Computational Fluid Dynamics for the Design Optimization of Dentrite Generators

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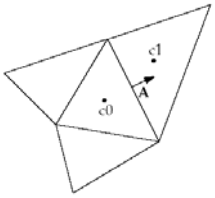
Agenda

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

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

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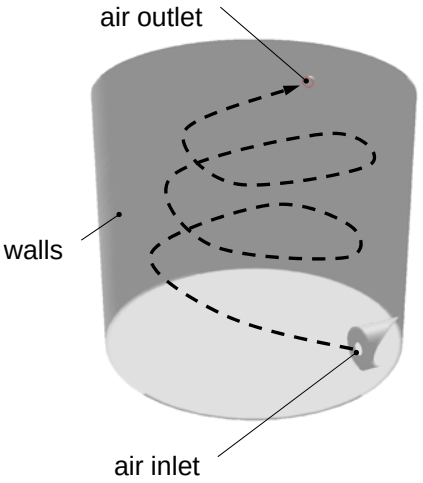
Computational Domain

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

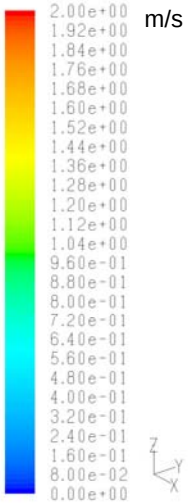
Spatial discretization:

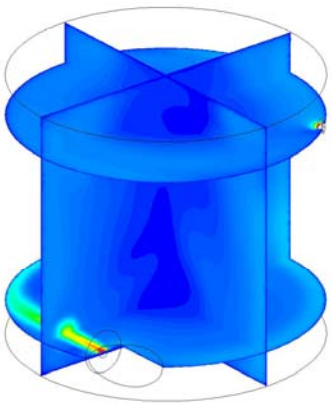
- Approx. $1.5 \cdot 10^6$ discrete volume elements



Simulation Results

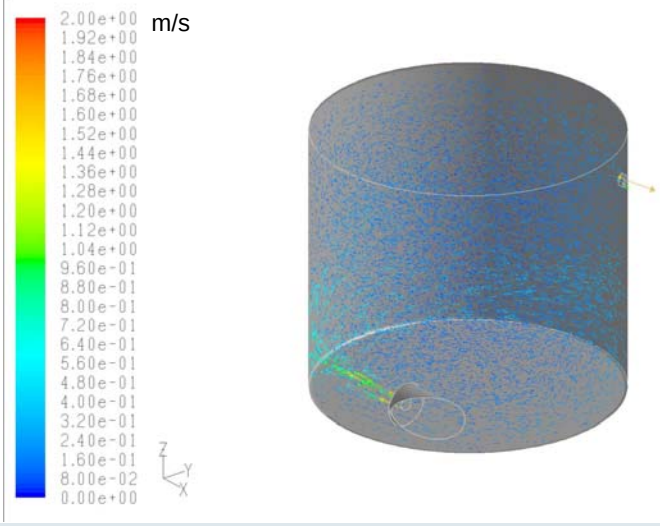
Velocity magnitude on cutting planes





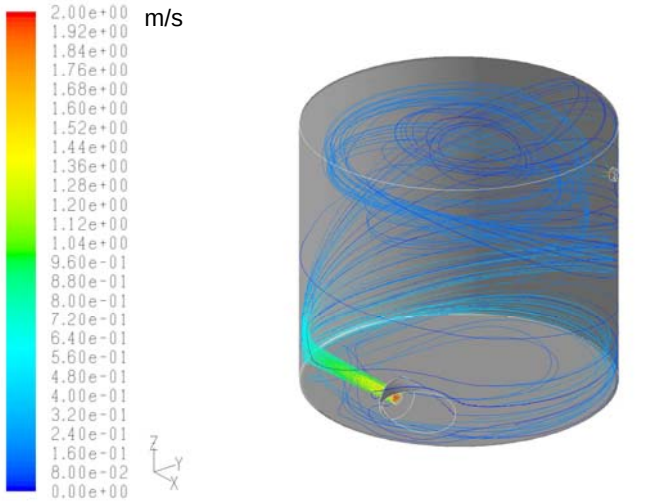
Simulation Results

Velocity vectors, colored by velocity magnitude



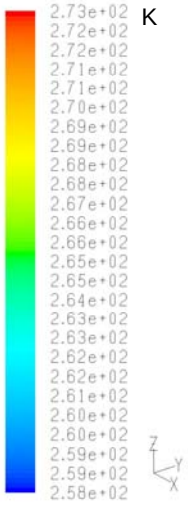
Simulation Results

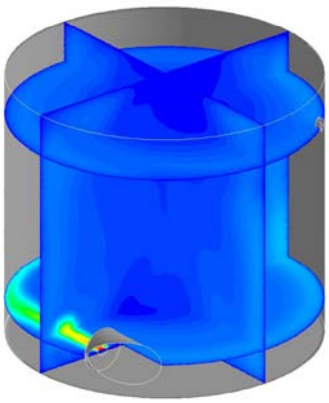
Path lines, colored by velocity magnitude



Simulation results

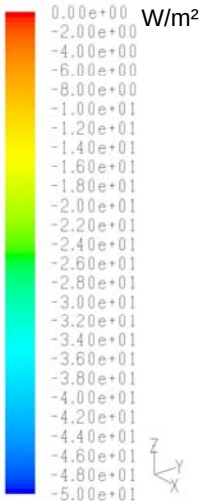
Temperature on cutting planes





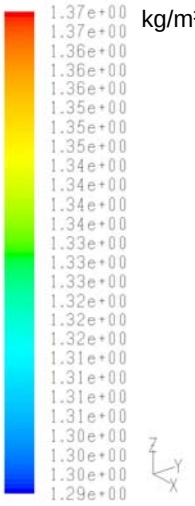
Simulation Results

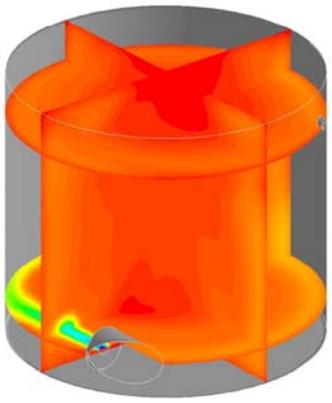
Surface heat flux



Simulation Results

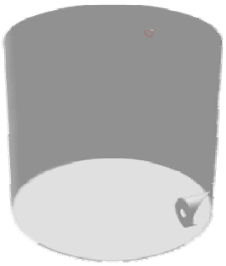
Density on cutting planes

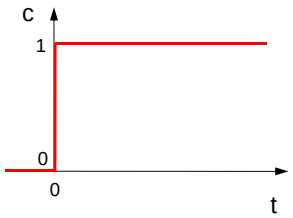




Simulation Results

- Residence time in Liebherr drum
- Transient simulation
- Additional conservation equation
  - Species transport (passive scalar)
  - Convective and diffusive transport
- Change inlet specification
  - At t=0
  - species transport

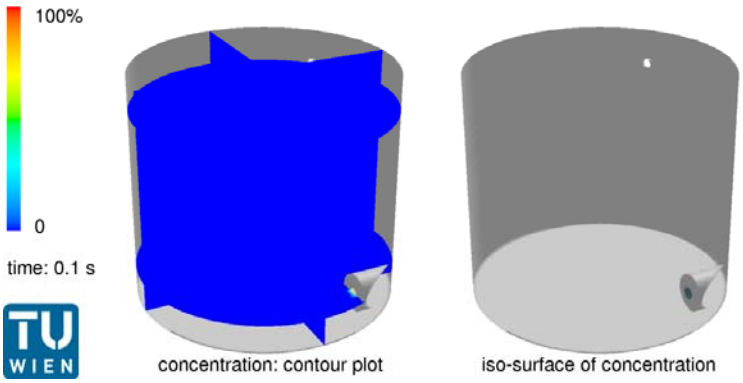




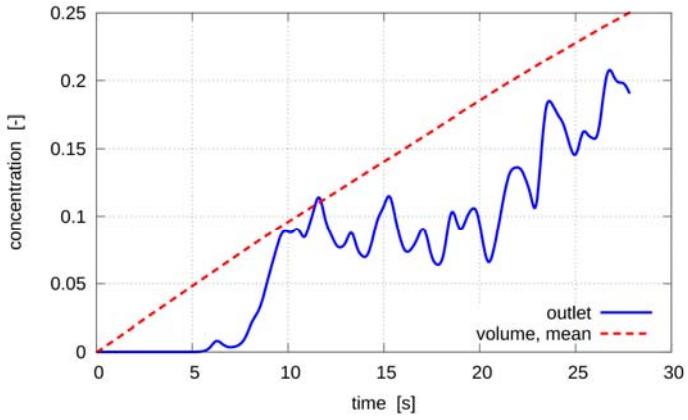
- Post-Processing
  - Investigation of concentration field
  - Visualization: Animation
  - Time history of concentration profile on outlet

Animation

- Time evolution of concentration profile in drum



- Concentration profile
  - Outlet
  - Mean volumetric concentration



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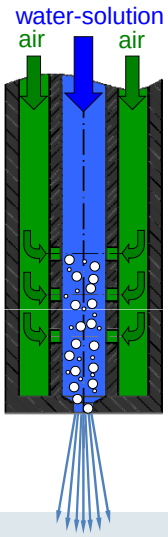
Example: Injection Nozzle

- 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



Experimental work: Setup

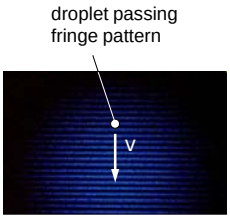
- Nozzle: mounted in optically transparent enclosure (1.5 x 1.5 x 3 m)
- Discharge orifice directing downwards

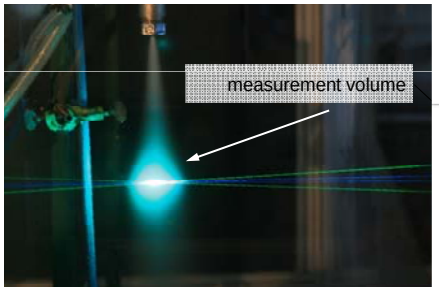
- Flow rates
  - influence of NH_3 on atomization process considered negligible
  - water: 60 l/h
  - air: 7.5 m^3_{STP}/h at 4.5 bar_g
  - gas/liquid mass flow ratio: 0.16

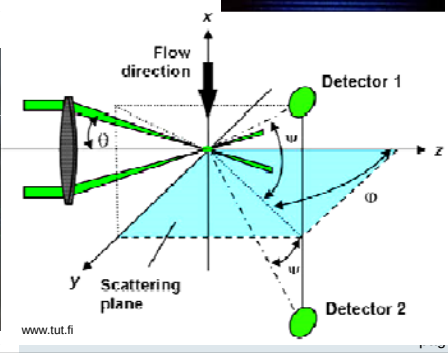
- Measurement of the spray-characteristics using Phase-Doppler-Particle-Anemometry (PDPA)
  - Droplet size distribution
  - Droplet velocity

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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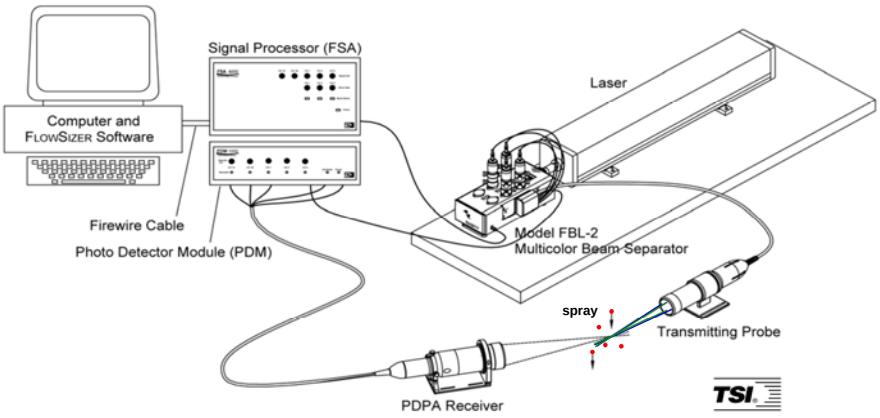
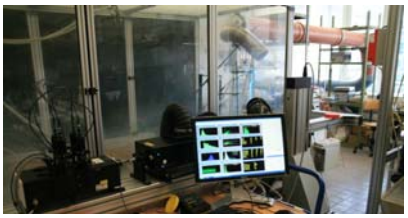
Experiments: Equipment

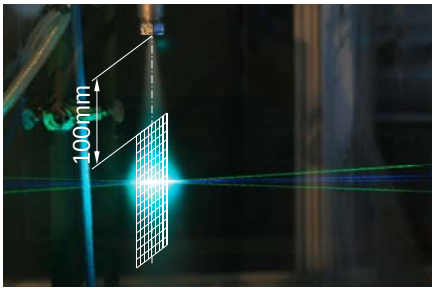
- Equipment: 2d-PDPA-System
  - Air-cooled Ar^+ laser (max. 300 mW laser output)
  - Fiberlight beam separator: 514.5 nm, 488 nm
  - Transmitter and receiver optics
  - Droplet size measurement range: 0.6–200 µm



Experiments: Equipment

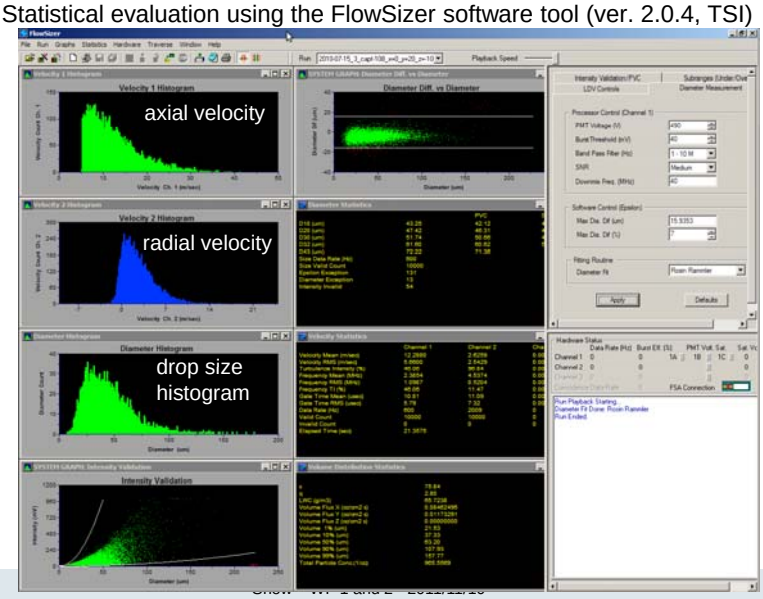
- Optical transmitter and receiver mounted on 3d-traverse-system
- Convenient repositioning of the measurement volume
- Applied spatial resolution of measurements:
  - 5 mm horizontal
  - 10 mm axial direction
  - Measurements closest to nozzle: axial distance of 100 mm (high spray density)
  - Each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





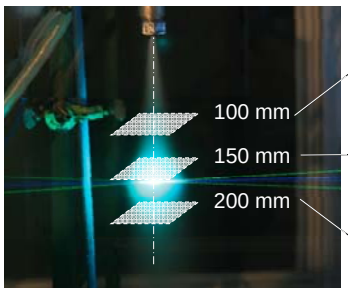
Experiments: Data Analysis

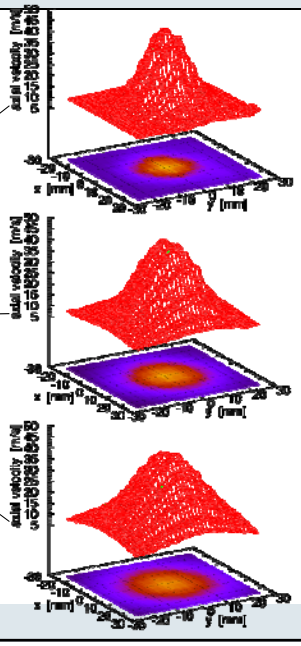
- Statistical evaluation using the FlowSizer software tool (ver. 2.0.4, TSI)



Experiments: Results

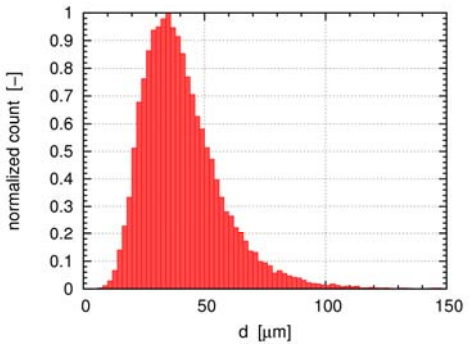
- Velocity data: axial velocity component
- Horizontal planes





Experiments: Results

- Droplet size distribution



- Sauter mean diameter: $d_{32} = \frac{\sum d_i^3}{\sum d_i^2} = 56 \mu m$
- 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