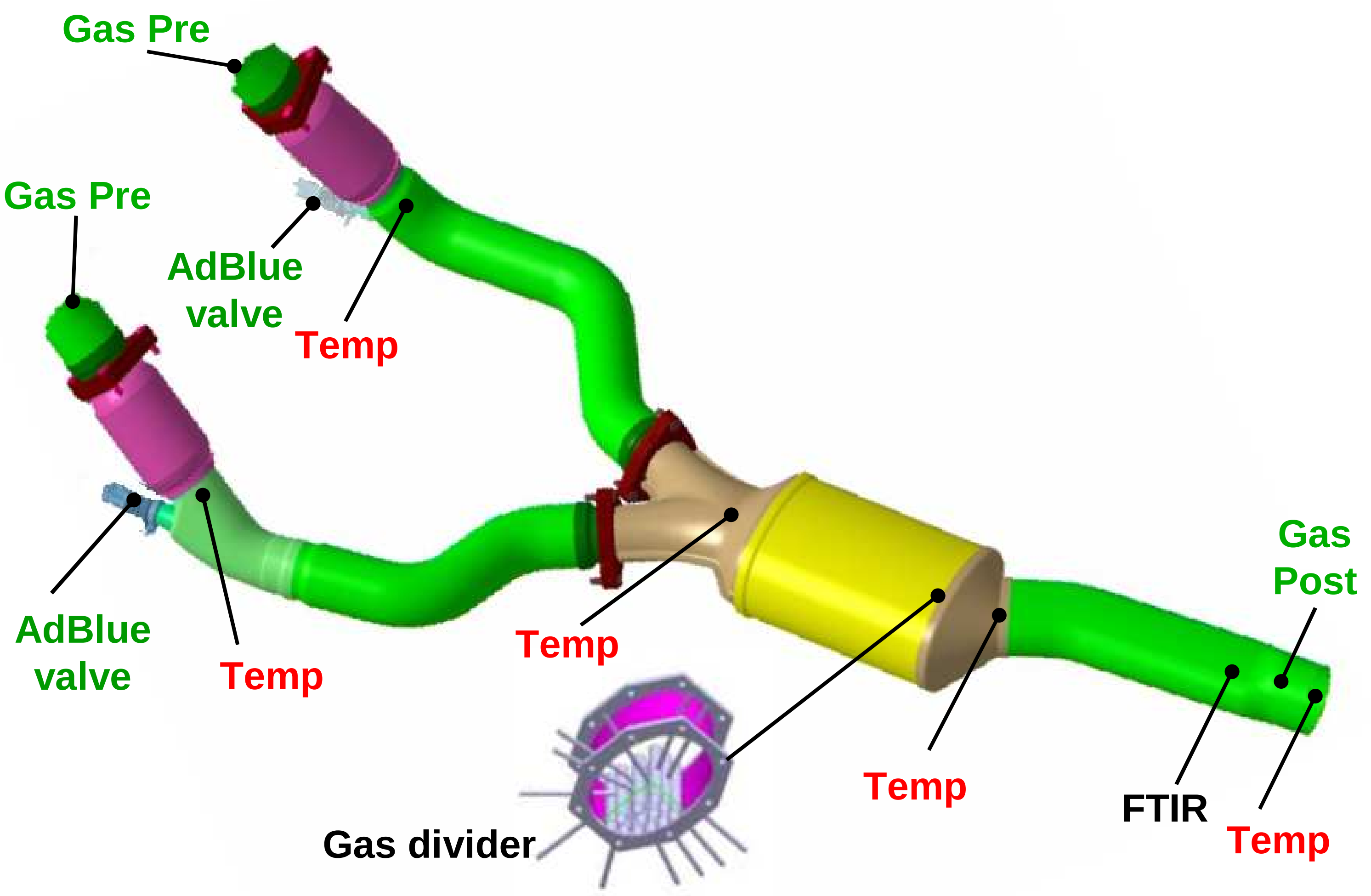
## Operating Points:

| Operating point (OP) | | A | B |
|---|---|---|---|
| Speed | [rpm] | 1700 | 3200 |
| Load | [Nm] | 160 | 390 |
| Mass Intake Air | [kg/h] | 136 | 700 |
| T before SCR | [℃] | 300 | 450 |

## Dosing strategy

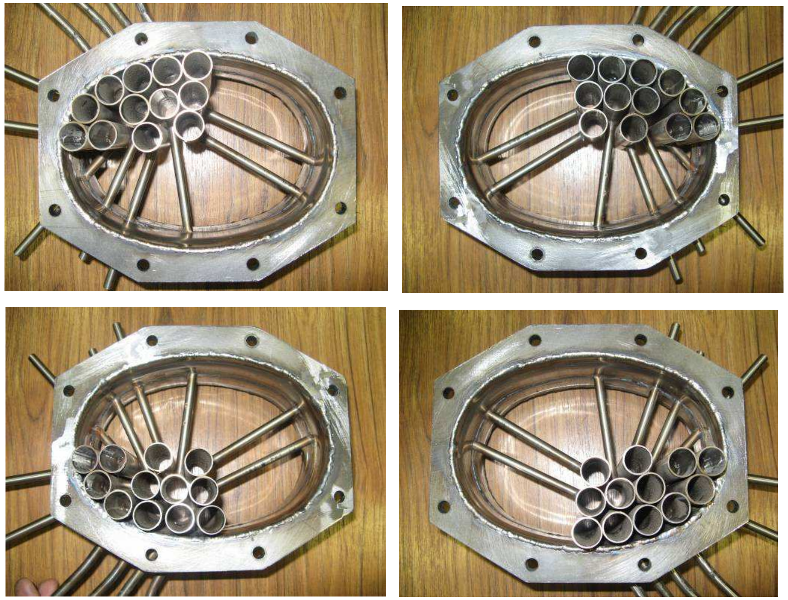


# ENGINE TEST BENCH SET-UP

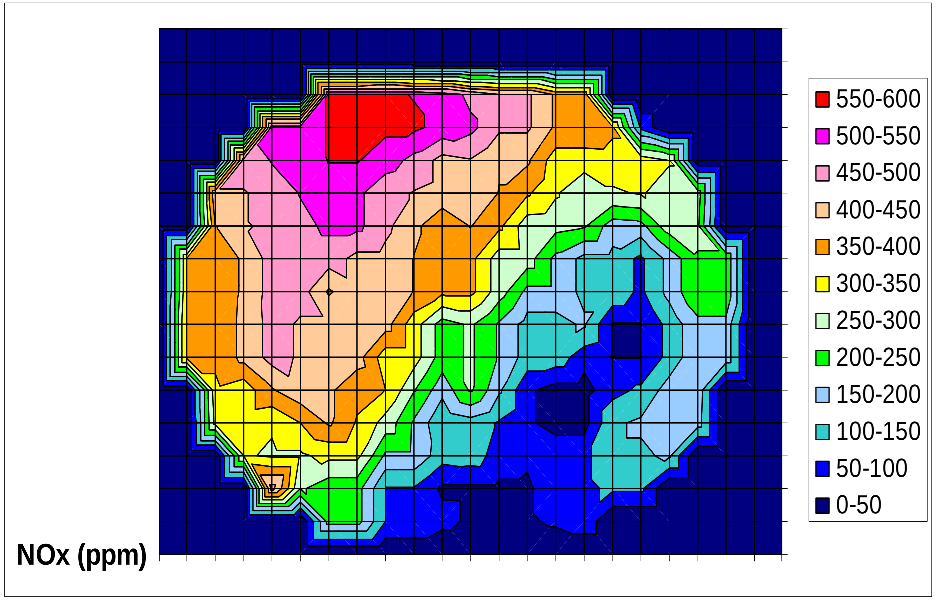


## NOx DISTRIBUTION MEASUREMENTS

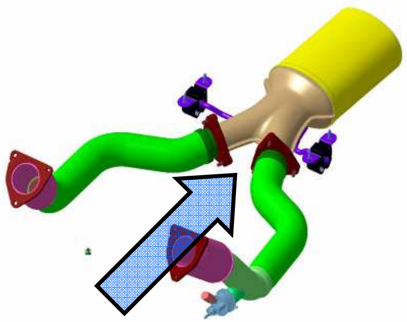
Gas divider



Mapping: 48 $NO_x$ + $NH_3$ sampling points

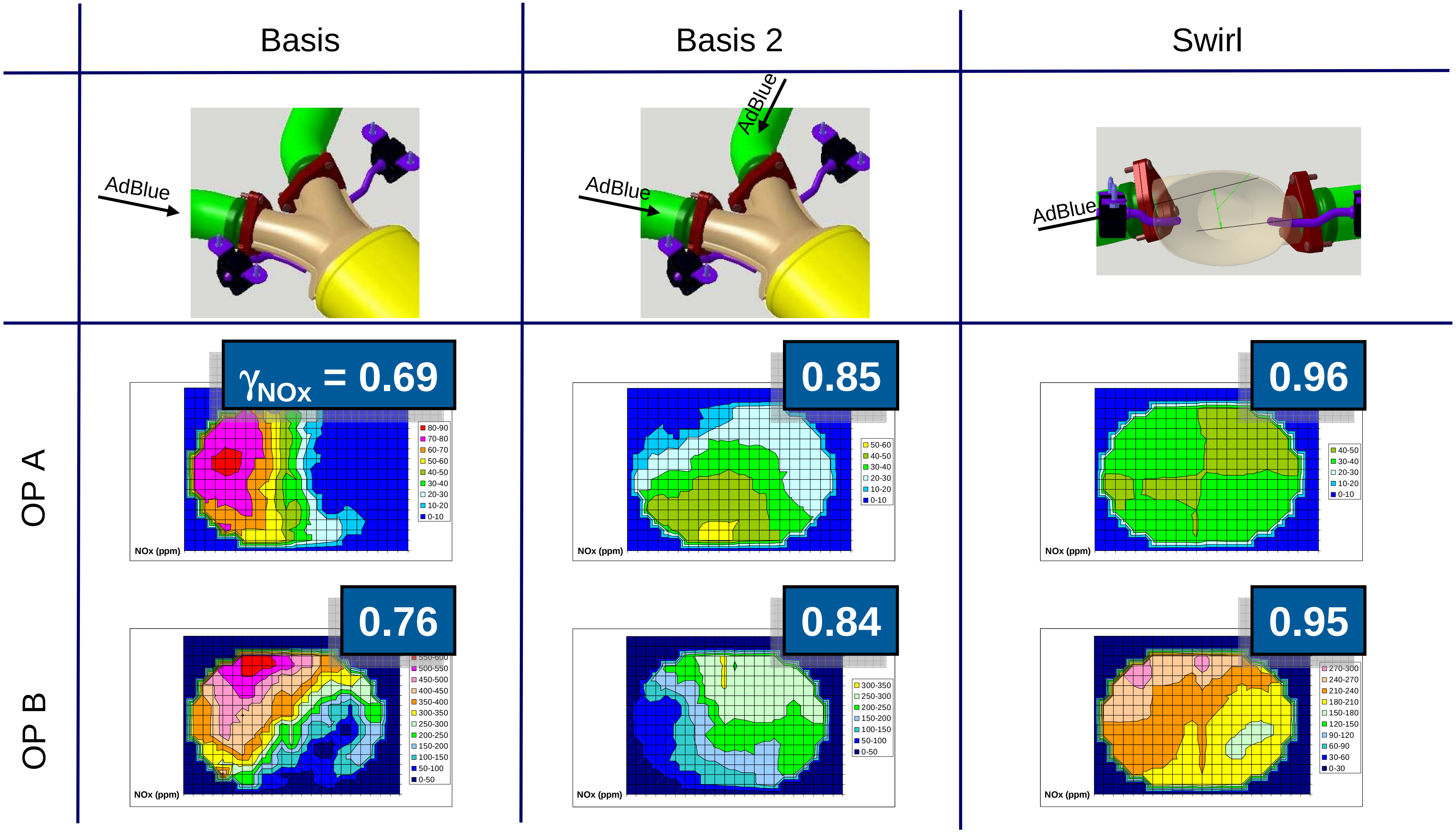



$$\gamma = 1 - \frac{\sum_{i=1}^{n} \left| c_i - \bar{c} \right|}{2n\bar{c}}$$

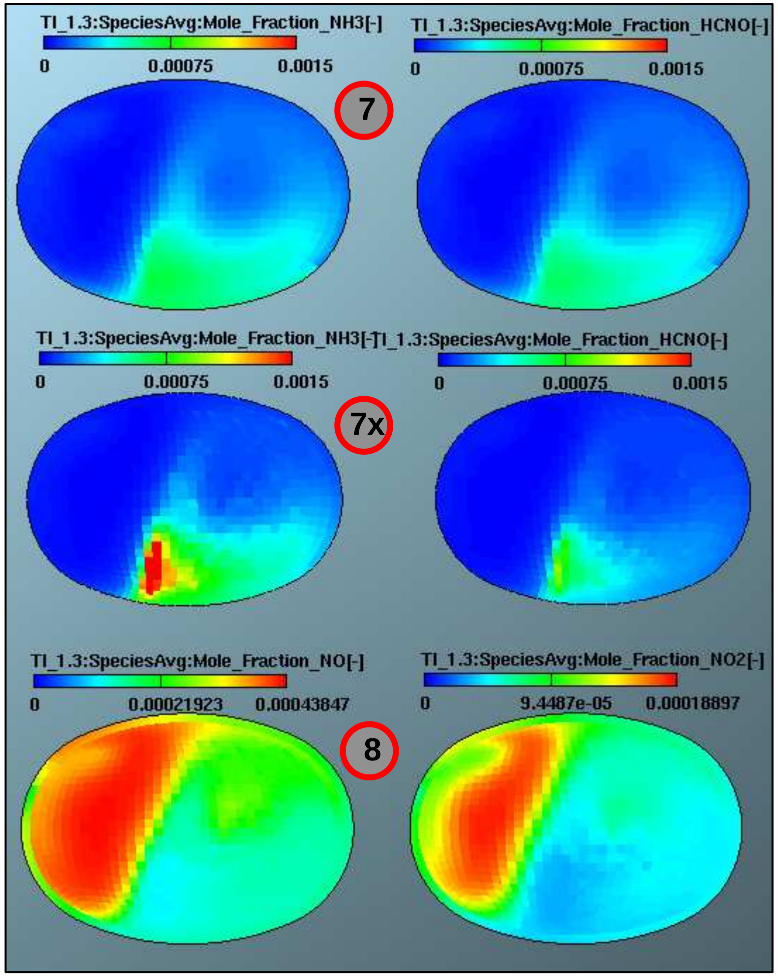


# NOx DISTRIBUTION MEASUREMENTS

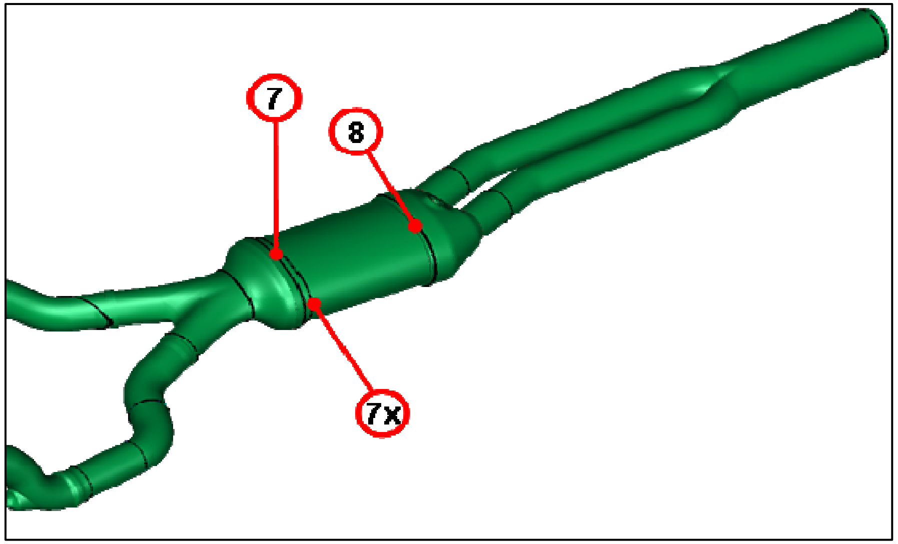
## Results

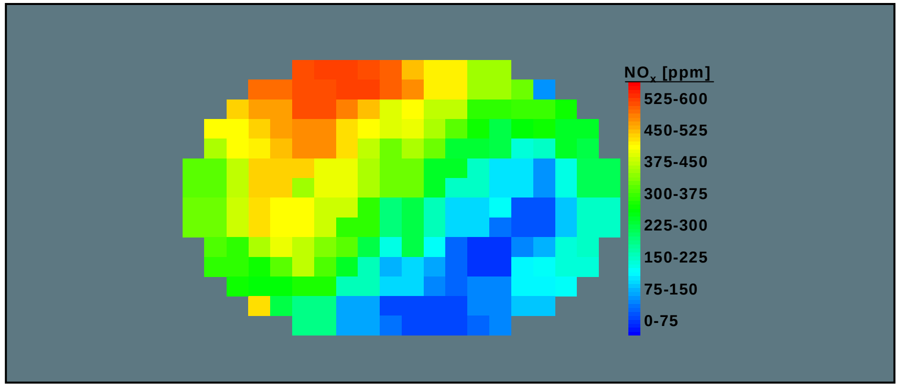


# CFD-SCR-SIMULATION
## Results basic design– comparison with engine bench




Simulation

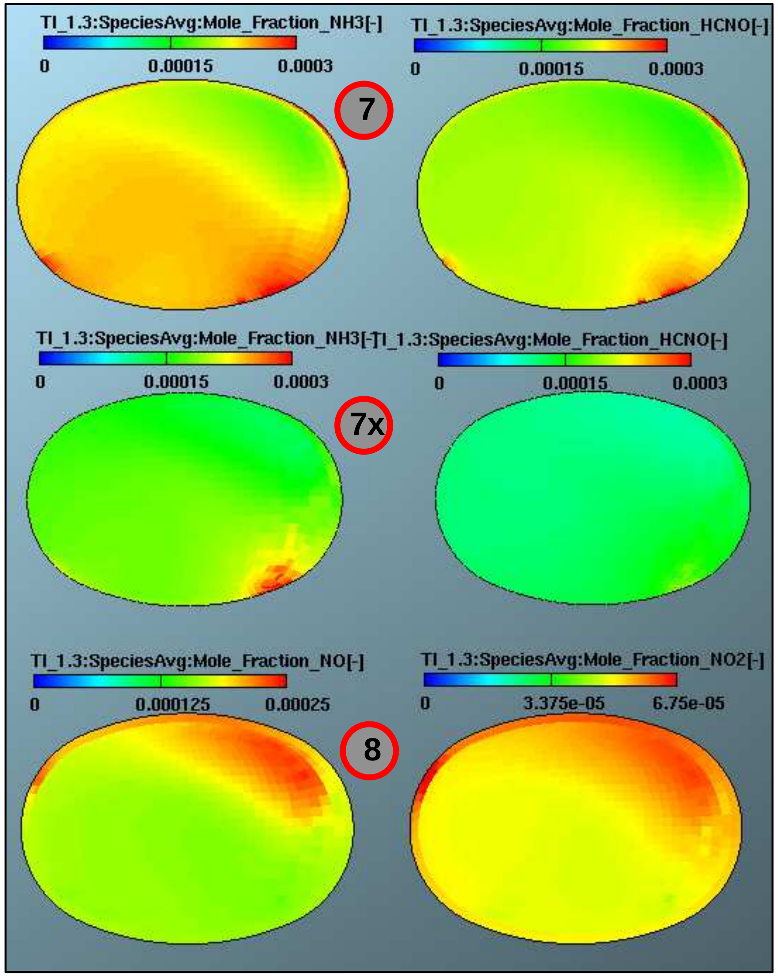


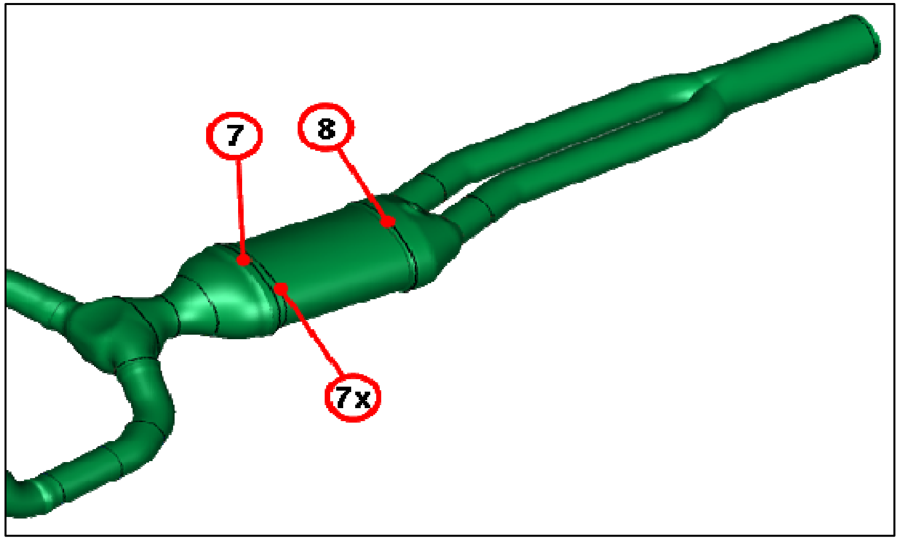

Measurement

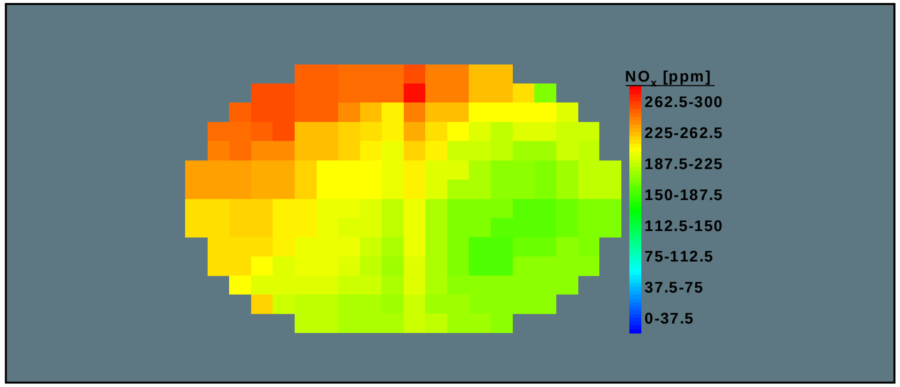
# CFD-SCR-SIMULATION

## Results swirl design– comparison with engine bench




Simulation




Measurement

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# CONCLUSIONS

- Advanced CFD models for ad-blue sprays and spray-wall interaction have been applied → accurate prediction of NH3-uniformity in good correlation with test bed results
- Successful development of a high performance SCR system for a dual line exhaust system (V8-engine) → Swirl cone design allows a high performance of the SCR catalytic converter
- In such exhaust system only one AdBlue injection is necessary to achieve a sufficient ammonia distribution on the SCR catalyst → Reduction of system costs and complexity of SCR control
- The application of accurate simulation-tools enables a fast and cost-effective virtual system development

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AVL

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