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

8th VERT Forum
March 17th, 2017

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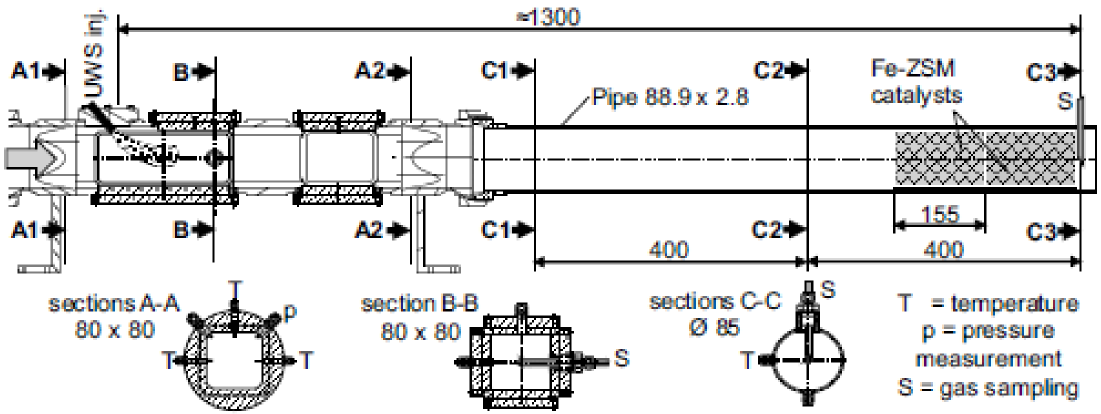
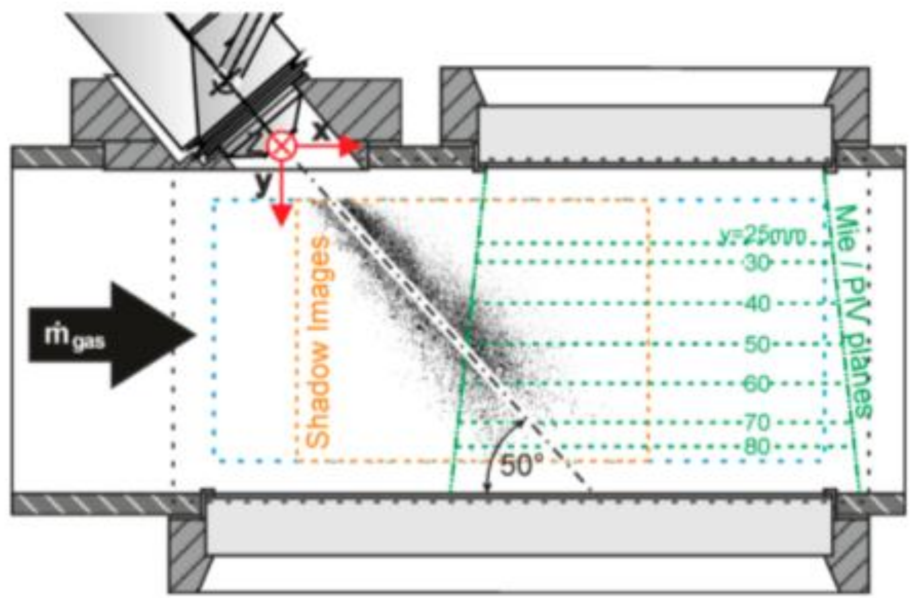
Automotive Powertrain Laboratory

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



Air cross flow
$T = [20 - 600]°$ C
$\dot{m} = [0 - 500]\ \frac{kg}{h}$
Precise Feed Gas composition



Investigations in 4 commercially available UWS Injectors

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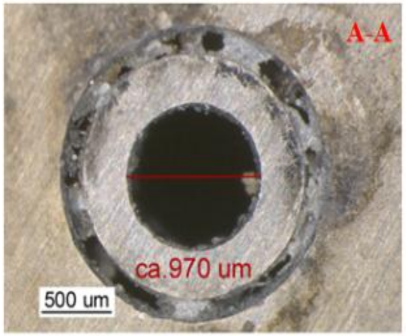

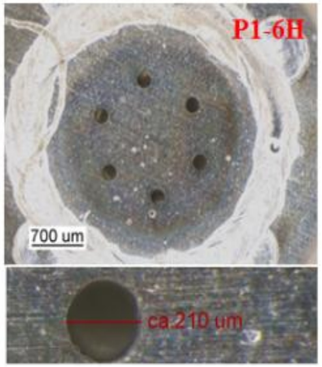

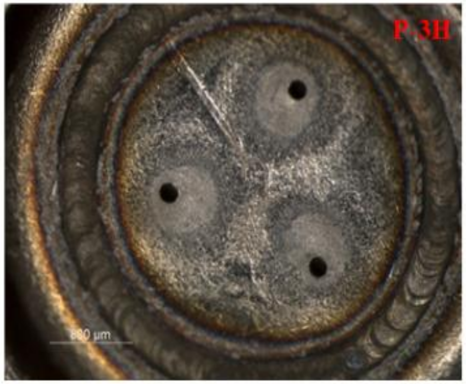

Injector	A-A	P1-6H	P-3H	P2-6H
Driven mechanism	air-assist	pressure	pressure	pressure
Pressure	-	9bar	9bar	9bar
Air-pressure	1.5bar	-	-	-
Static flow rate	2.64kg/h	15.2kg/h	7.2kg/h	7.3kg/h
Nozzle diameter	970µm	210µm	190µm	130µm
Nozzle number	1	6	3	6
Spacing diameter	-	1.3mm	1.9mm	1.9mm

Fluid dynamic characterization based on laser diagnostic techniques

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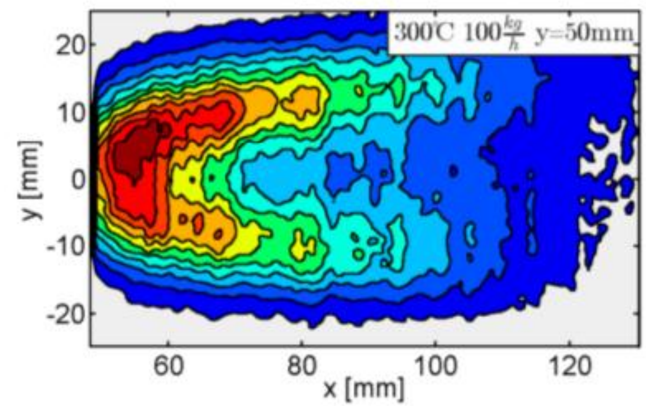
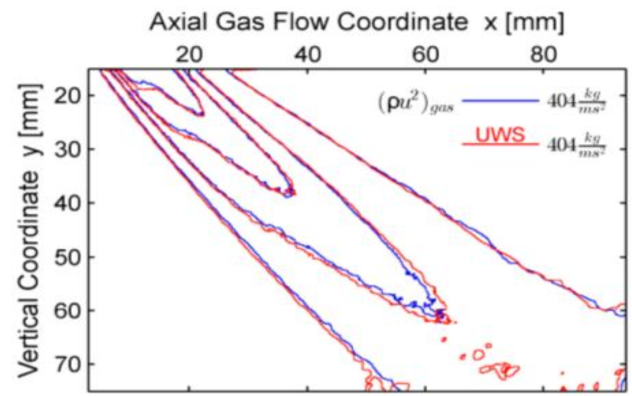
- Mie Scattering
  Distribution of the liquid spray in the exhaust flow



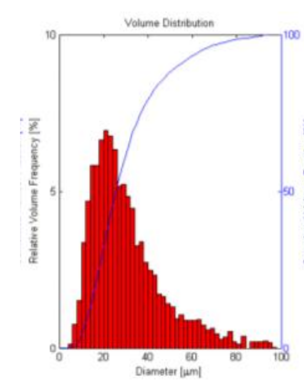
Spiteri A., Dimopoulos Eggenschwiler P., *Experimental Fluid Dynamic Investigation of Urea-Water Sprays for Diesel Selective Catalytic Reduction-DeNOx Applications*, Industrial & Engineering Chemistry Research (2014) 53(8), 3047-3055.

- 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

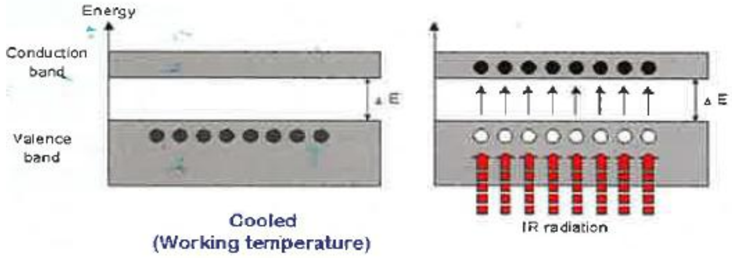
- Phase Doppler Anemometry
  Drop size and velocity distributions



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.

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

InSb Quantum detector



Source: FLIR

Camera calibration

Object temperature → IR radiation → Signal voltage → Digital output

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

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

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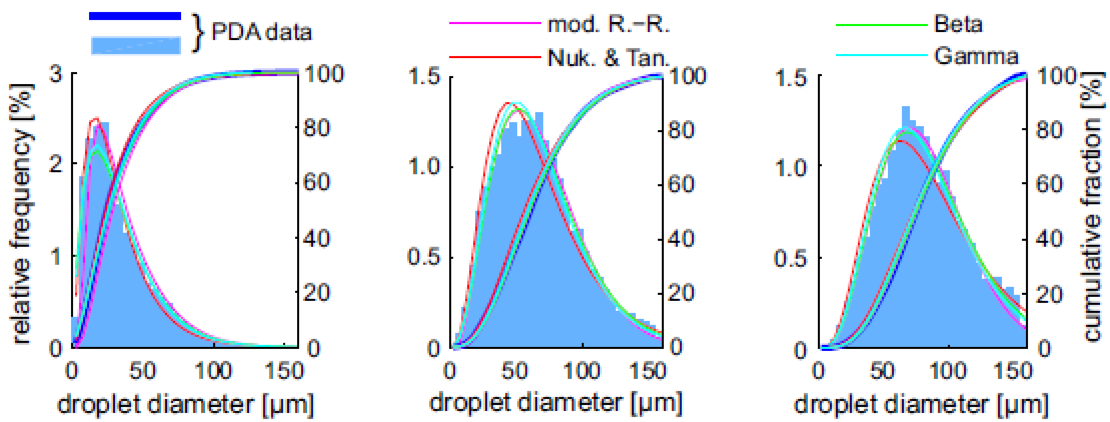
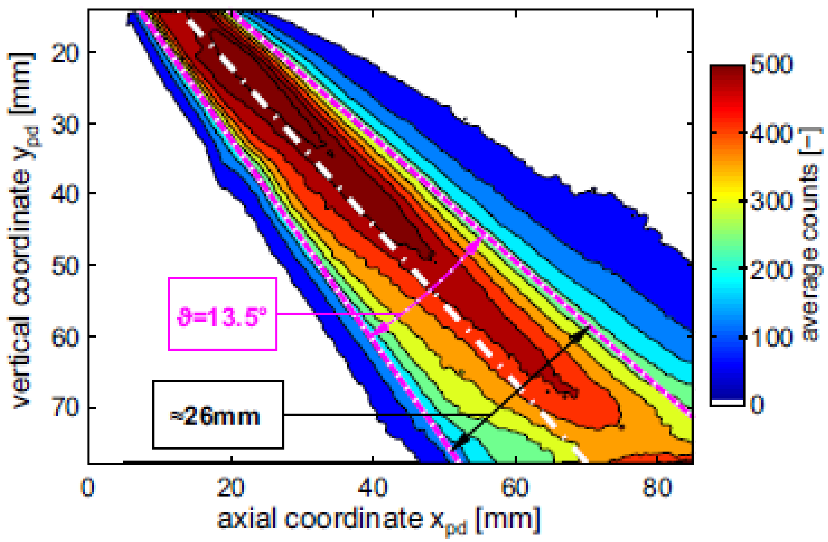
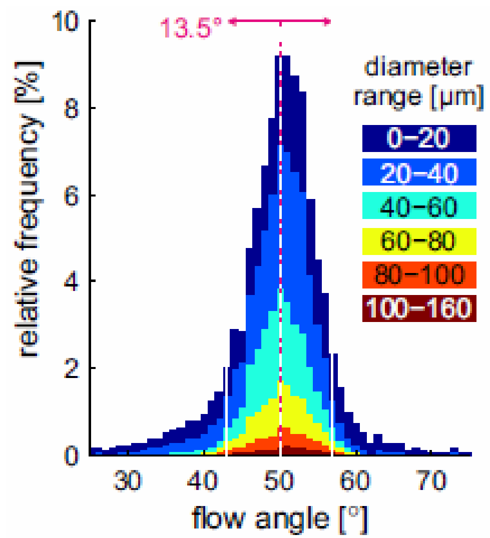


(a) number distribution (b) area distribution (c) volume distribution

number mean D_{10}	area mean D_{20}	volume mean D_{30}	Sauter mean D_{32}	de Brouck. D_{43}	volume mode D_{peak}	10% mass $D_{0.1}$	mass median $D_{0.5}$	90% mass $D_{0.9}$	[μm]
32	40	47	66	82	67	40	78	132	

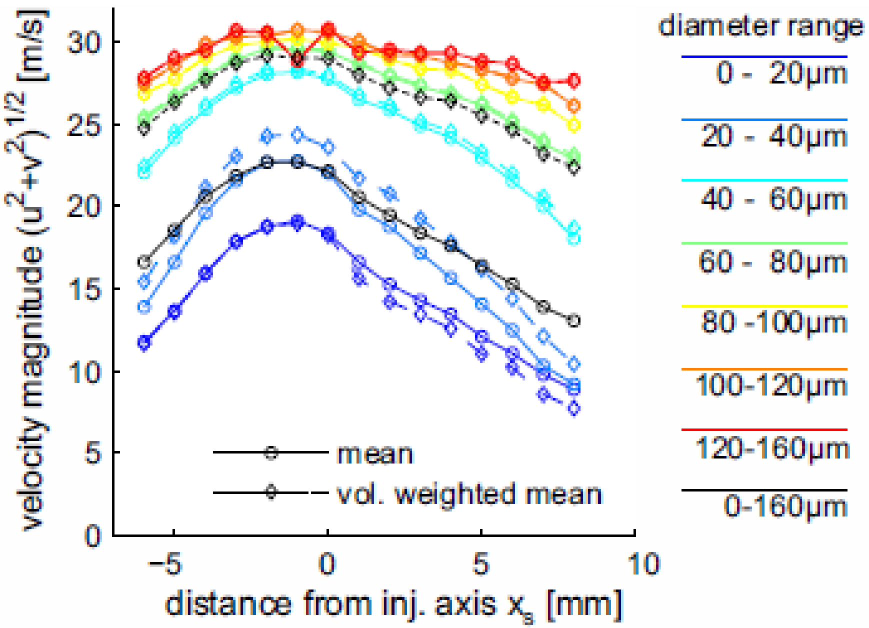
94% of all droplets larger than 40μm are inside the 13.5°angle

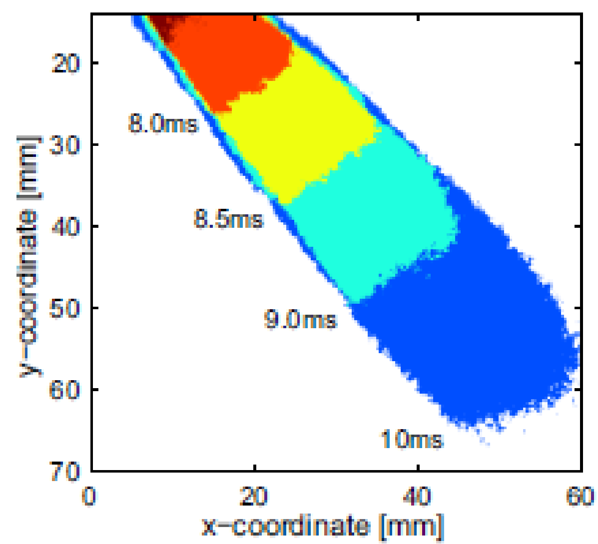




Spraycones for all 6 holes have merge in one single cone

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

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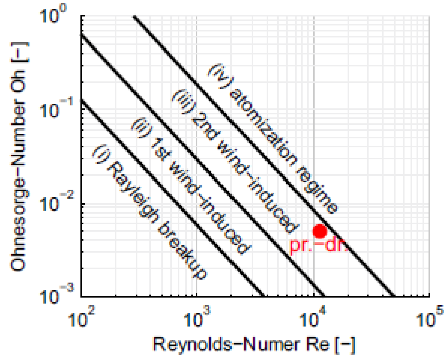
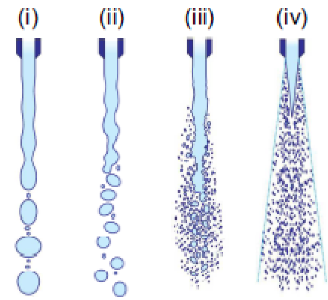
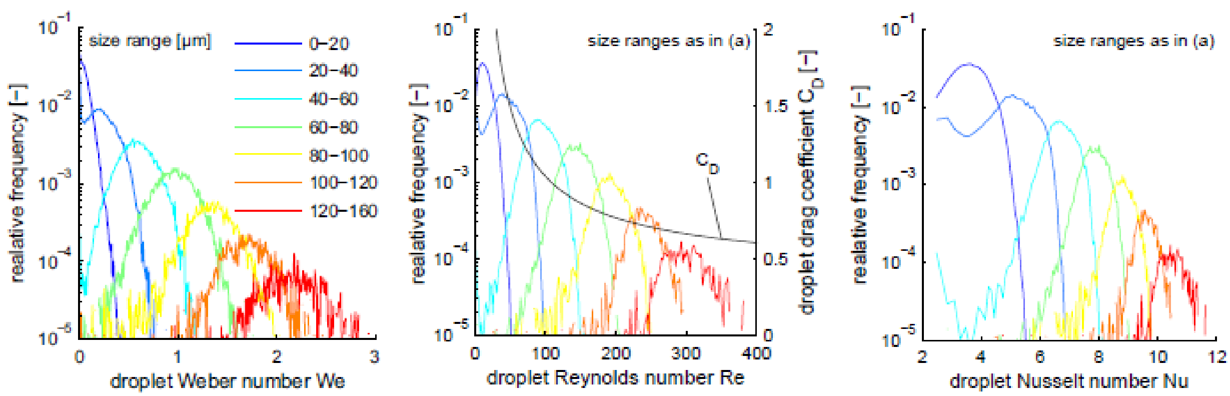
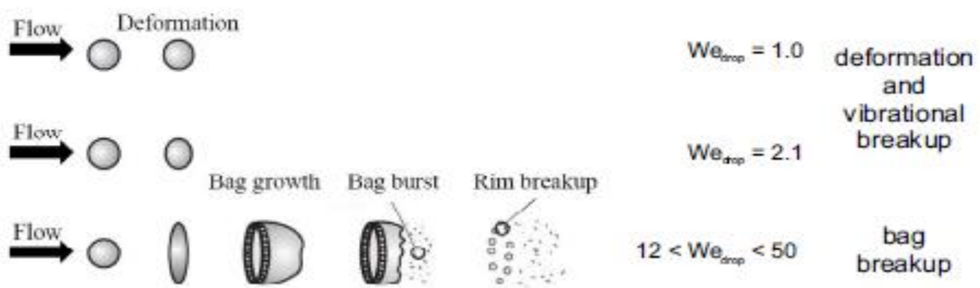
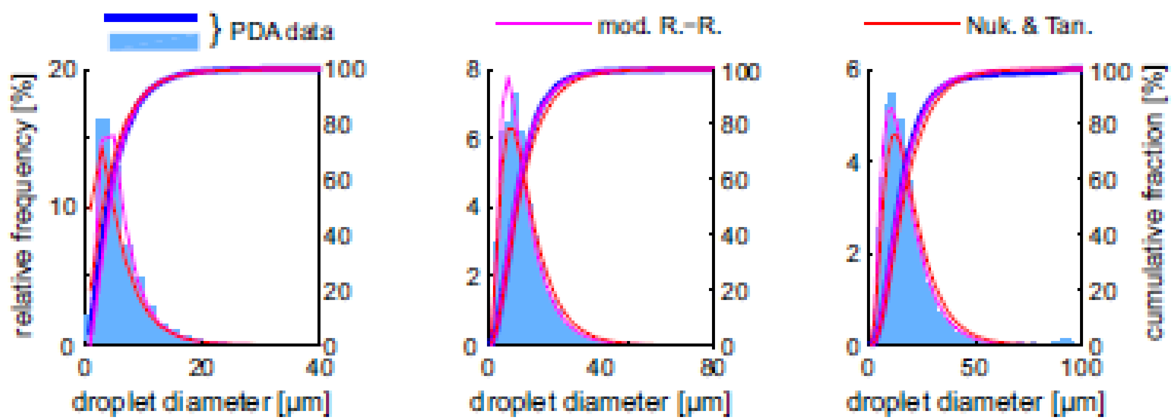








Air assisted injection: Droplet diameters <10μm for 90% of the droplets, 50% of area and 45% of mass



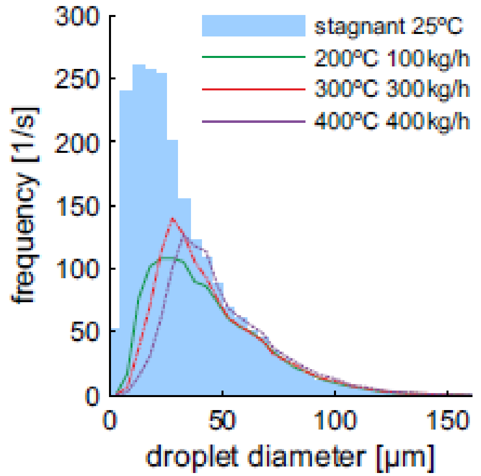
(a) size distribution (b) area distribution (c) volume distribution

p_{air}^{tot} [MPa]	number mean D_{10}	area mean D_{20}	volume mean D_{30}	Sauter mean D_{32}	de Brouck. D_{43}	volume mode D_{peak}	10% mass $D_{0.1}$	mass median $D_{0.5}$	90% mass $D_{0.9}$
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	14.0	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

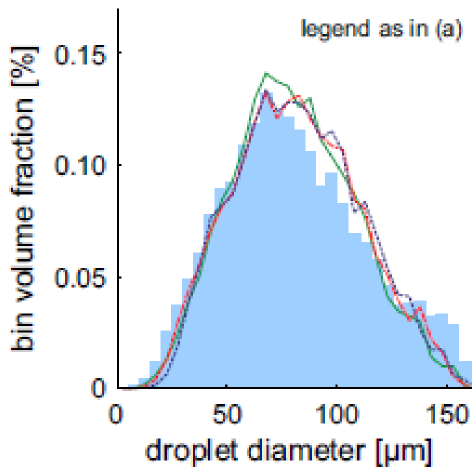
*x-traverse only

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

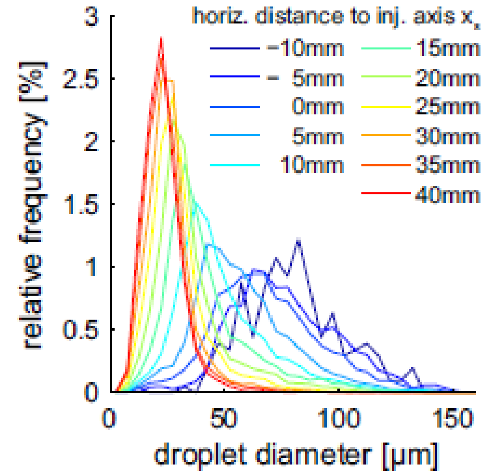
Entrainment of droplets smaller than 30μm, but these are a small fraction of total droplets



(a) total droplet frequency

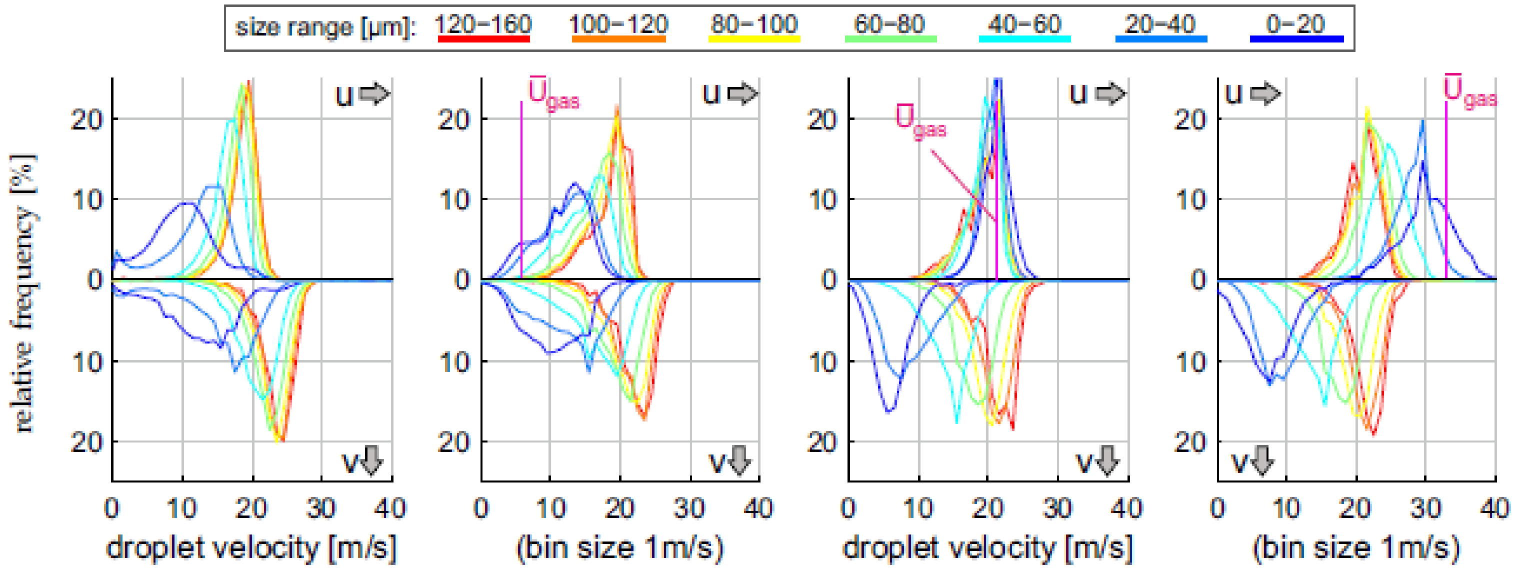


(b) total volume distribution



(c) local size distribution for 300 °C and 300 $\frac{kg}{h}$

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



(a) 25 °C and 0 $\frac{kg}{h}$ (b) 200 °C and 100 $\frac{kg}{h}$ (c) 300 °C and 300 $\frac{kg}{h}$ (d) 400 °C and 400 $\frac{kg}{h}$

Air-assisted injector leads to smaller droplets with higher velocities

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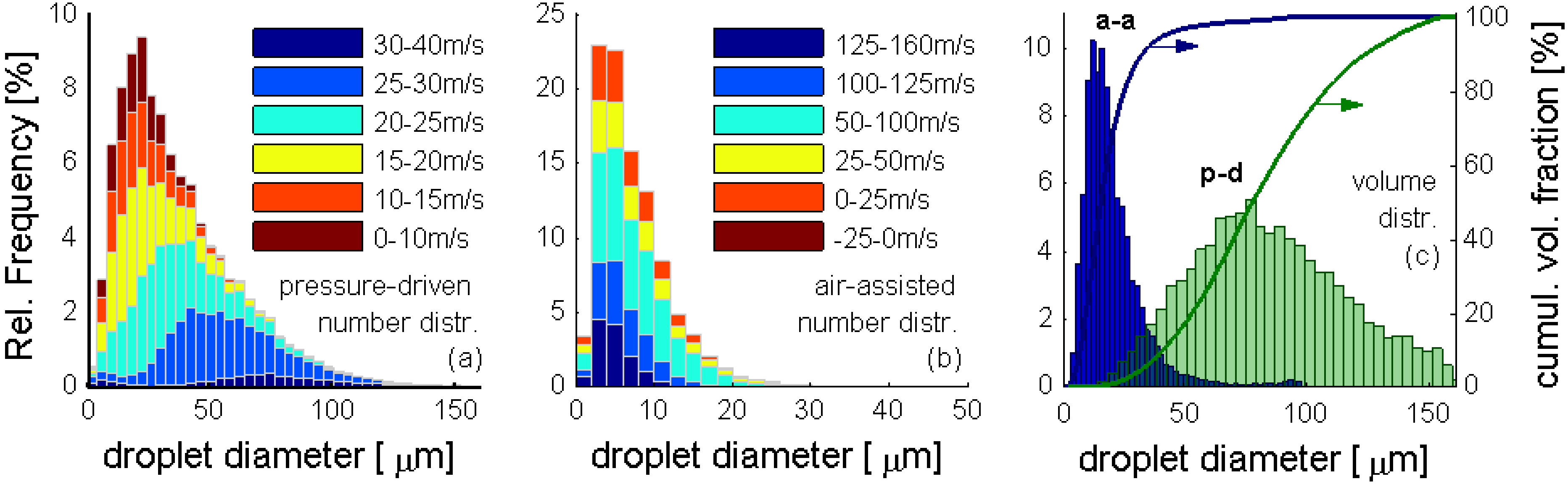
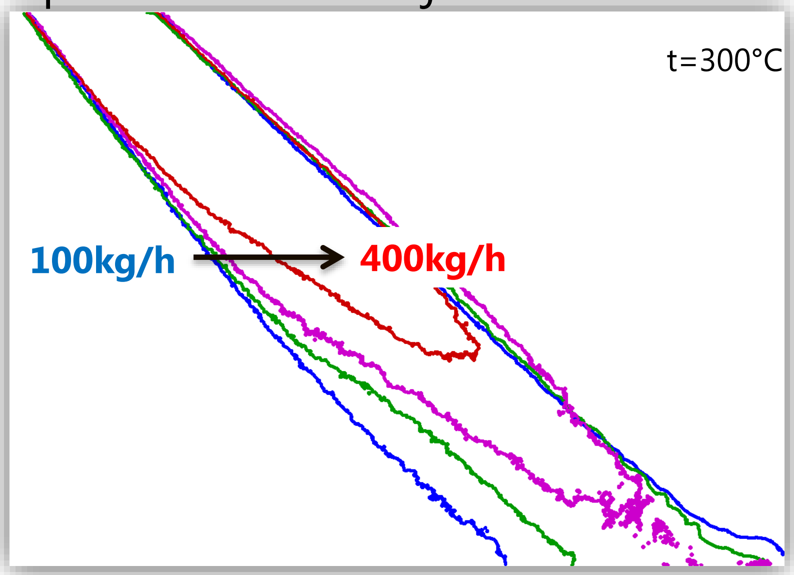
pressure-driven injection | air-assisted injection | volume distribution

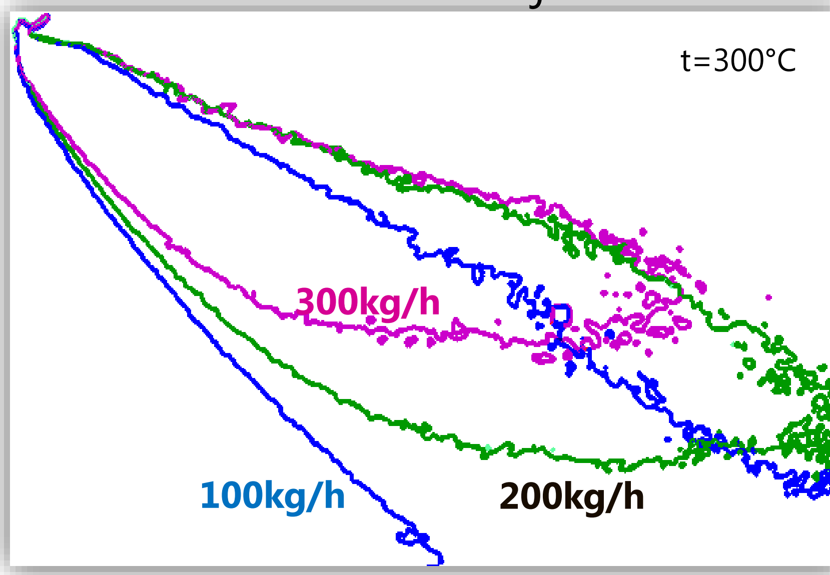


Different entrainment characteristics

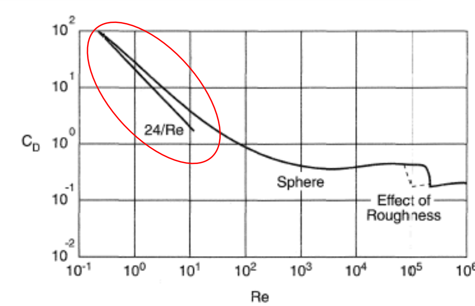
- pressure-driven injection



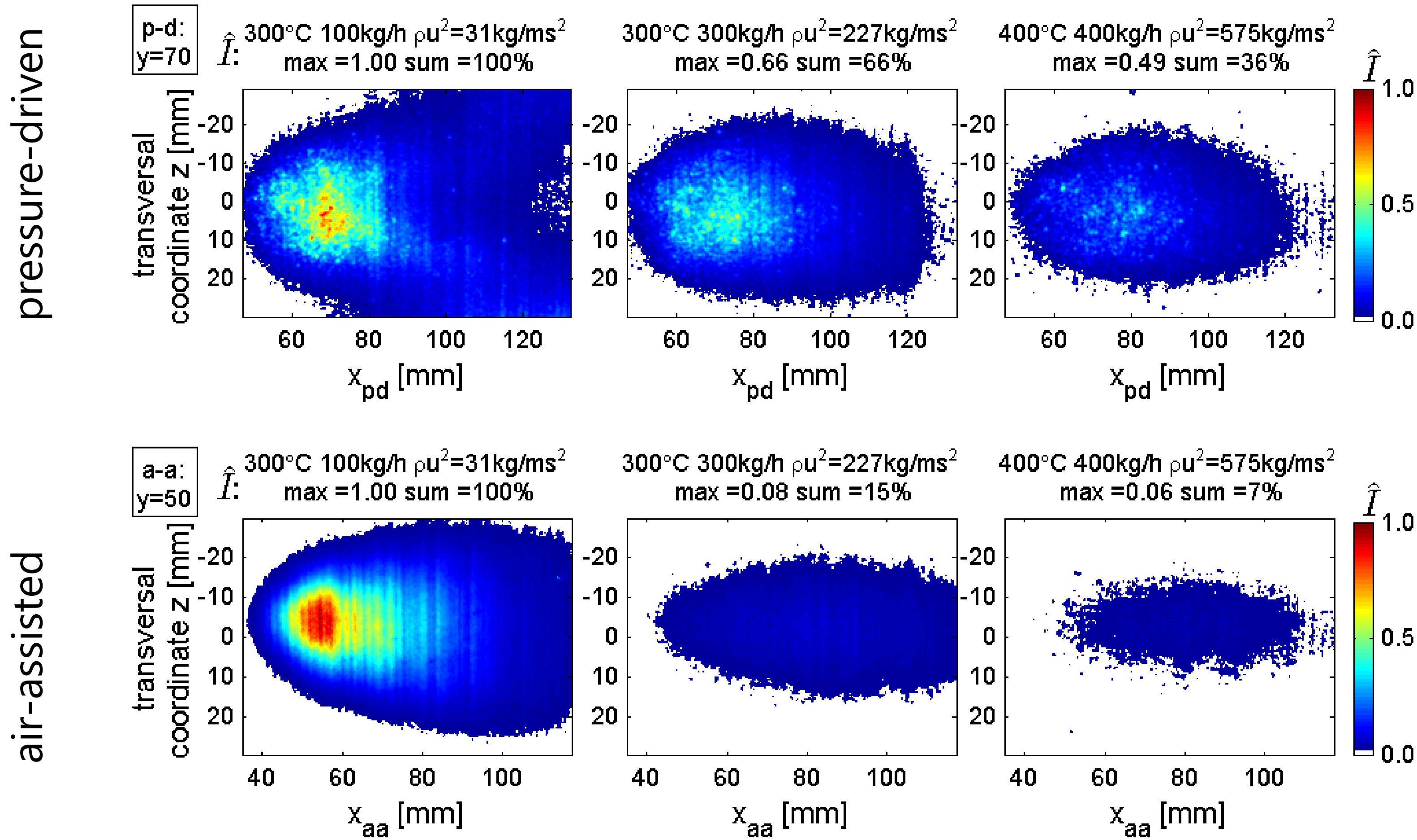
- coaxial air-assisted injection



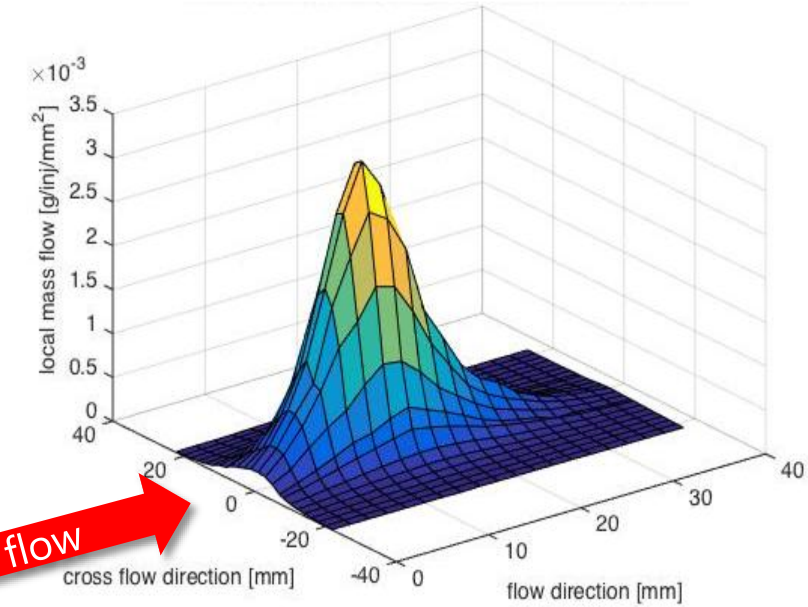
Order of Magnitude:	v = identical	d_{pd}=70μm	d_{aa}=20μm
– Inertia	$m \sim d^3$	$(d_{pd}/d_{aa})^3$	43
+ momentum exchange	$A \sim d^2$	$(d_{pd}/d_{aa})^2$	12
+ resistance coeff. c_D	$1/Re \sim 1/d$	(d_{pd}/d_{aa})	0.3

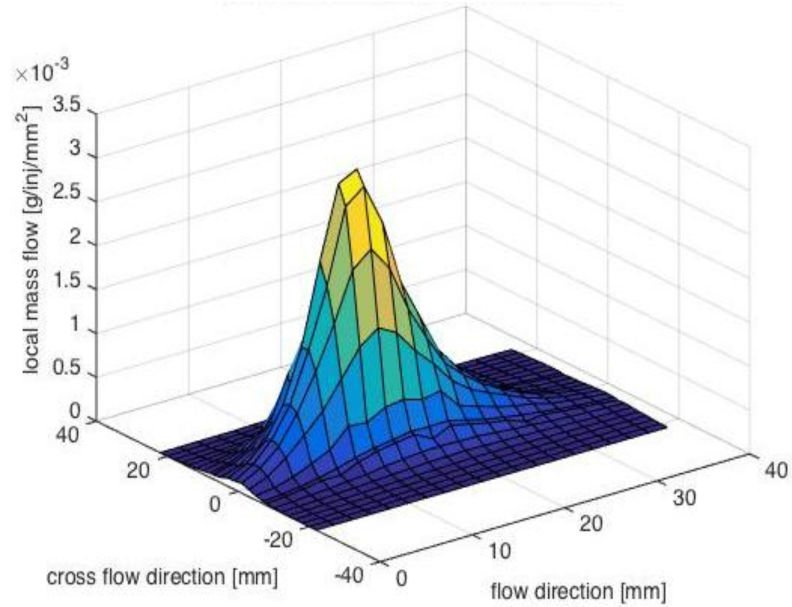


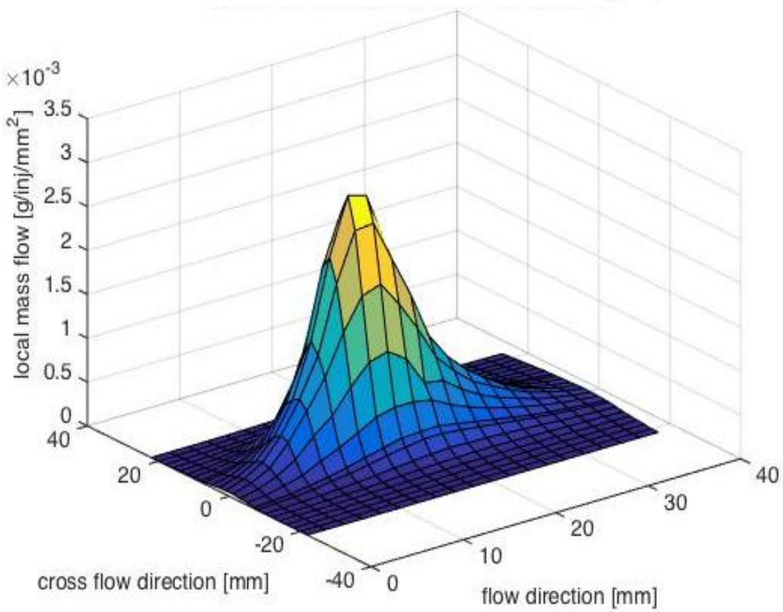
Air-assisted spray entrainment much stronger



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







	Entrainment	Max rate [g/inj/mm^2]	At which x [mm]
No flow	-	0.0033	12mm
100kg/h	3%	0.0031	14mm
200kg/h	9%	0.0028	14mm

- Spray Characterization
- Interaction of Spray with the Cross Flow
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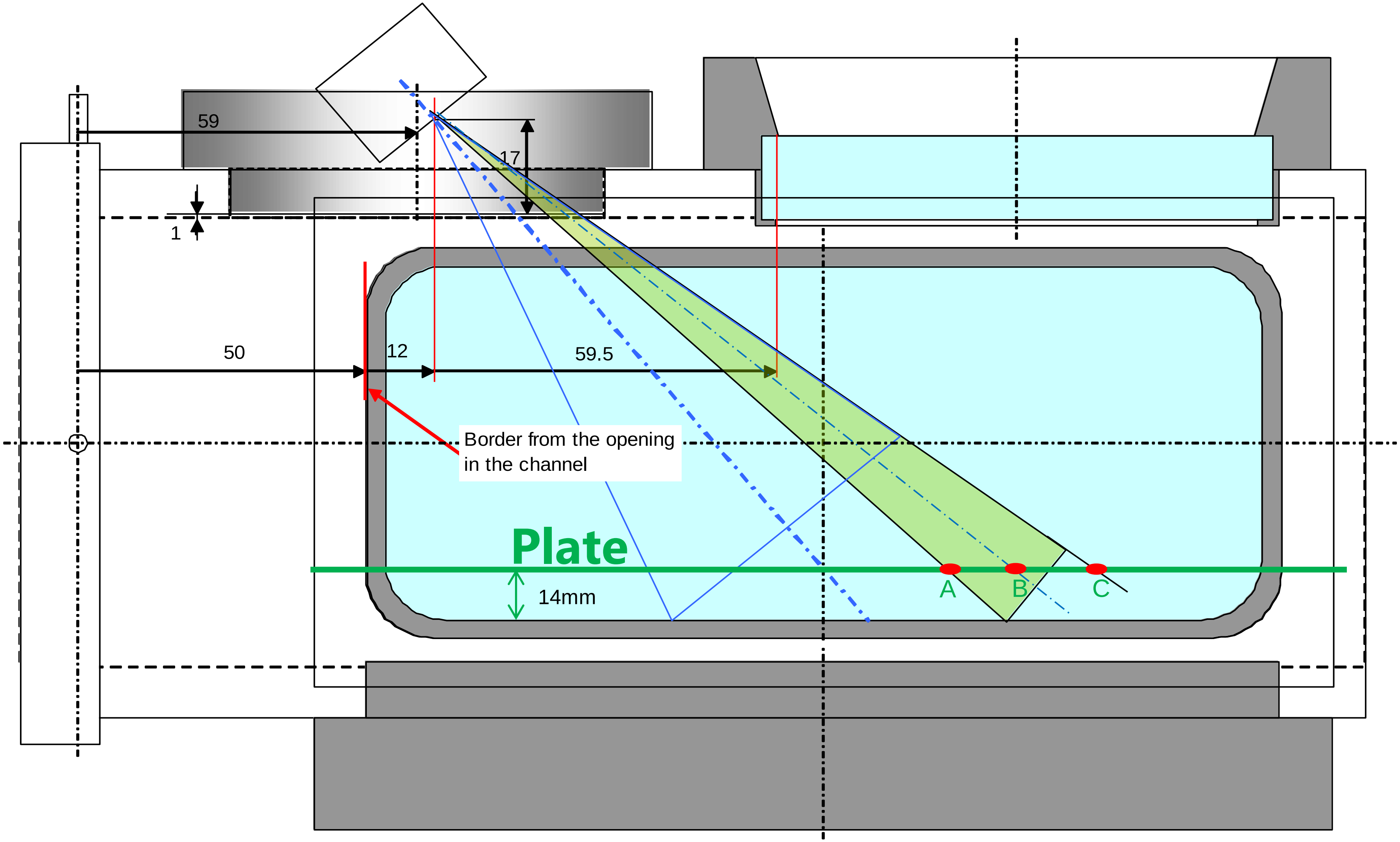
- NOx Conversion in the Catalyst

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

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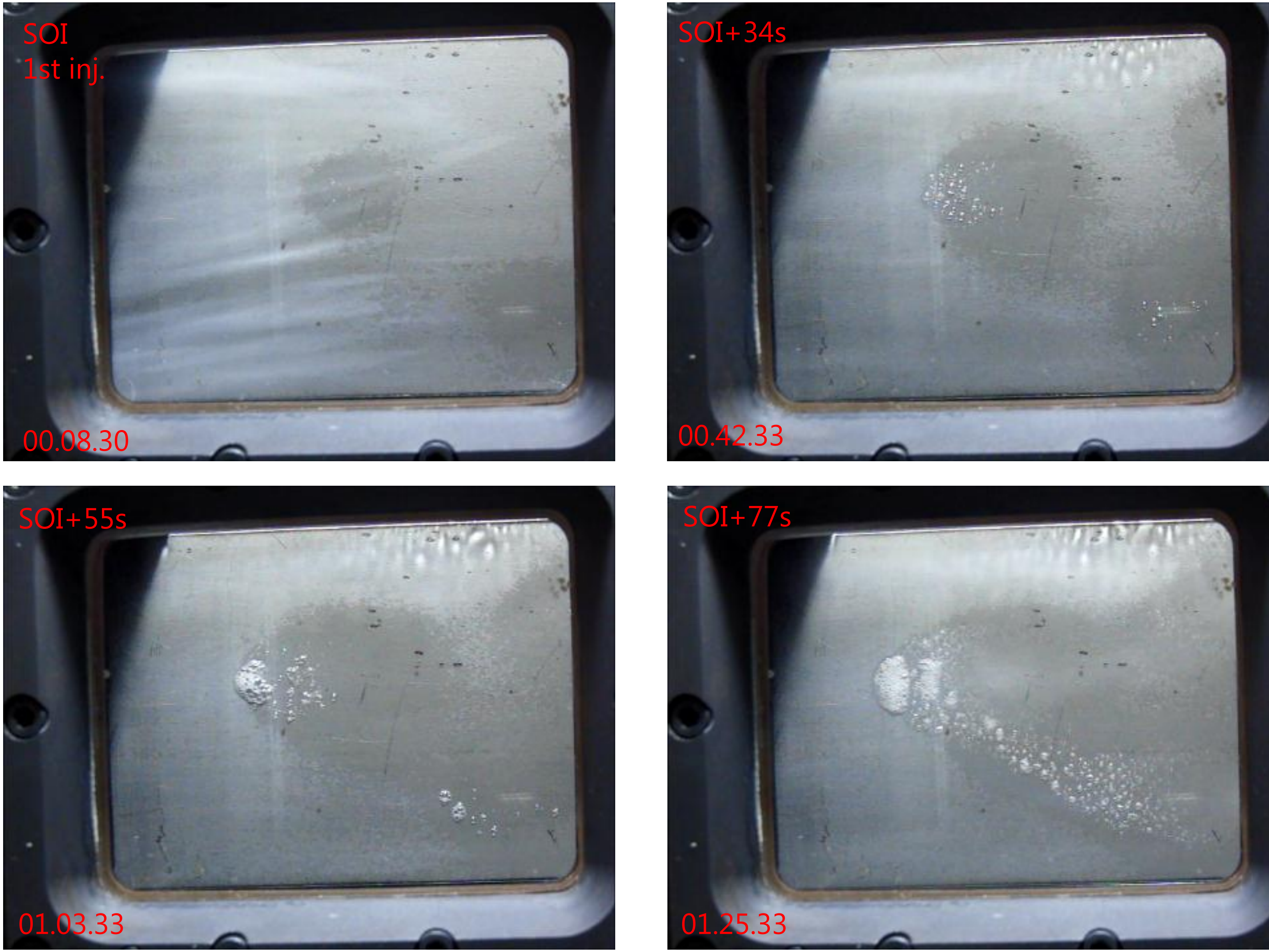

Gas flow

300°C,
100kg/h,
60ms,
150s

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

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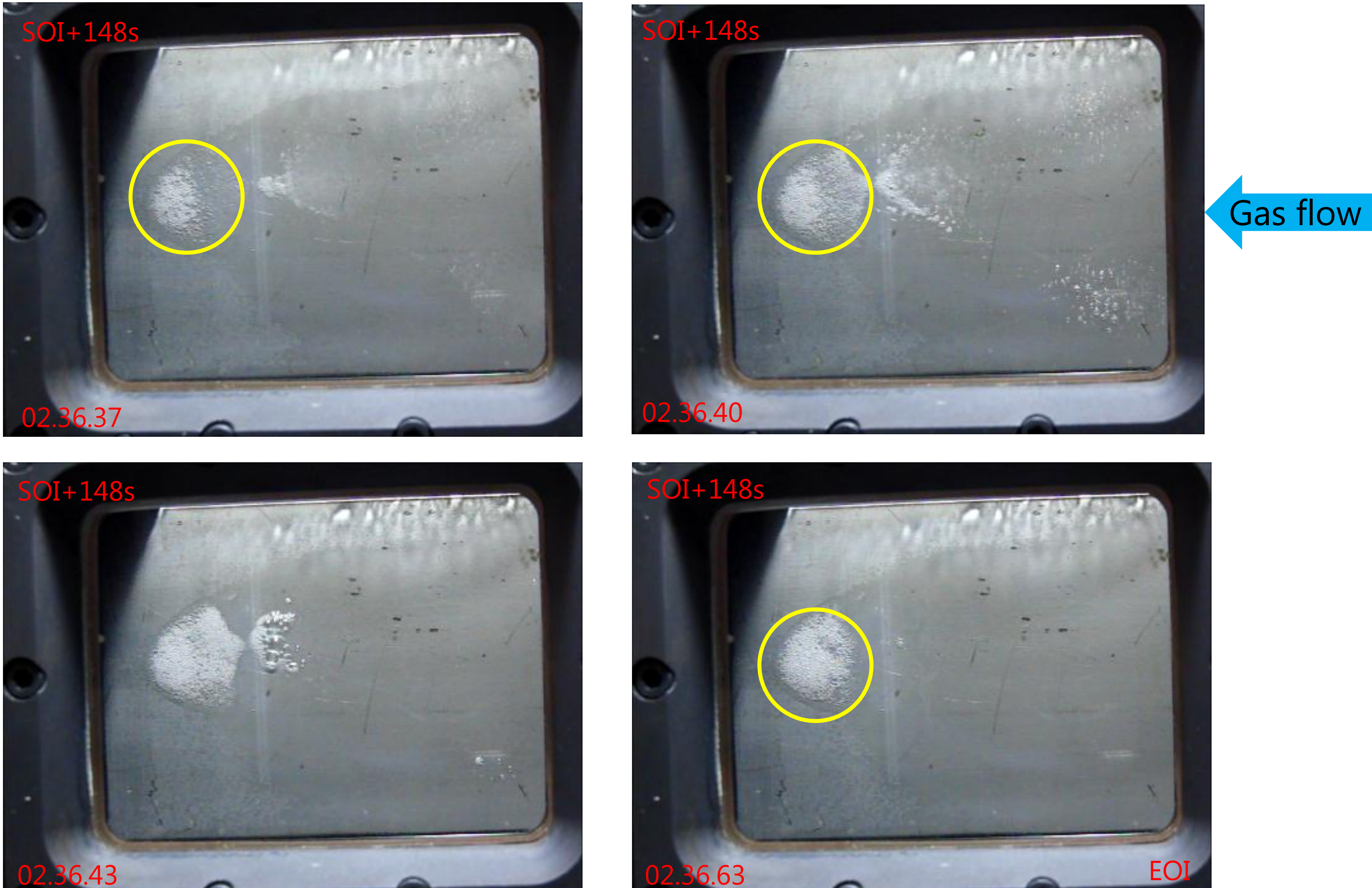

Urea enriched film starts drying out, first crystals appear

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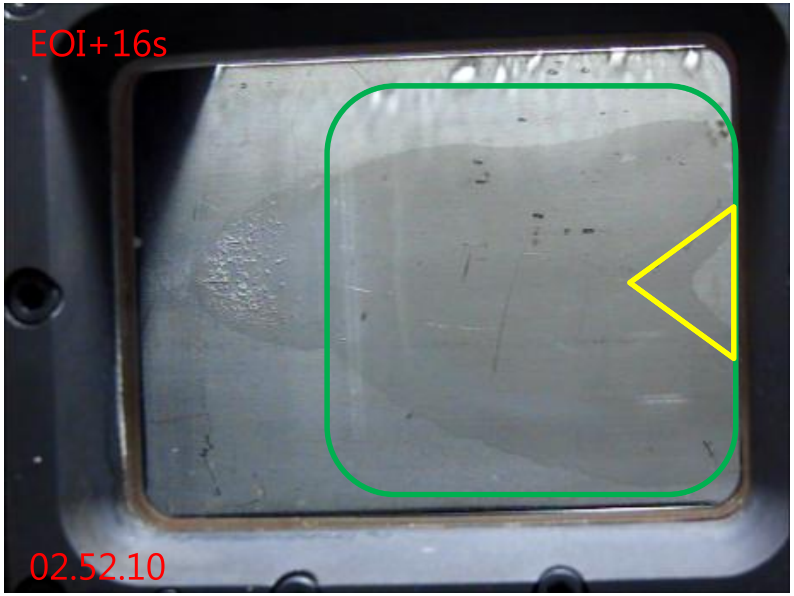

Gas flow

300°C,
100kg/h,
60ms,
150s

Crystals form persistent solid deposits not melting at 300°C

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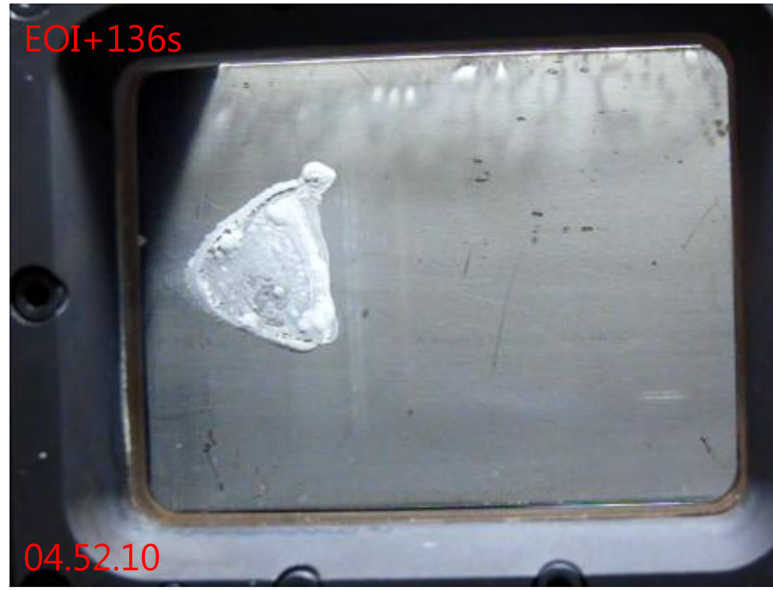
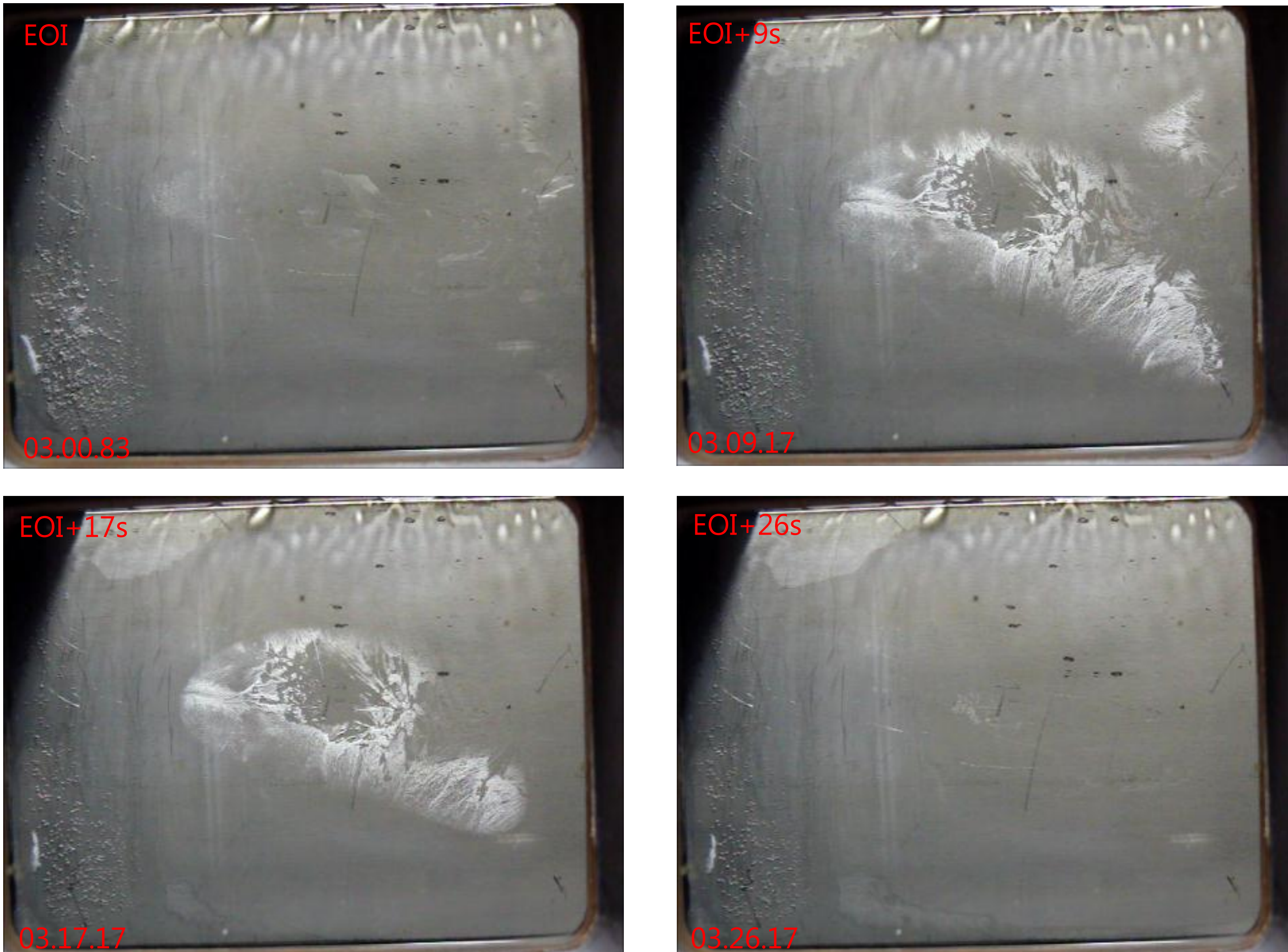


Gas flow

300°C,
100kg/h,
60ms,
150s

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



Gas flow

300°C,
100kg/h,
120ms,
150s

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

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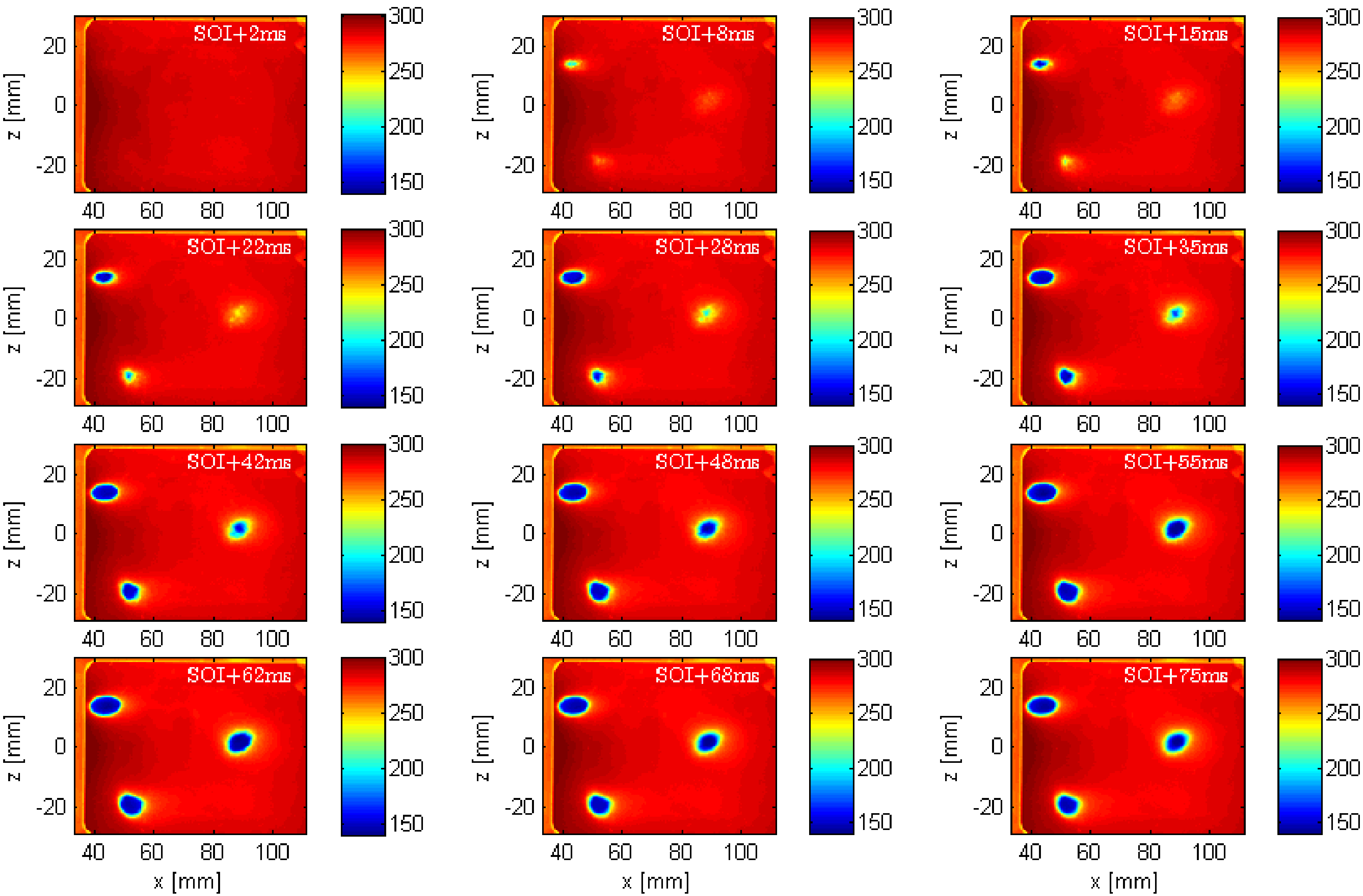
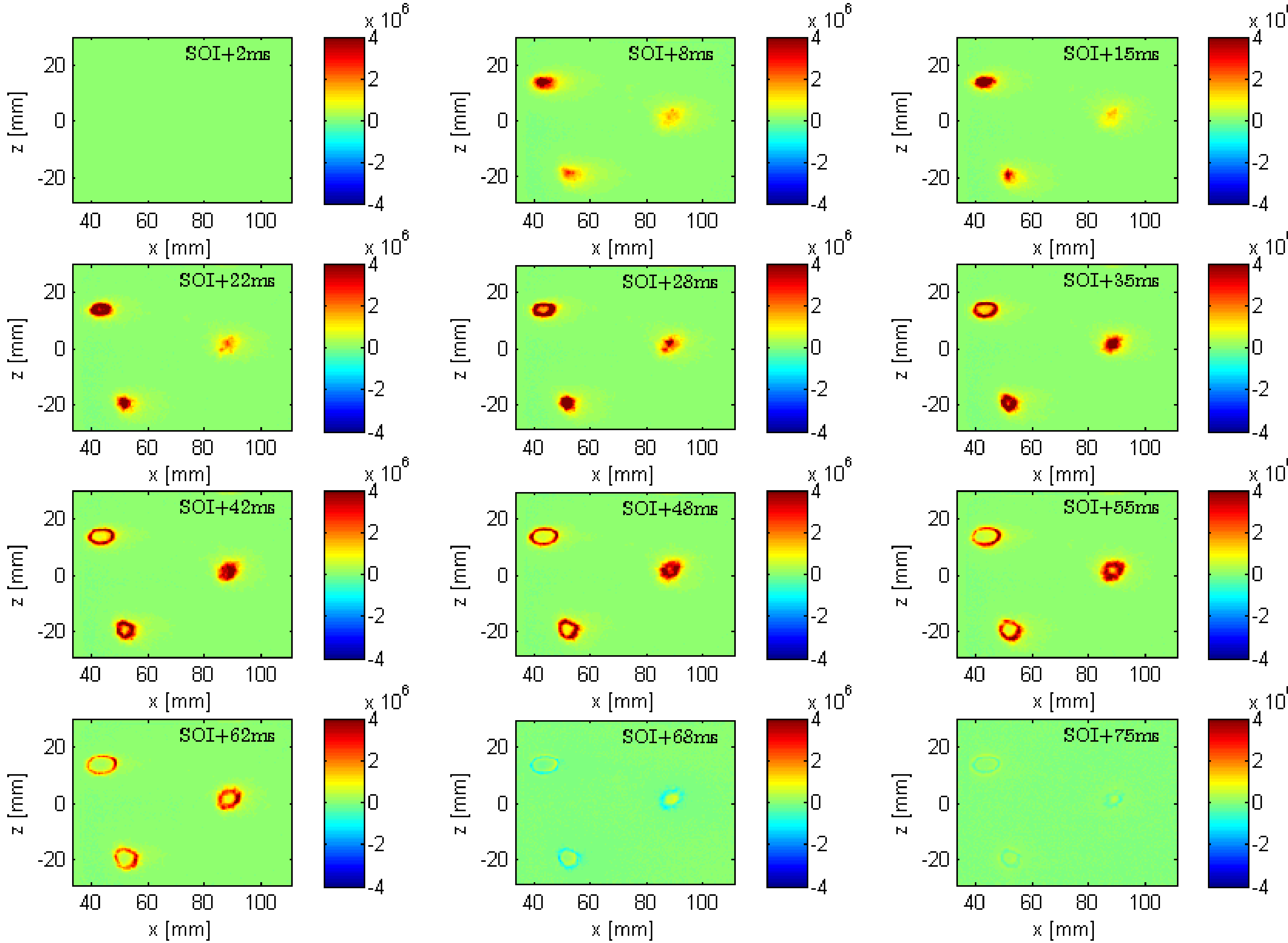


Local cooling rates in MW/m2 order



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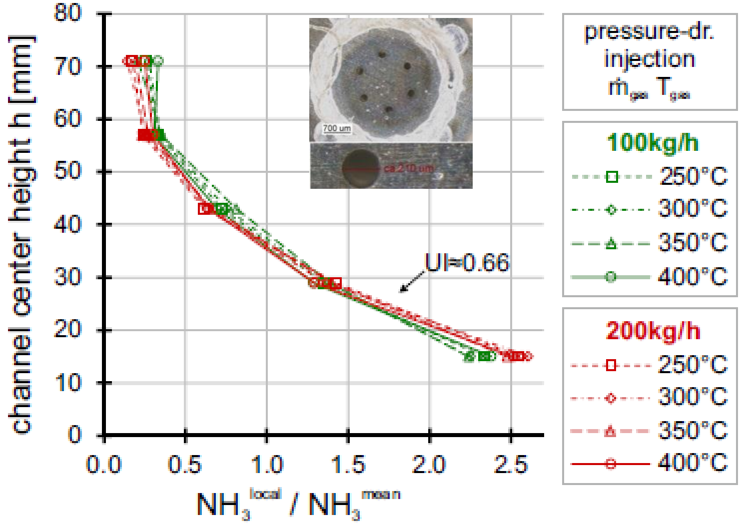
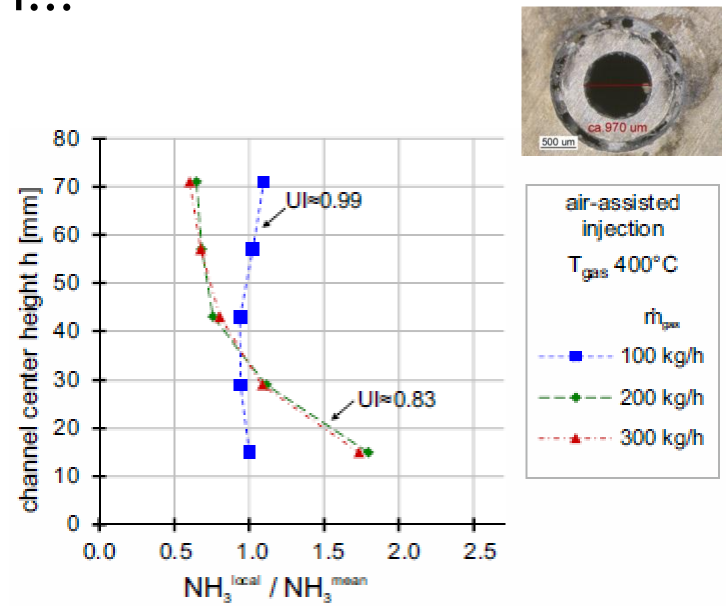
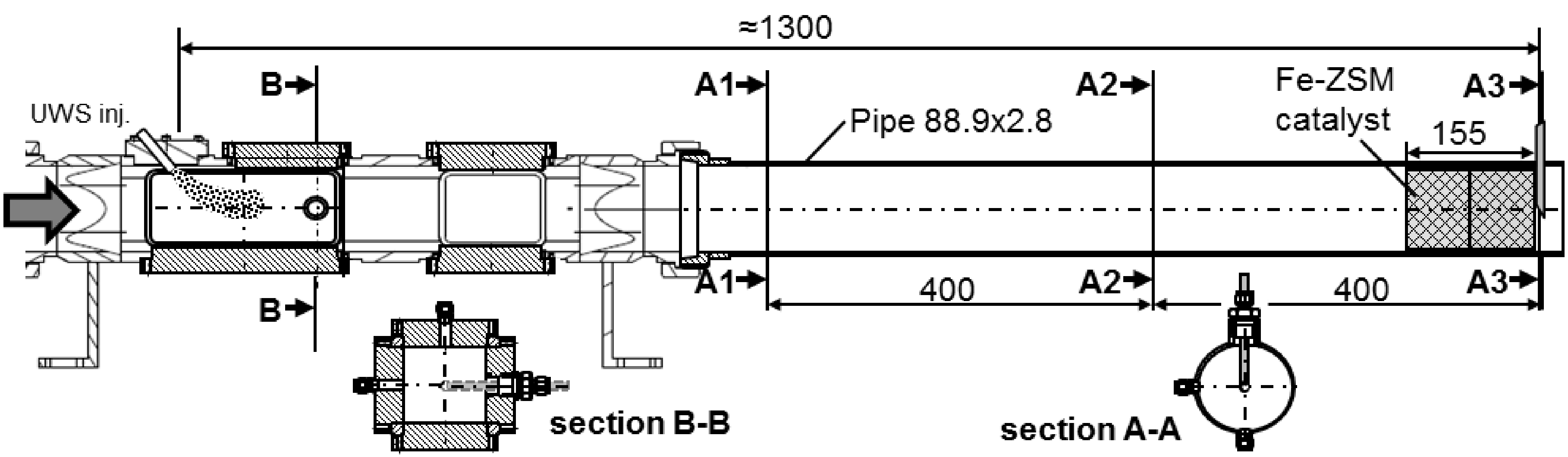
- Spray Characterization
- Interaction of Spray with the Cross Flow
- Wall Impingement
- NOx Conversion in the Catalyst

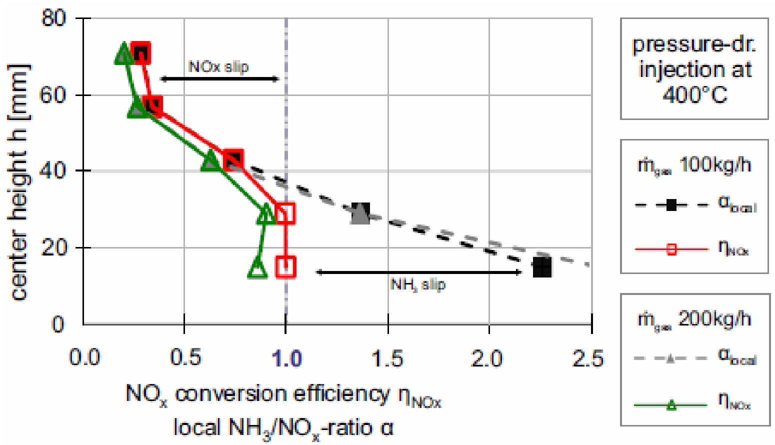
NH3 spatial distribution upstream the catalyst is strongly affected by the injection…

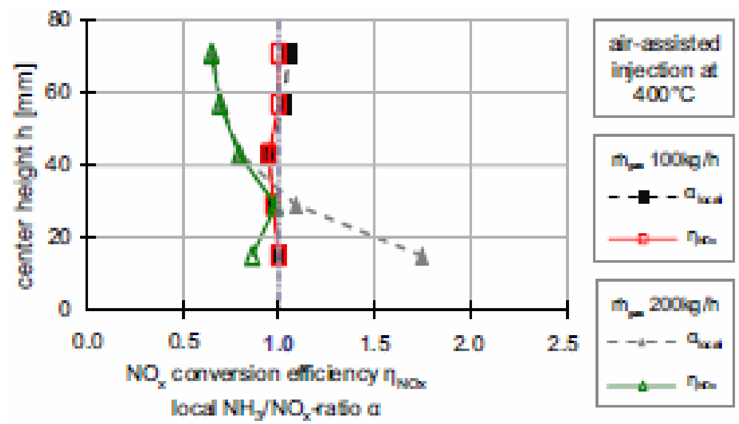


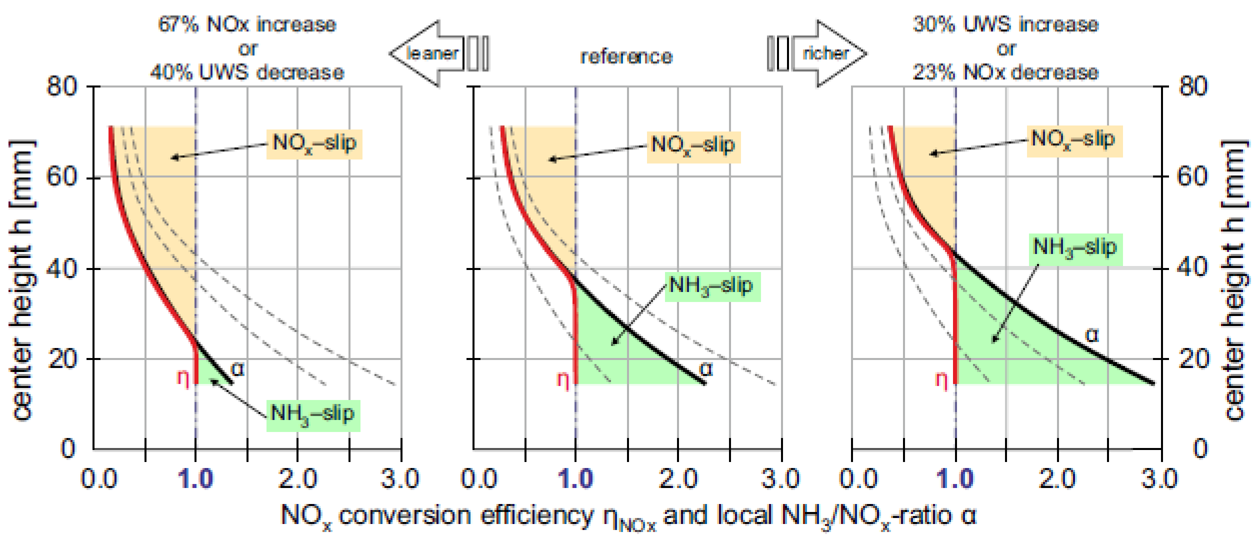




…leading to NOx conversion deficiencies and Ammonia slip







Thanks to

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- A. Spiteri, PhD 2016, ETHZ
- L. Nocivelli, PhD 2017, PoliMi
- Y. Liao, PhD 2017, ETHZ
- M. Crialesi Esposito, 2014, Masterthesis, Universita degli Studi di Parma
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- Swiss Oil Association (FEV), CH
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- Robert Bosch GmbH