


**Computational Fluid Dynamics for
the Design Optimization of Dentrife
Generators**

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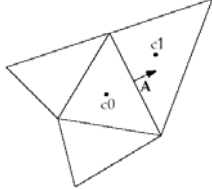
- CFD-Simulation: Introduction
- Some simulation results: Liebherr-drum
 - Flow field
 - Evaluation of residence time distribution
- Experimental
 - PDA/LDA-system
 - Example: spray-nozzle
- Summary, Outlook

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CFD-Simulation: Introduction


- Pre-Processing
 - Geometry implementation using special 3d-CAD-software (Gambit™)
 - Simplification necessary
 - Spatial discretization: grid generation
 - Grid export
- CFD-Simulation
 - Grid import into actual flow solver (FLUENT®)
 - Definition of boundary conditions
 - Thermodynamic properties (viscosity, thermal conductivity,...)
 - Calculation of the flow field:
iterative solution of governing balance equations:
 - Continuity
 - Momentum balance
 - Energy- and species balances
- Post-Processing
 - Interpretation of data fields
 - Plausibility check
 - Visualisation: plot of velocity, temperature and species contours, pathlines, heat transfer rates,...



$$\oint \rho \phi \vec{v} \cdot d\vec{A} = \oint \Gamma_\phi \nabla \phi \cdot d\vec{A} + \int_V S_\phi dV$$

ρ	=	density
\vec{v}	=	velocity vector (= $u \hat{i} + v \hat{j}$ in 2D)
\vec{A}	=	surface area vector
Γ_ϕ	=	diffusion coefficient for ϕ
$\nabla \phi$	=	gradient of ϕ (= $\partial \phi / \partial x \hat{i} + (\partial \phi / \partial y) \hat{j}$ in 2D)
S_ϕ	=	source of ϕ per unit volume


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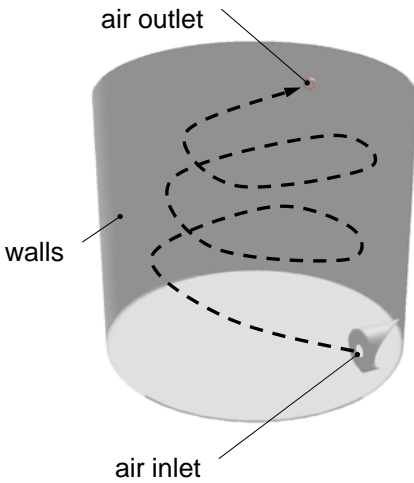


Computational Domain

- Liebherr-drum
 - diameter: 1.134m
 - height: 1m
- Tangential air inlet
- Rotary flow field
- Inlet: 2m/s, 273K
- Wall temperature: 258K


Spatial discretization:

- Approx. $1.5 \cdot 10^6$ discrete volume elements



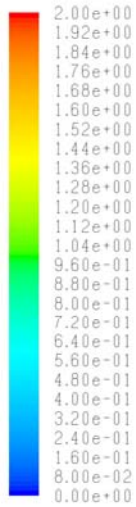
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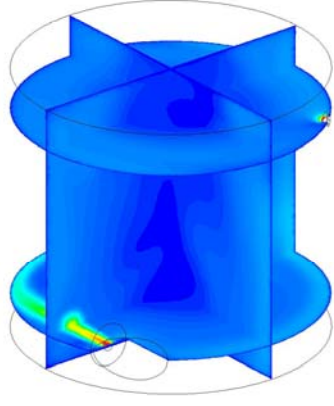



Simulation Results

Velocity magnitude on cutting planes



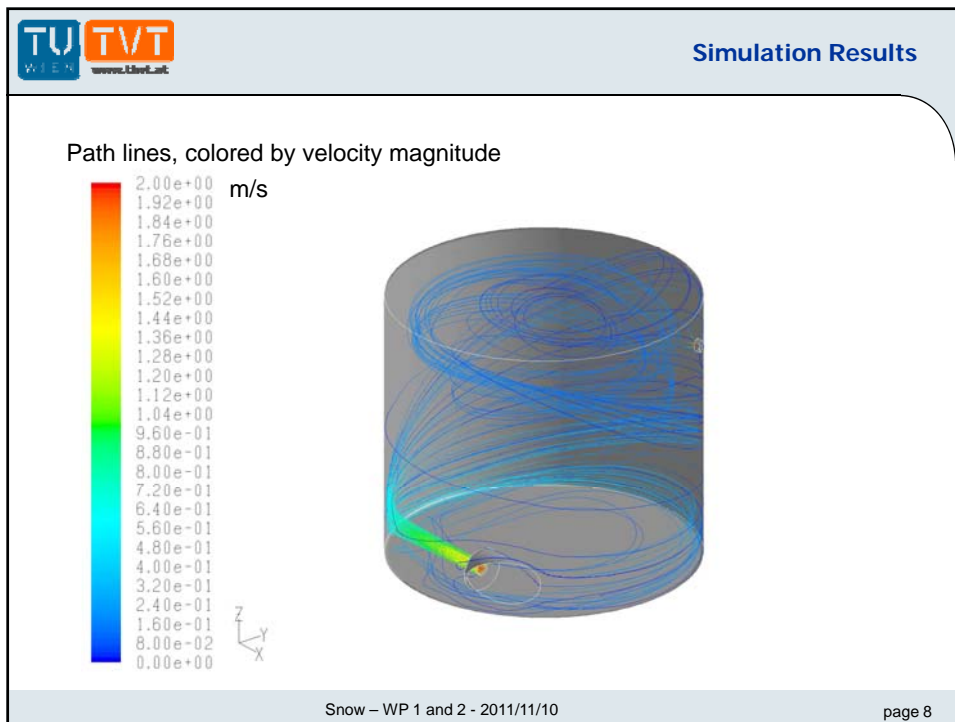
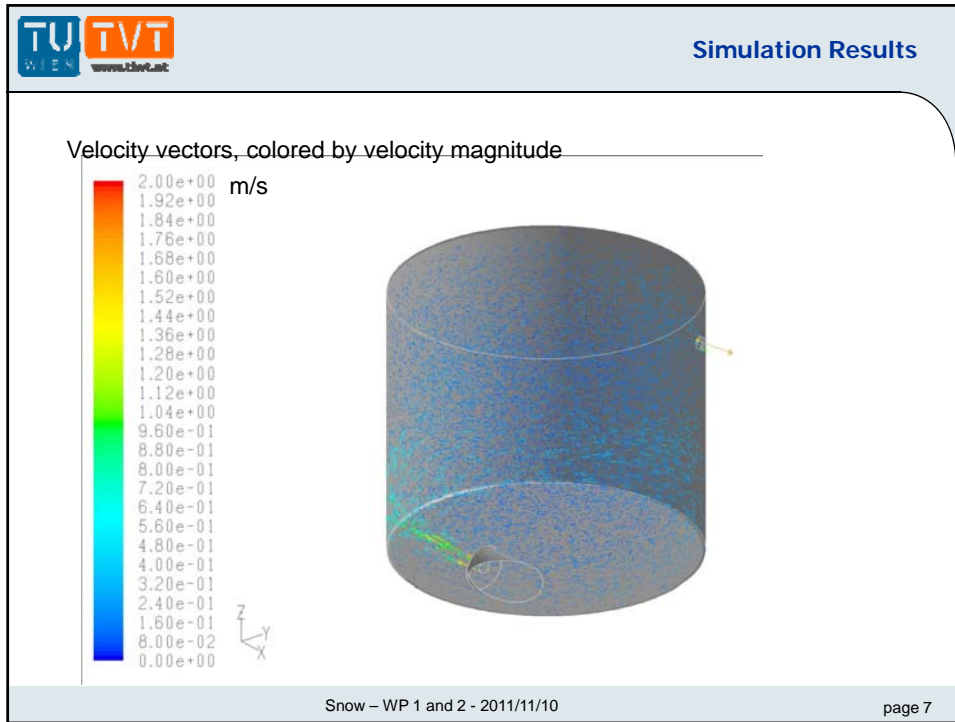
m/s

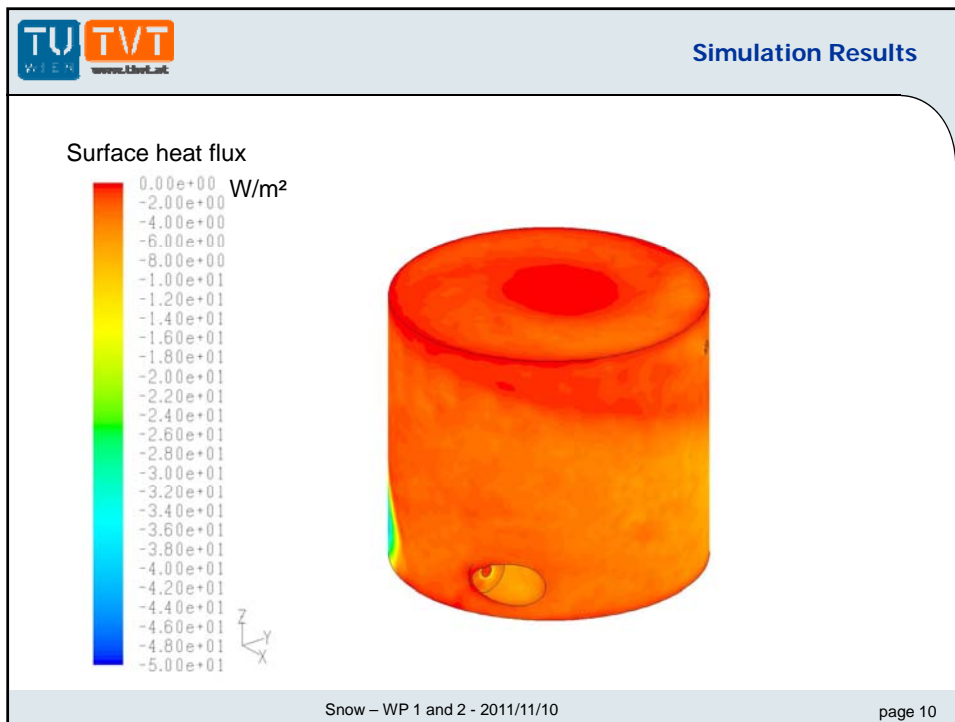
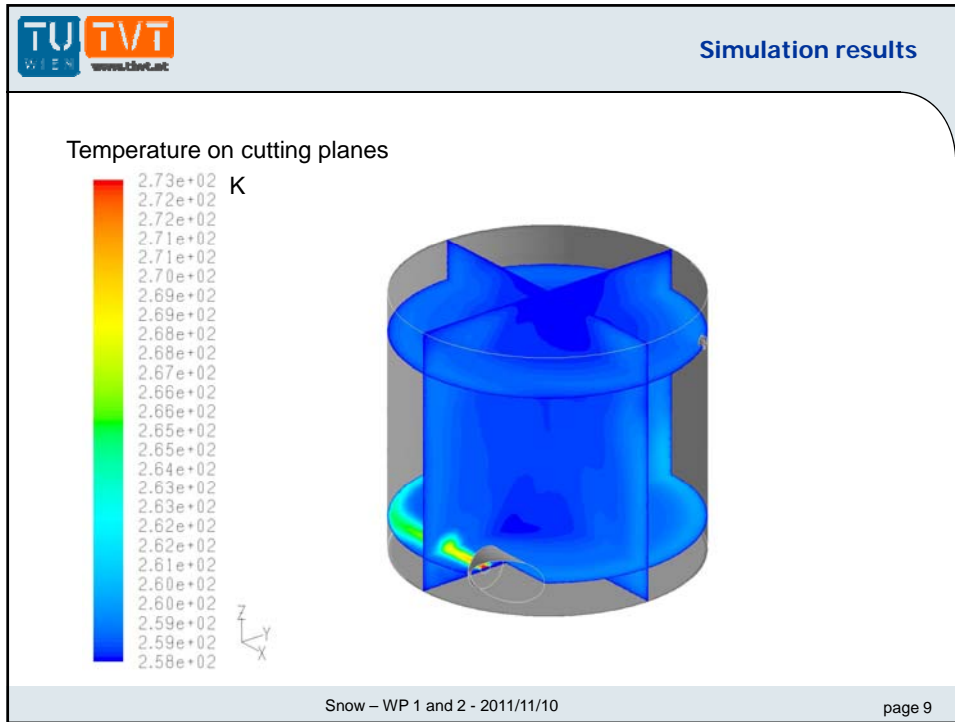


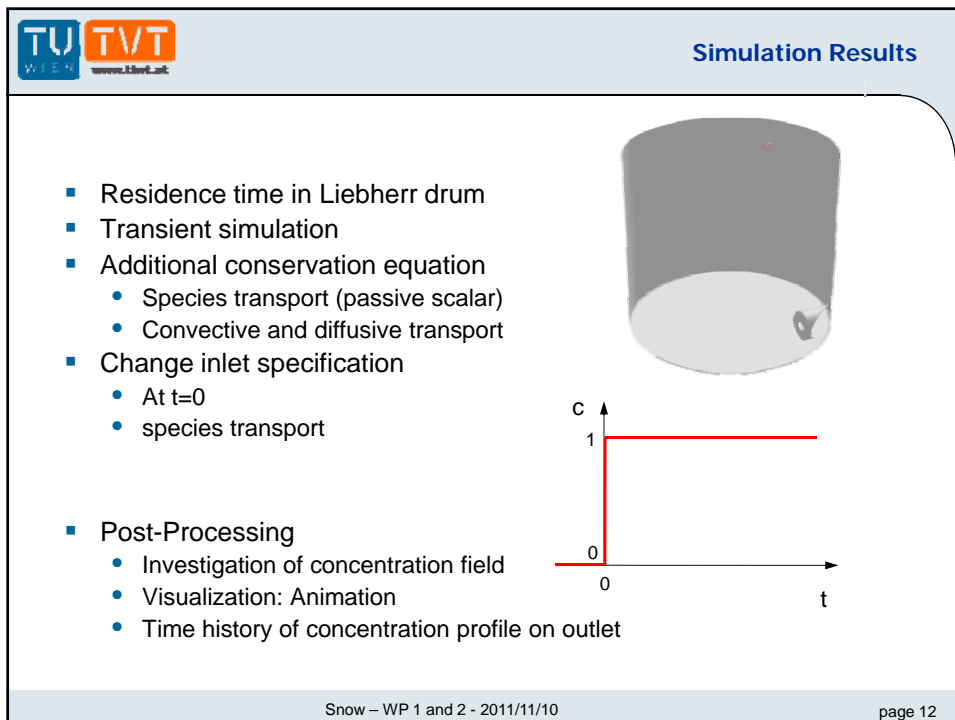
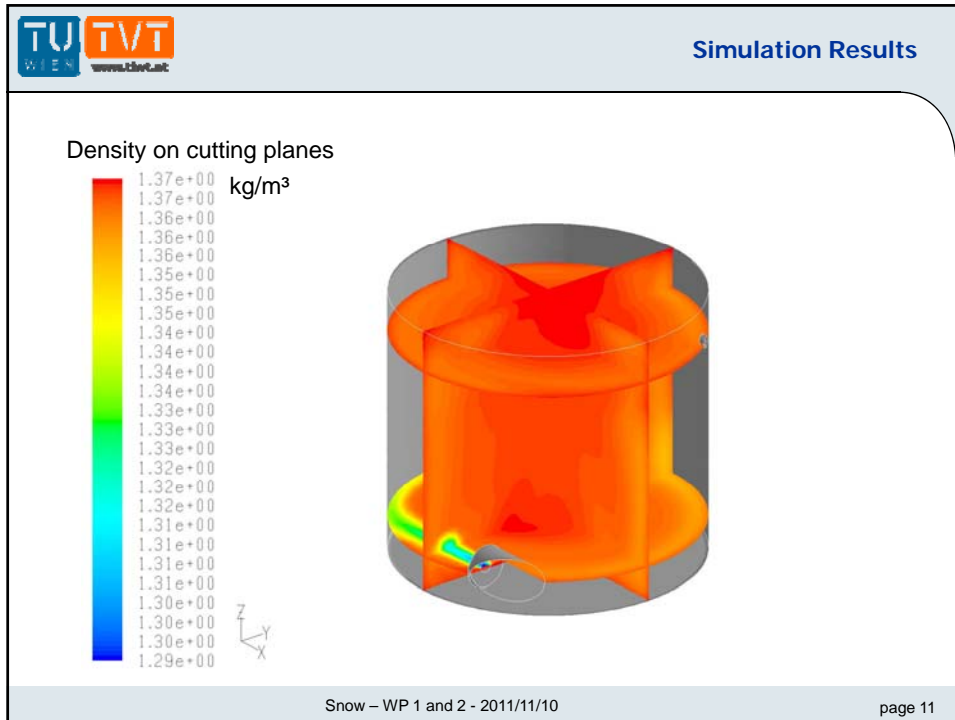



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Simulation Results

Animation


- Time evolution of concentration profile in drum

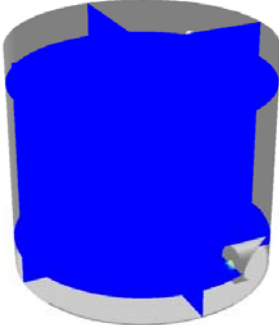


100%


0

time: 0.1 s






concentration: contour plot



iso-surface of concentration

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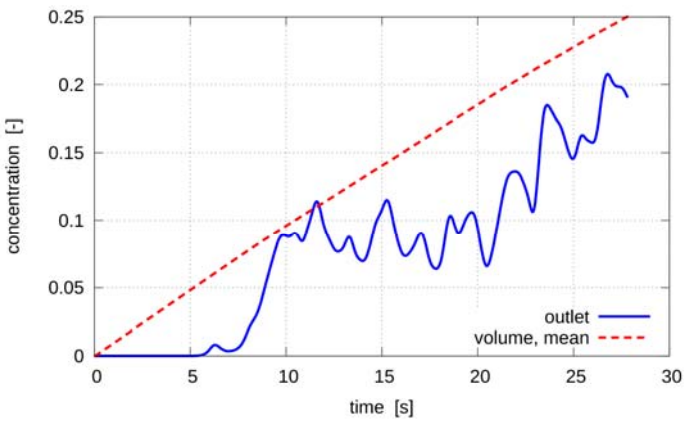
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Simulation Results

- Concentration profile
 - Outlet
 - Mean volumetric concentration




Time [s]	Outlet Concentration [-]	Volume Mean Concentration [-]
0	0.00	0.00
5	0.00	0.04
10	0.08	0.08
15	0.10	0.12
20	0.10	0.16
25	0.18	0.20
30	0.20	0.25

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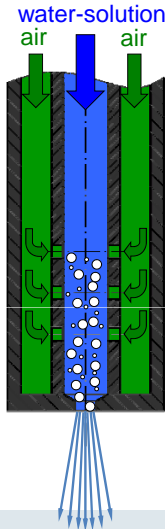
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Example: Injection Nozzle

- Experimental investigation of the SNCR-nozzle
- Two-fluid-nozzle: „Effervescent nozzle“ type
- Sudden expansion of the gas bubbles at the discharge orifice
- Liquid stream shattered by gas bubbles
- Reduced injection pressures



The diagram illustrates the internal structure of an injection nozzle. It features a central channel for 'water-solution' (blue) and two side channels for 'air' (green). The air is injected into the water-solution stream, creating a series of bubbles. As the mixture approaches the discharge orifice, the bubbles expand suddenly, causing the liquid stream to shatter into a spray of fine droplets and gas bubbles.


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Experimental work: Setup

- Nozzle: mounted in optically transparent enclosure (1.5 x 1.5 x 3 m)
- Discharge orifice directing downwards
- Flow rates
 - influence of NH_3 on atomization process considered negligible
 - water: 60 l/h
 - air: $7.5 \text{ m}^3_{\text{STP}}/\text{h}$ at 4.5 bar_g
 - gas/liquid mass flow ratio: 0.16
- Measurement of the spray-characteristics using Phase-Doppler-Particle-Anemometry (PDPA)
 - Droplet size distribution
 - Droplet velocity

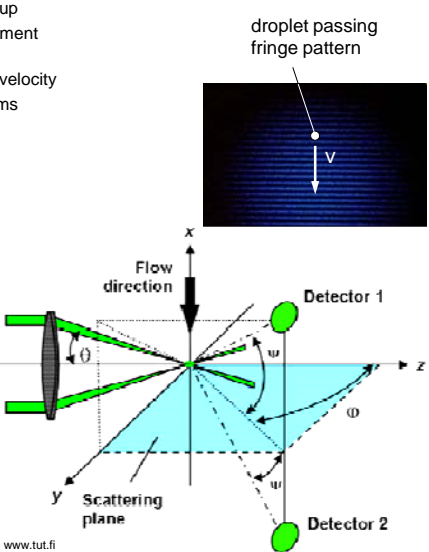
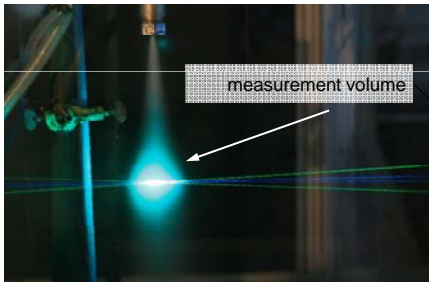
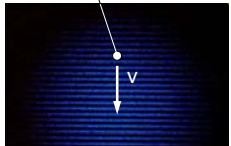


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Phase Doppler Particle Anemometry

- Velocity measurement
 - Intersection of a pair of coherent, collimated laser beams
 - Fringe pattern – distance defined by optical setup
 - Light scattered by droplet passing the measurement volume is detected
 - Intensity fluctuations representative for droplet velocity
 - For each velocity component: pair of laser beams
- Droplet size measurement
 - Minimum of 2 detectors at a defined distance
 - Measurement of scattered light
 - Size information in phase shift between the two signals

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Experiments: Equipment

- Equipment: 2d-PDPA-System
 - Air-cooled Ar⁺ laser (max. 300 mW laser output)
 - Fiberlight beam separator: 514.5 nm, 488 nm
 - Transmitter and receiver optics
 - Droplet size measurement range: 0.6–200 μm

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Experiments: Equipment

- Optical transmitter and receiver mounted on 3d-traverse-system
- Convenient repositioning of the measurement volume
- Applied spatial resolution of measurements:
 - 5 mm horizontal
 - 10 mm axial direction
 - Measurements closest to nozzle: axial distance of 100 mm (high spray density)
 - Each position: 10000 measurements to obtain representative values for velocity and dropsize

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- Statistical evaluation using the FlowSizer software tool (ver. 2.0.4, TSI)

The screenshot displays the FlowSizer software interface with several data analysis windows:

- Velocity 1 Histogram:** Shows axial velocity distribution.
- Velocity 2 Histogram:** Shows radial velocity distribution.
- Diameter Histogram:** Shows drop size histogram.
- Intensity Validation:** Shows a scatter plot of intensity vs. diameter.
- System Status:** Displays hardware and software parameters.

Hardware Status:

Channel	Data Rate (Hz)	Start ER (Hz)	PHI (Vol)	Stat.	Set Pt.	
Channel 1	0	0	1A	10	1C	0
Channel 2	0	0				

Run Parameters:

Parameter	Value
Velocity Mean (mm/s)	12.2588
Velocity Std Dev (mm/s)	2.4578
Volume Mean (mm ³)	3.2659
Volume Std Dev (mm ³)	4.5154
Frequency (Hz)	1.9267
Frequency (Hz)	11.44
Gate Time (ms)	7.51
Gate Time (ms)	7.57
Gate Count	702
Gate Count	206
Event Count	9
Event Time (ms)	21.5579

Intensity Validation Statistics:

Parameter	Value
1.00 gain	79.84
Volume Flow 1 (mm ³ /s)	43.7238
Volume Flow 2 (mm ³ /s)	63.044985
Volume Flow 3 (mm ³ /s)	9.8113281
Volume Flow 4 (mm ³ /s)	6.038888
Volume Flow 5 (mm ³ /s)	21.83
Volume Flow 6 (mm ³ /s)	43.26
Volume Flow 7 (mm ³ /s)	101.71
Volume Flow 8 (mm ³ /s)	140.227
Total Particle Count/Trap	340.5558

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- Velocity data: axial velocity component
- Horizontal planes

The figure shows three 3D surface plots of axial velocity (mm/s) versus x and y coordinates (mm) at different horizontal planes. The velocity is highest in the center and decreases towards the edges. The planes are labeled as 100 mm, 150 mm, and 200 mm.

Velocity data: axial velocity component

Horizontal planes

100 mm

150 mm

200 mm

axial velocity [mm/s]

x [mm]

y [mm]

axial velocity [mm/s]

x [mm]

y [mm]

axial velocity [mm/s]

x [mm]

y [mm]

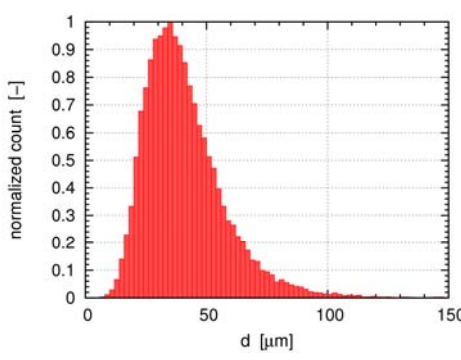
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Experiments: Results

- Droplet size distribution



- Sauter mean diameter: $d_{32} = \frac{\sum d_i^3}{\sum d_i^2} = 56 \mu\text{m}$
- Rosin Rammler fit: $Y = 1 - e^{-\left(\frac{d}{69.6}\right)^{2.7}}$

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Summary, Outlook

- CFD: Flow field in snow chamber
 - Gas flow field
 - Local gas properties such as moisture, temperature, density,...
 - Residence time distribution
 - Optimization of geometry and operating conditions
- Experimental
 - Characterization of spray in terms of droplet size and droplet velocity
 - Definition of boundary conditions for simulation runs
- Outlook
 - Implementation of models for snow formation
 - Definition of programming interfaces
 - Modeling approach: UDS vs. Lagrangian

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And finally...

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