Willkommen Welcome Bienvenue



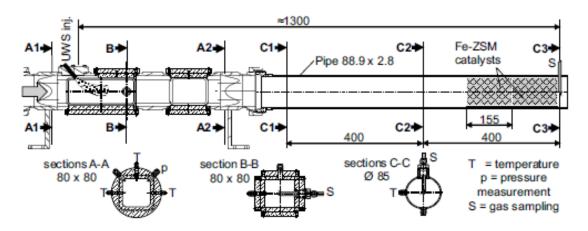
### Fuid Dynamic Characteristics of AdBlue Injectors and influence on the SCR Catalyst Performance

SAE Naples Workshop 2016 Sponsored by KOHLER Engines

> P. Dimopoulos Eggenschwiler, Dr. sc. techn. Automotive Powertrain Laboratory

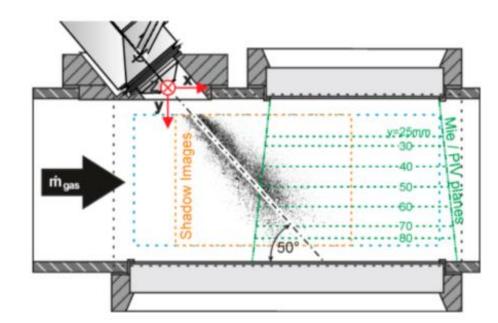


#### Channel for analysing the UWS injection phenomena and their influence on SCR catalyst performance



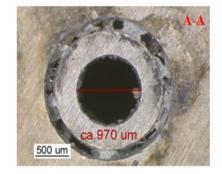
Air cross flow  

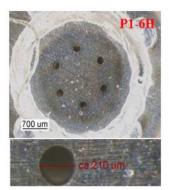
$$T = [20 - 600]^{\circ} C$$
  
 $\dot{m} = [0 - 500] \frac{kg}{h}$   
Precise Feed Gas  
composition



### Investigations in 4 commercially available UWS Injectors











Injector	A-A	P1-6H	P-3H	P2-6H	
Driven mechanism	air-assist	pressure	pressure	pressure	
Pressure	-	9bar	9bar	9bar	
Air-pressure	1.5bar	-	-	-	
Static flow rate	2.64kg/h	15.2kg/h	7.2kg/h	7.3kg/h	
Nozzle diameter	970µm	210µm	190µm	130µm	
Nozzle number	zle number 1		3	6	
Spacing diameter	-	1.3mm	1.9mm	1.9mm	

# Fluid dynamic characterization based on laser diagnostic techniques

 Mie Scattering Distribution of the liquid spray in the exhaust flow

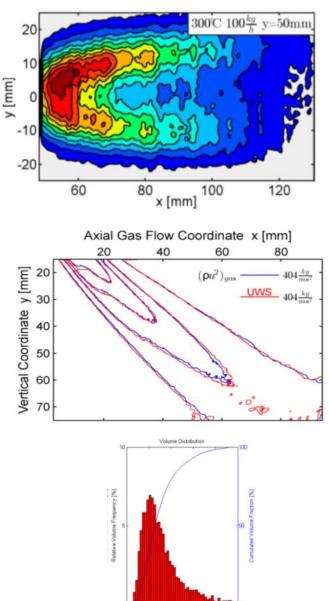
Spiteri A., Dimopoulos Eggenschwiler P., *Experimental Fluid Dynamic Investigation of Urea-Water Sprays for Diesel Selective Catalytic Reduction-DeNOx Applications,* Industrial & Engineering Chemistry Research (2014) 53(8), 3047-3055.

 Shadow Imaging Quantification of the droplets entrainment by the gas flow

A. Spiteri, P. Dimopoulos Eggenschwiler, Y. Liao, G. Wigley, K. A Michalow-Mauke, M. Elsener, O.Kröcher, K. Boulouchos, *Comparative analysis on the performance of pressure and air-assisted urea injection for Selective Catalytic Reduction of Nox,* Fuel, 2015 ACCEPTED

 Phase Doppler Anemometry Drop size and velocity distributions

Liao, Y., Dimopoulos Eggenschwiler, P., Spiteri, A., Nocivelli, L. et al., "Fluid Dynamic Comparison of AdBlue Injectors for SCR Applications," SAE Int. J. Engines 8(5):2015, doi:10.4271/2015-24-2502.



Diameter [µm]

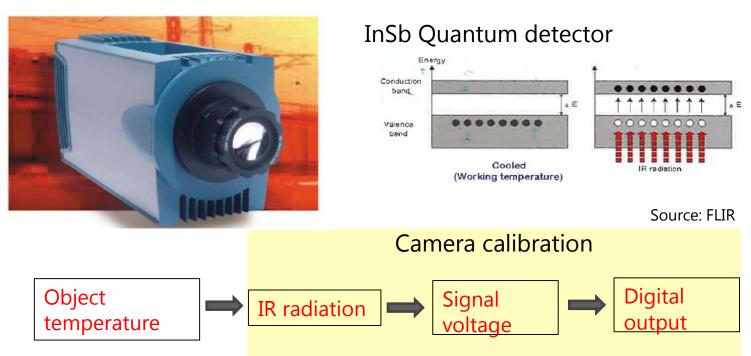


### ...but also on more conventional techniques, and temperature measurements with IR thermography









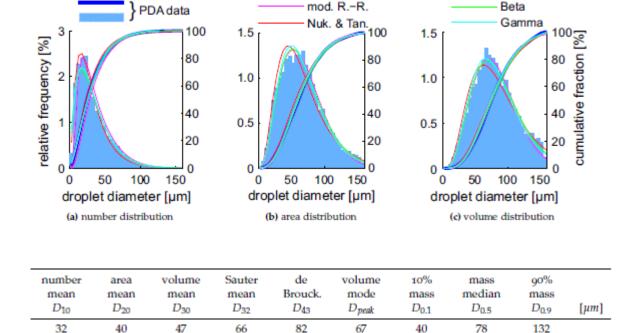


### Spray Characterization

- Interaction of Spray with the Cross Flow
- Wall Impingement
- NOx conversion in the catalyst

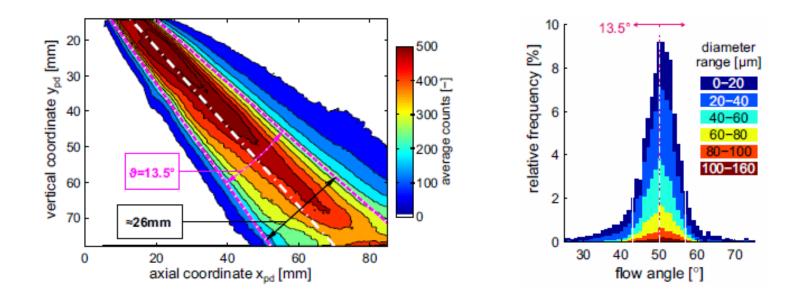
Pressure driven injection: Droplet diameters  $<50\mu m$  for 80% of the droplets, but these droplets make up for 36% of area and 20% of mass





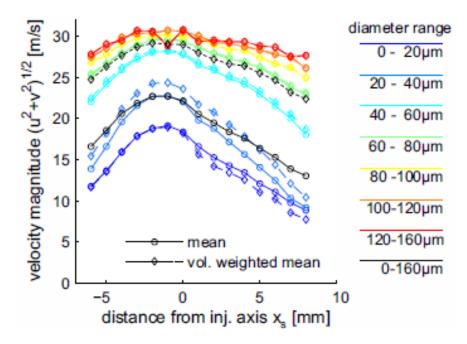


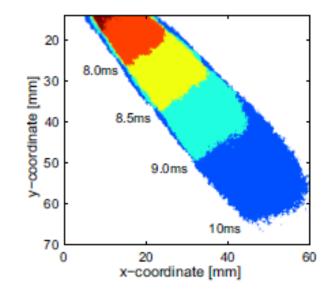
## 94% of all droplets larger than 40 $\mu m$ are inside the 13.5° angle



Spraycones for all 6 holes have merge in one single cone

Big droplets, high velocities originating from the nozzle, smaller droplets low velocities, spray tip with 28m/s

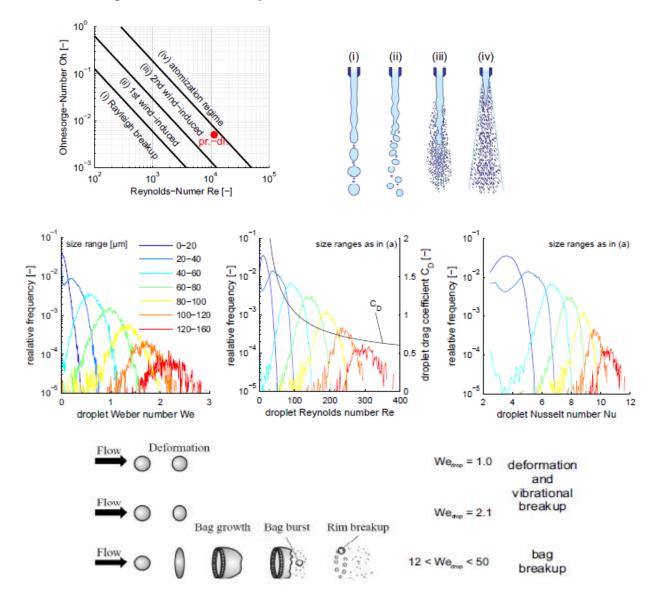






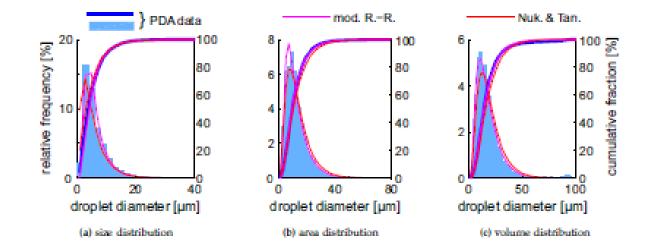


### Primary Breakup: Nozzle Flow Properties; No secondary breakup





Air assisted injection: Droplet diameters  $<\!10\mu m$  for 90% of the droplets, 50% of area and 45% of mass



p <sup>tot</sup> [MPa]	number mean D <sub>10</sub>	area mean D <sub>20</sub>	volume mean D <sub>30</sub>	Sauter mean D <sub>32</sub>	de Brouck. D <sub>43</sub>	volume mode D <sub>paik</sub>	10% mass D <sub>0.1</sub>	mass median D <sub>0.5</sub>	90% mass D <sub>0.9</sub>
0.163	5.6	7.1	9.1	15.1	24.3	12.1	7.6	20.0	46.4
0.185	5.1	6.4	8.1	12.9	20.6	10.3	6.4	16.0	36.2
0.220	4.8	5.9	7-3	11.0	16.5	9.2	5.8	140	30.4
0.271*	5.6	6.8	8.3	12.1	17.0	10.8	6.6	14.9	30.0
0.325*	5.2	6.8	7-5	10.7	15.0	9.6	5-9	13.1	26.2

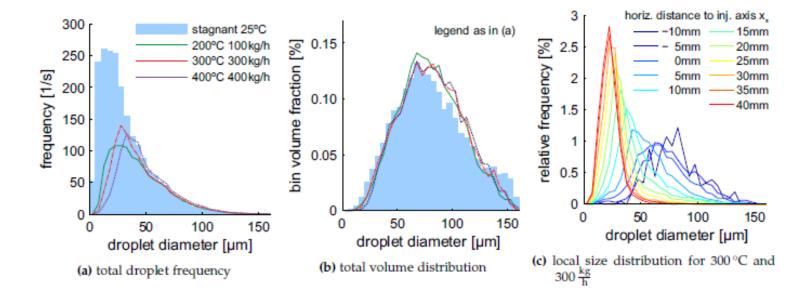
\*x-traverse only



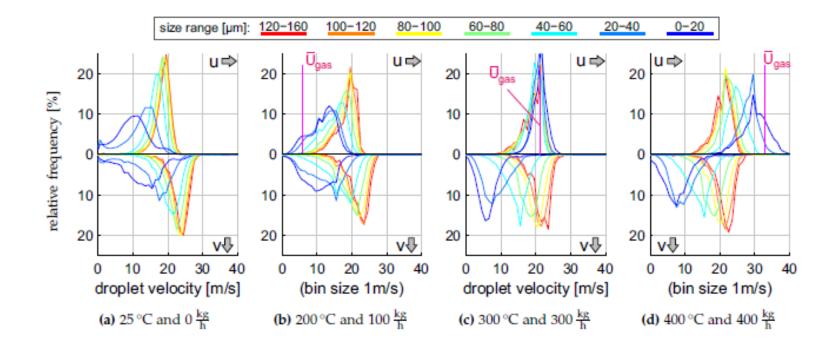
- Spray Characterization
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### Entrainment of droplets smaller than $30\mu m$ , but these are a small fraction of total droplets



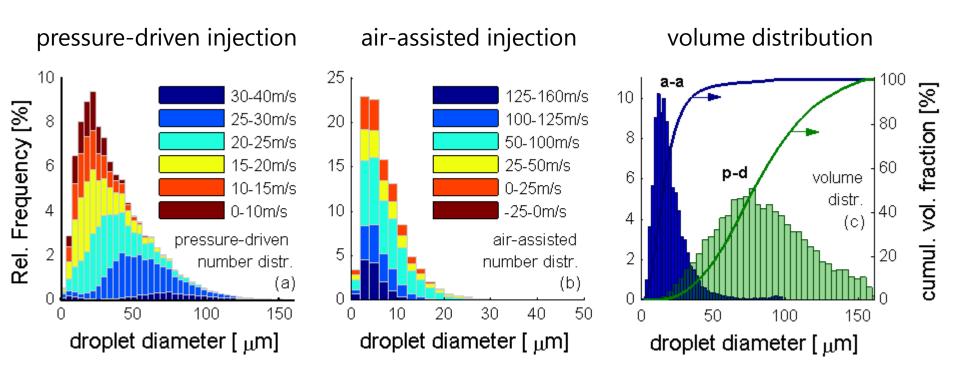


Smaller droplets are accelerated towards the crossflow velocity. Increasing crossflow increases droplet axial velocities in expense of the transversal component



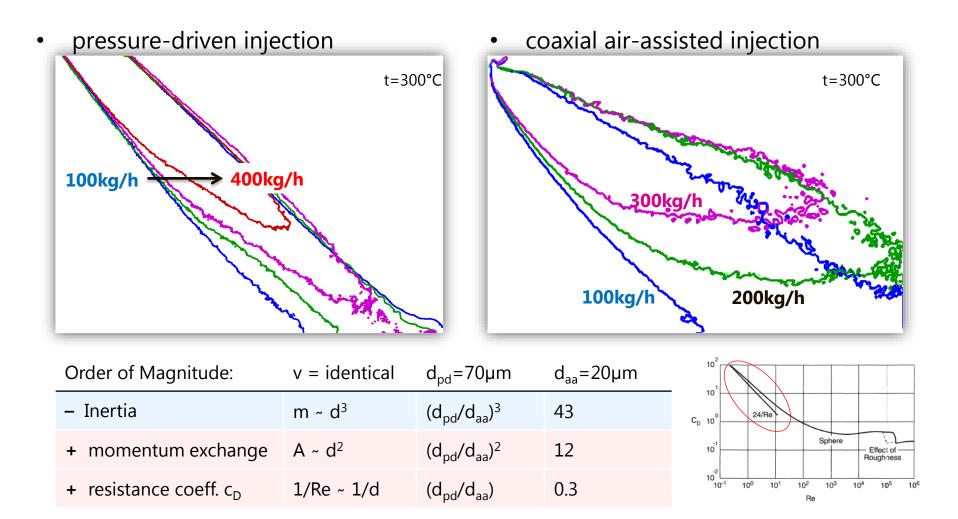
# Air-assisted injector leads to smaller droplets with higher velocities



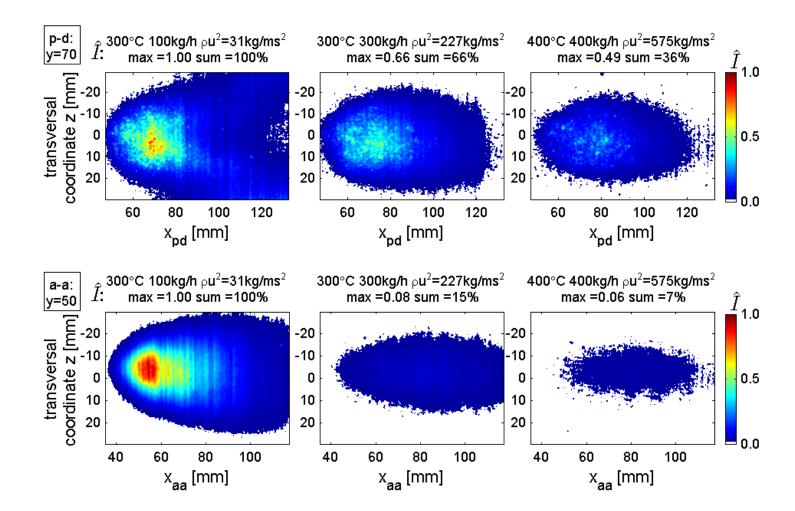


### Different entrainment characteristics





# Air-assisted spray entrainment much stronger



Empa

Materials Science and Technology

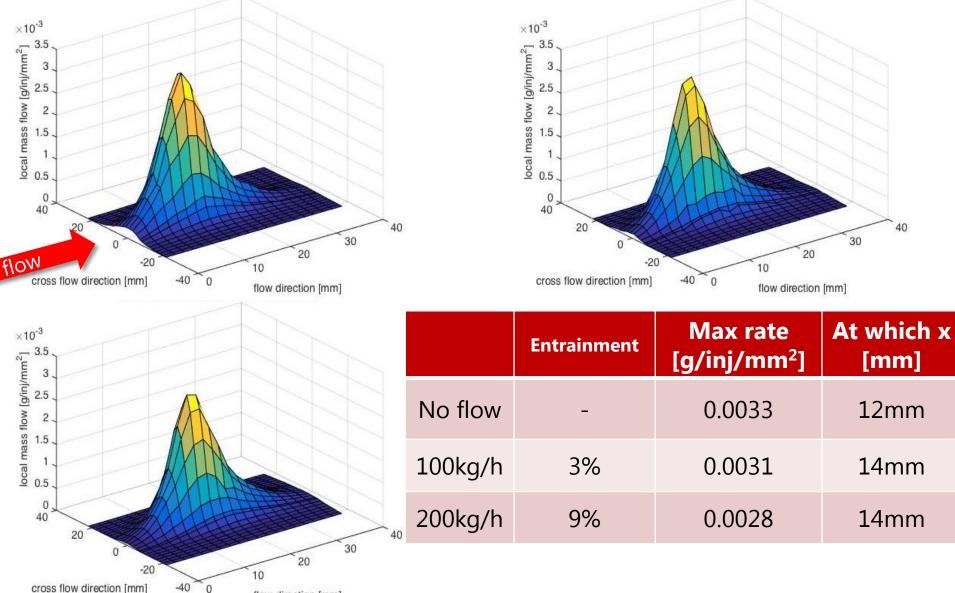
pressure-driven

air-assisted

#### Quantification of wall impinging mass and thus of entrainment with the «mechanical patternator»

Empa

Materials Science and Technolog



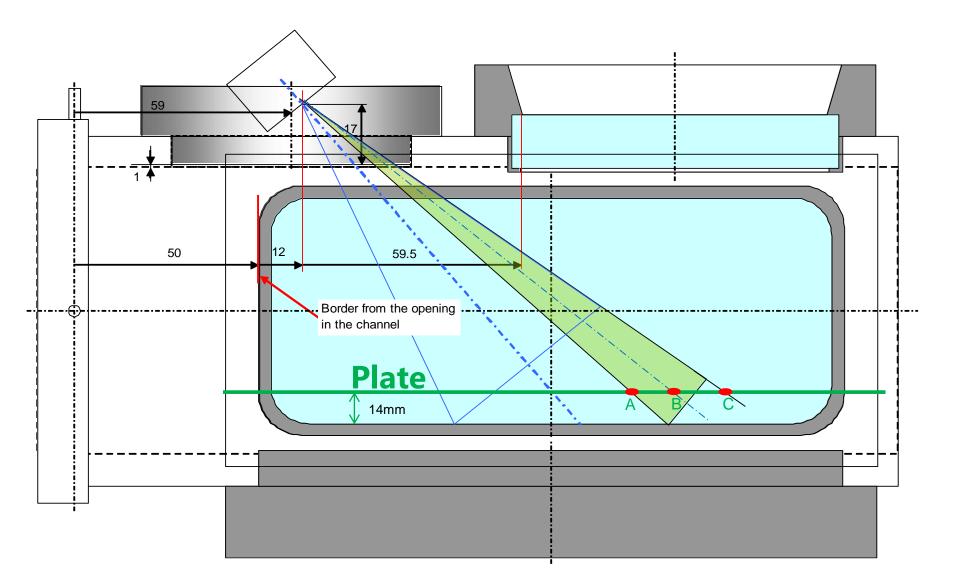
-40 0 flow direction [mm]



- Spray Characterization
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## Spray impinges on a plate in the gas flow for stable boundary conditions

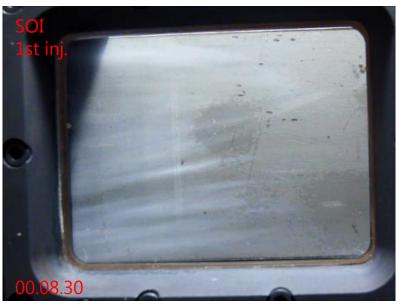


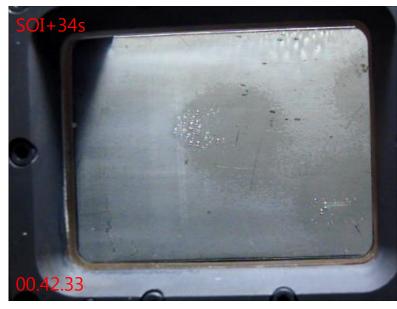


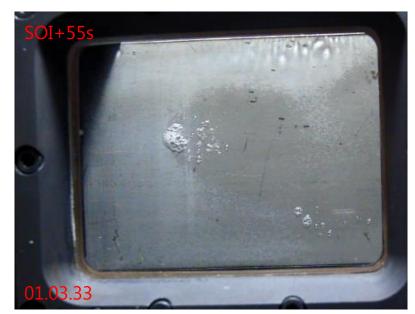
# Spray footprints visible and increasing until they merge forming a liquid film



Gas flow







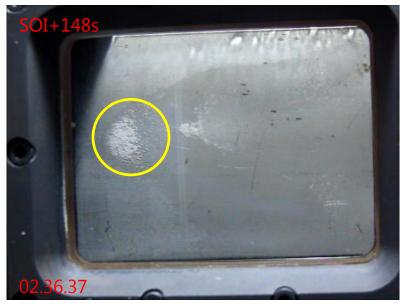


300°C, 100kg/h, 60ms, 150s

# Footprint tip with boiling conditions, water, remaining wet plate enriched urea



Gas flow









# Urea enriched film starts drying out, first crystals appear











300°C, 100kg/h, 60ms, 150s



# Crystals form persistent solid deposits not melting at 300°C



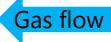






300°C, 100kg/h, 60ms, 150s

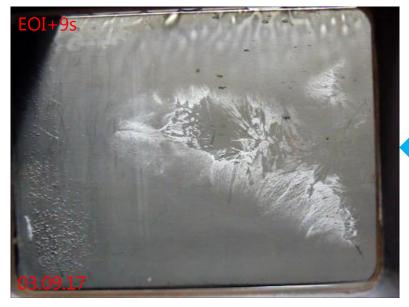


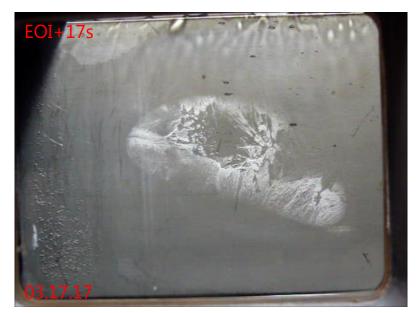


Increased UWS quantity, solid urea crystals can be seen, later melting and vaporising











300°C,

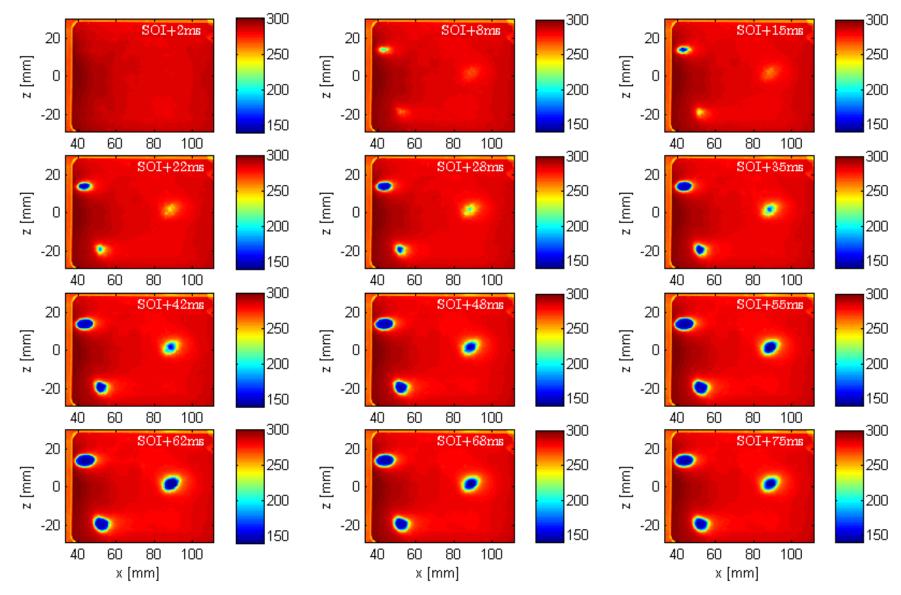
120ms,

150s

Gas flow

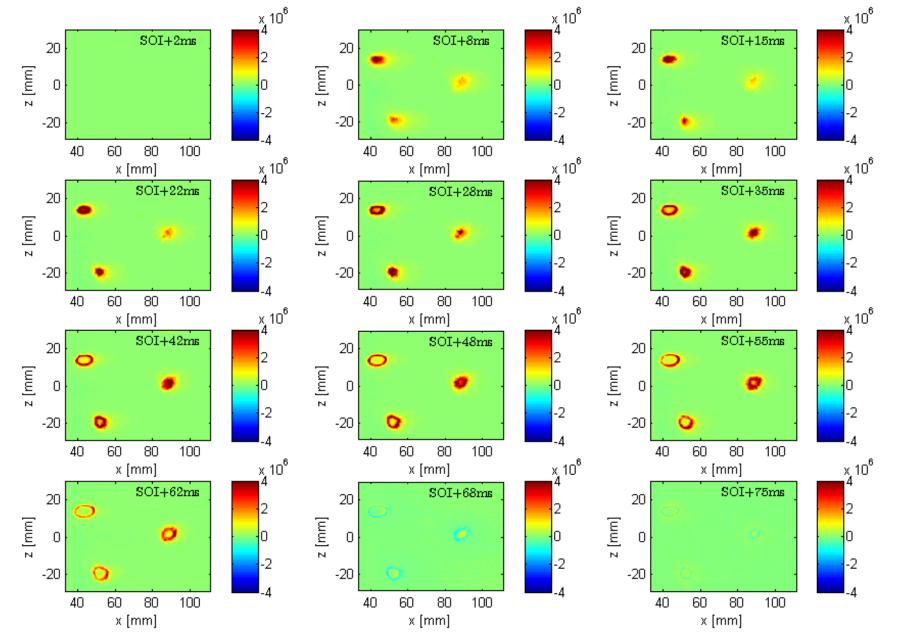
Thermal impact of one single injection on the plate: almost instant 150° temperature drop





### Local cooling rates in MW/m2 order



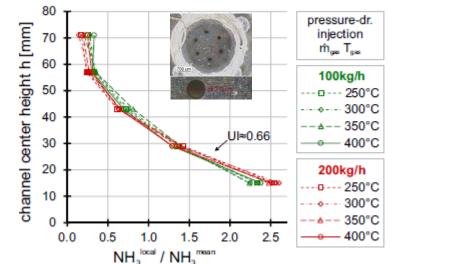


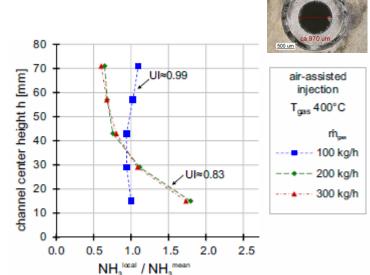


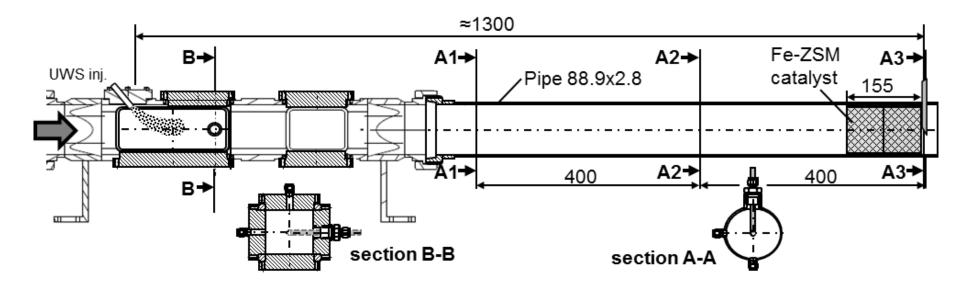
- Spray Characterization
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### NH3 spatial distribution upstream the catalyst is strongly affected by the injection...



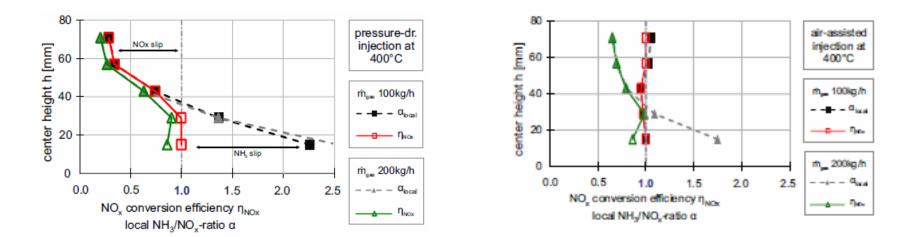


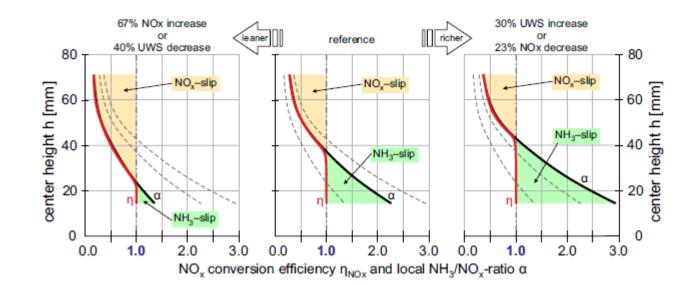




# ...leading to NOx conversion deficiencies and Ammonia slip







#### Thanks to



- A. Spiteri, PhD 2016, ETHZ
- L. Nocivelli, PhD 2016, PoliMi
- Y. Liao, PhD 2017, ETHZ
- M. Crialesi Esposito, Masterthesis, Universita degli Studi di Parma
- A. Vogel, 2016, Masterthesis ETHZ
- F. Curto, 2016, Masterthesis, PoliMi
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