Computational Fluid Dynamics for the Design Optimization of Dentrite Generators

Michael HARASEK, Christian JORDAN, Tanja SIEGMANN-HEGERFELD

Technische Universität Wien
Institut für Verfahrenstechnik, Umwelttechnik und Technische Biowissenschaften

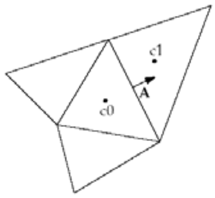
michael.harasek@tuwien.ac.at

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

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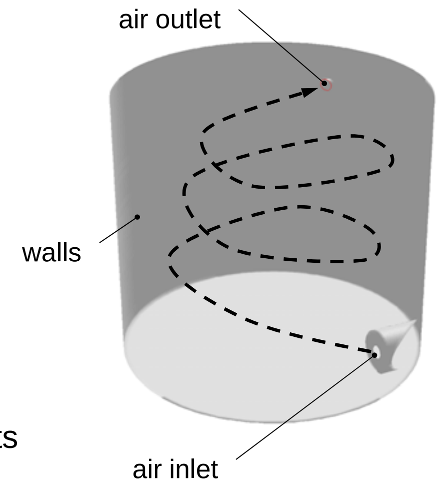
Computational Domain

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

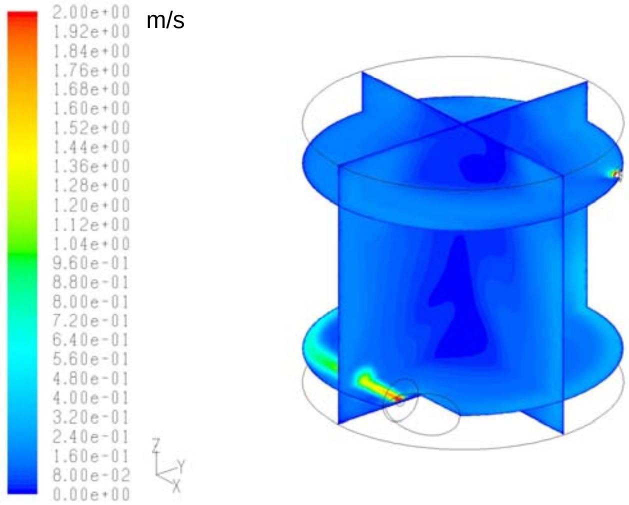
Spatial discretization:

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



Simulation Results

Velocity magnitude on cutting planes



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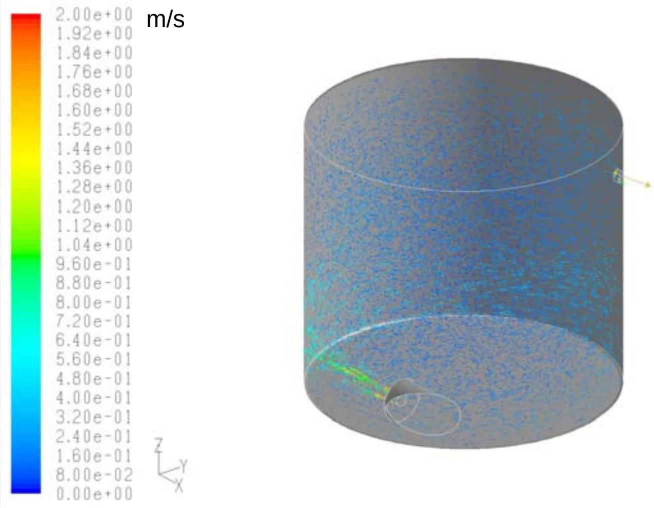
Simulation Results

Velocity vectors, colored by velocity magnitude



Snow – WP 1 and 2 - 2011/11/10 page 7

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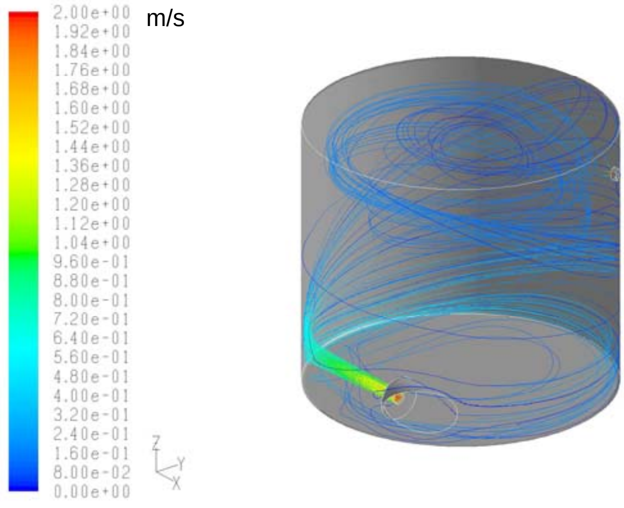
Simulation Results

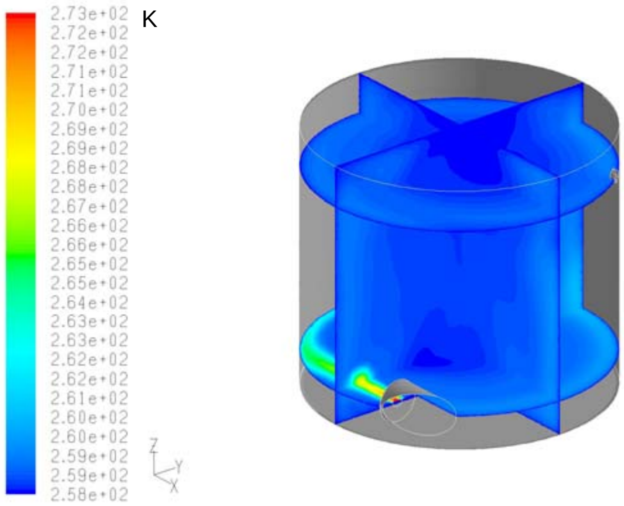
Path lines, colored by velocity magnitude



Snow – WP 1 and 2 - 2011/11/10 page 8

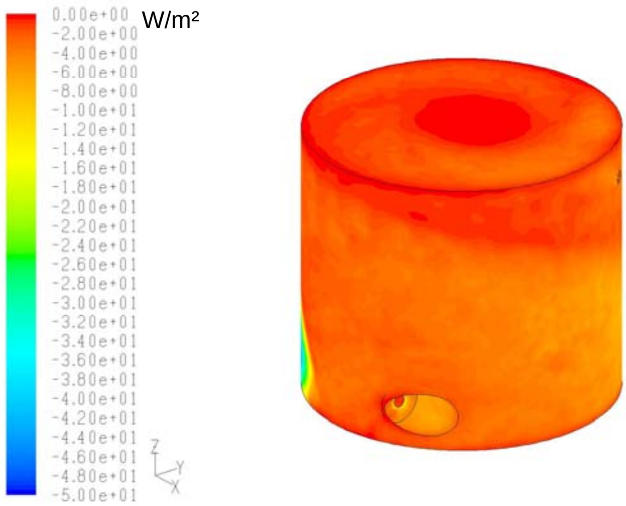
Simulation results

Temperature on cutting planes



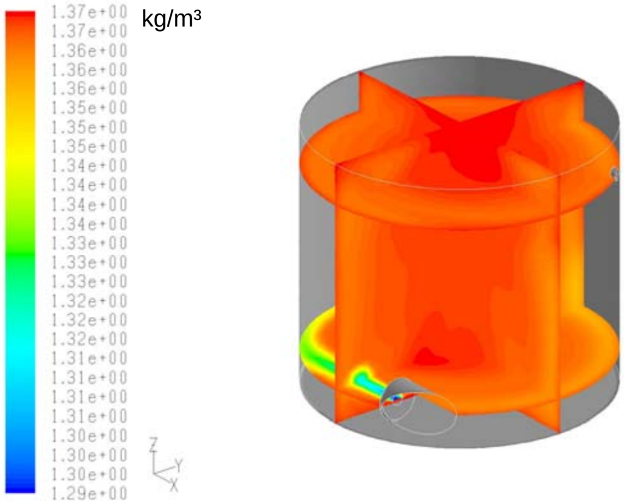
Simulation Results

Surface heat flux



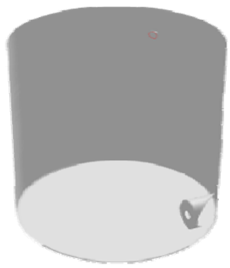
Simulation Results

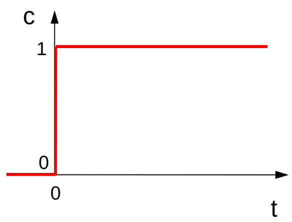
Density on cutting planes



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



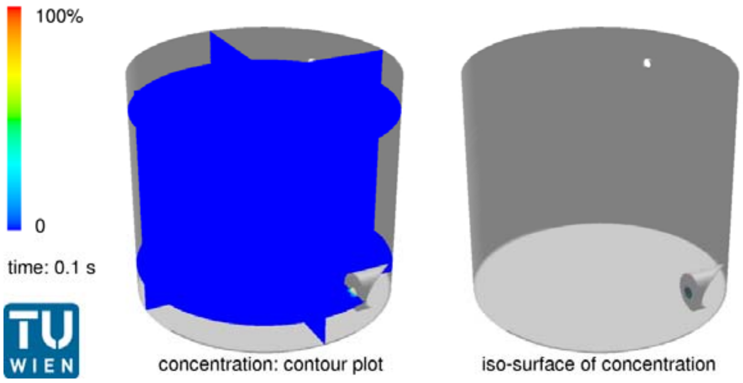


- Post-Processing
  - Investigation of concentration field
  - Visualization: Animation
  - Time history of concentration profile on outlet

Simulation Results

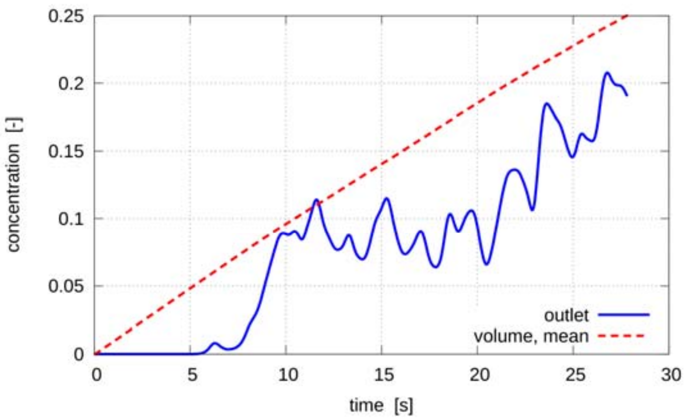
Animation

- Time evolution of concentration profile in drum



Simulation Results

- Concentration profile
  - Outlet
  - Mean volumetric concentration



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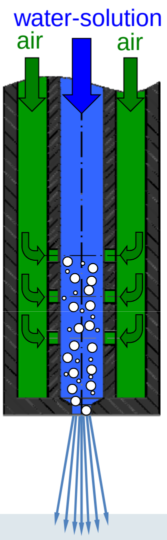
Example: Injection Nozzle

- 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



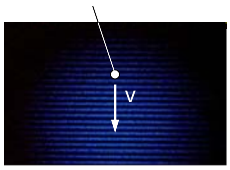
Experimental work: Setup

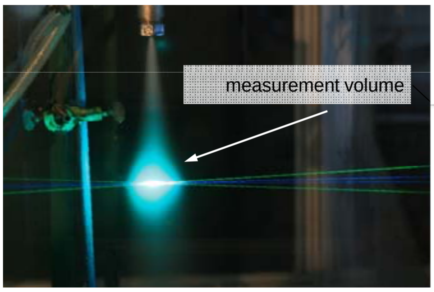
- Nozzle: mounted in optically transparent enclosure (1.5 x 1.5 x 3 m)
- Discharge orifice directing downwards
- Flow rates
  - influence of NH_3 on atomization process considered negligible
  - water: 60 l/h
  - air: 7.5 m^3_{STP}/h at 4.5 bar_g
  - gas/liquid mass flow ratio: 0.16
- Measurement of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

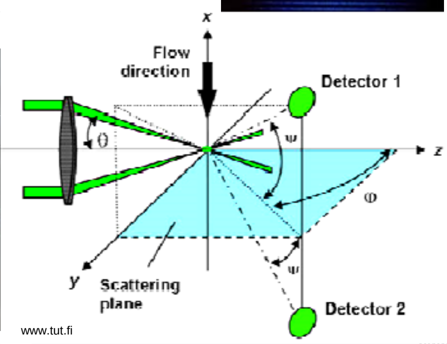
Phase Doppler Particle Anemometry

- 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

droplet passing
fringe pattern







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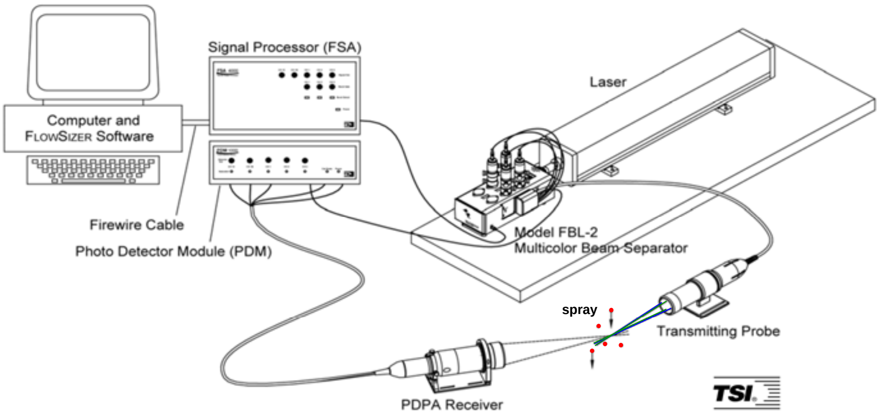
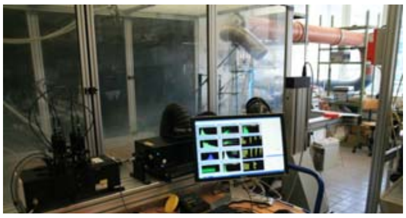
Experiments: Equipment

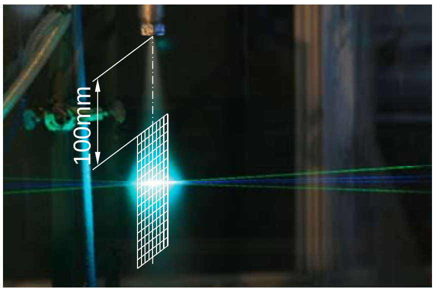
- Equipment: 2d-PDPA-System
  - Air-cooled Ar^+ laser (max. 300 mW laser output)
  - Fiberlight beam separator: 514.5 nm, 488 nm
  - Transmitter and receiver optics
  - Droplet size measurement range: 0.6–200 µm



Experiments: Equipment

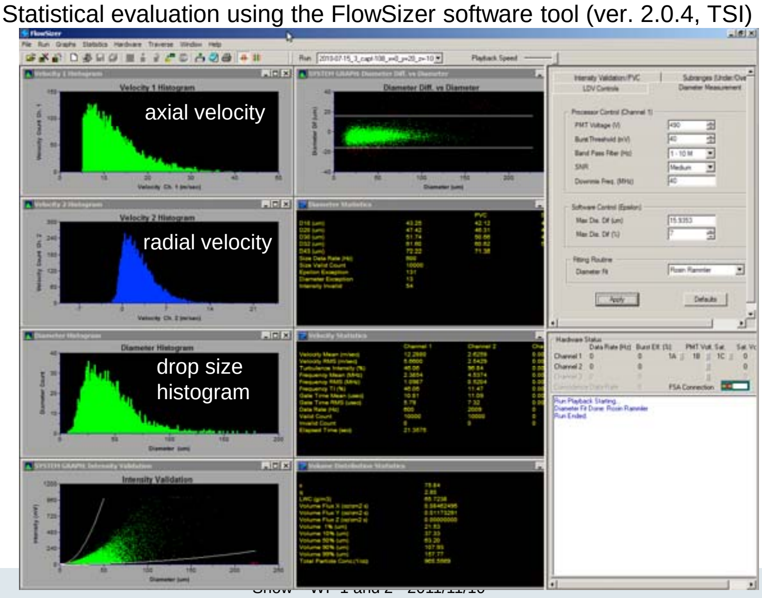
- Optical transmitter and receiver mounted on 3d-traverse-system
- Convenient repositioning of the measurement volume
- Applied spatial resolution of measurements:
  - 5 mm horizontal
  - 10 mm axial direction
  - Measurements closest to nozzle: axial distance of 100 mm (high spray density)
  - Each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





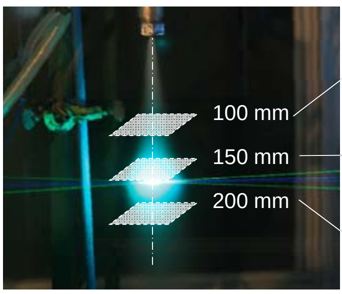
Experiments: Data Analysis

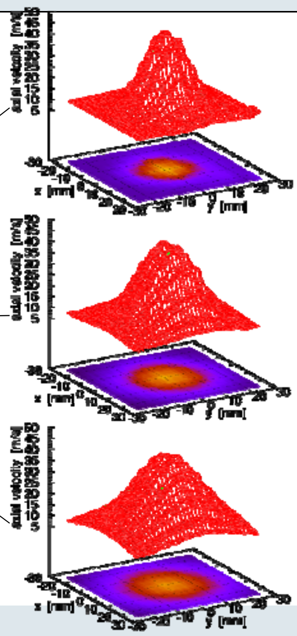
- Statistical evaluation using the FlowSizer software tool (ver. 2.0.4, TSI)



Experiments: Results

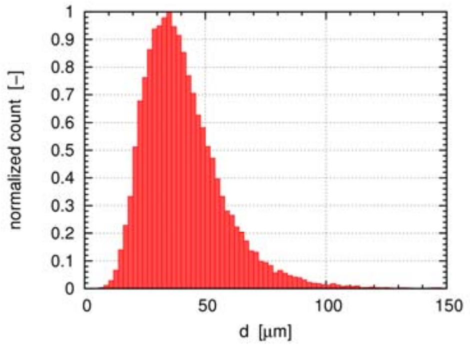
- Velocity data: axial velocity component
- Horizontal planes





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

Snow – WP 1 and 2 - 2011/11/10 page 25