CFD Simulation of the Two-Phase Flow around an Obstacle applying an Inhomogeneous Multiple Bubble Size Class Approach

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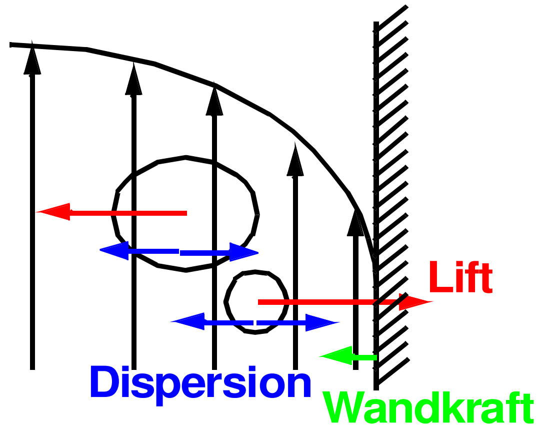
Outline

1. The concept of the inhomogeneous MUSIG model
   - role of the lift force for the flow regime
2. Application to the simulation of a complex flow situation

Nondrag bubble forces:
Forces perpendicular to the flow direction

- Turbulence Dispersion:
  - transfer of the turbulent fluctuations of the liquid on the bubbles
  - ➢ smoothing of radial volume fraction profiles



- Wall Force:
  - pushes bubbles away from the wall

- Lift Force:
  - gaseous bubbles in a shear flow: pressure differences from the liquid surrounding on the bubble surface
  - proportional to the gradient of the liquid flow field
  - ➢ direction dependent on the bubble size

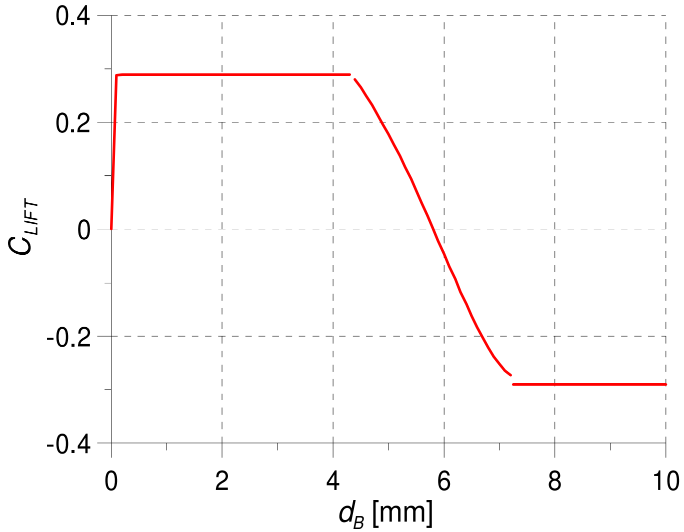
Tomiyama (1998): Experimental Investigation of single bubbles in a laminar shear flow (Glycol)

$$C_{Lift} = \begin{cases} \min[0.288\tanh(0.121\,\mathrm{Re}), f(Eo_d)] & \\ f(Eo_d) & for \\ -0.27 & \end{cases} \quad \begin{matrix} Eo_d < 4 \\ 4 < Eo_d < 10 \\ Eo_d > 10 \end{matrix}$$

$$with \qquad f(Eo_d) = 0.00105\,Eo_d^3 - 0.0159\,Eo_d^2 - 0.0204\,Eo_d + 0.474$$

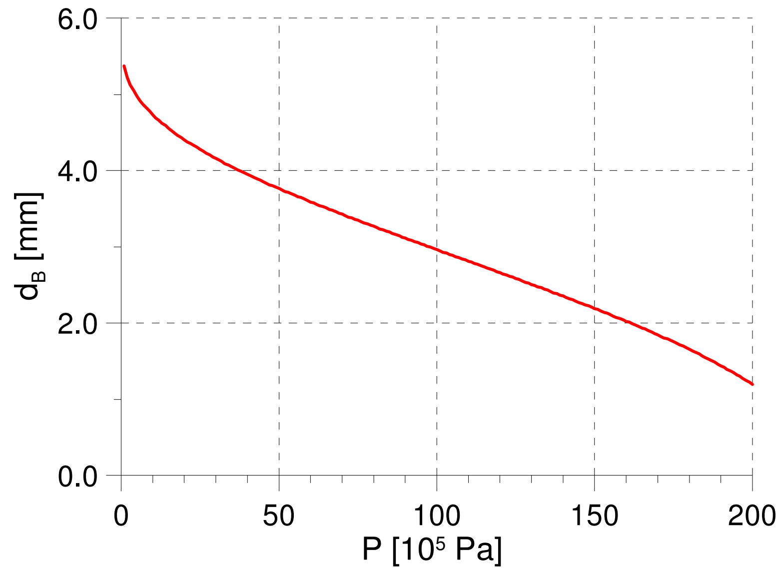
$$Eo_d = \frac{g(\rho_l - \rho_g)d_h^2}{\sigma}$$

- application of this correlation to air/water:
- C_{LIFT} changes the sign at d_B = 5.8 mm

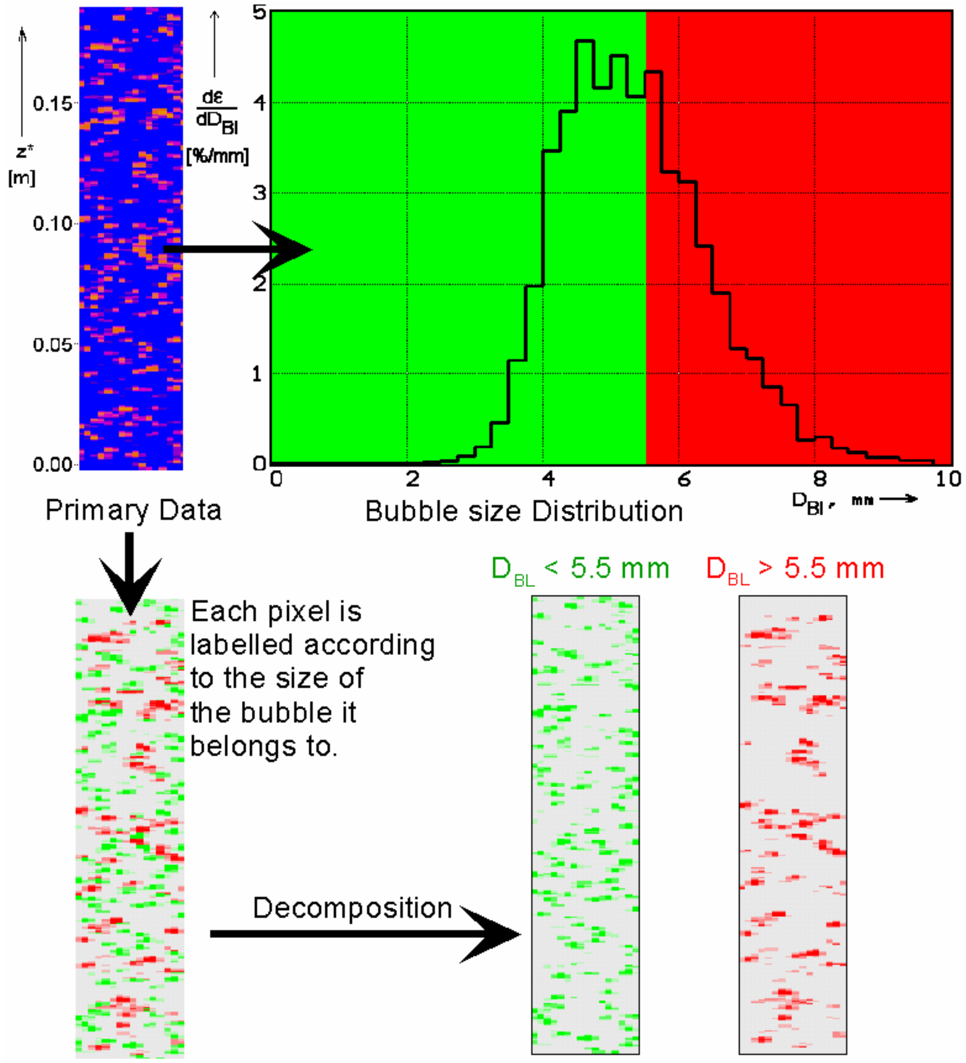


Conditions for steam/water

- evaluation of the Tomiyama correlation:
- ➢ with higher pressure the critical bubble size $d_B(C_{LIFT}=0)$ is decreased

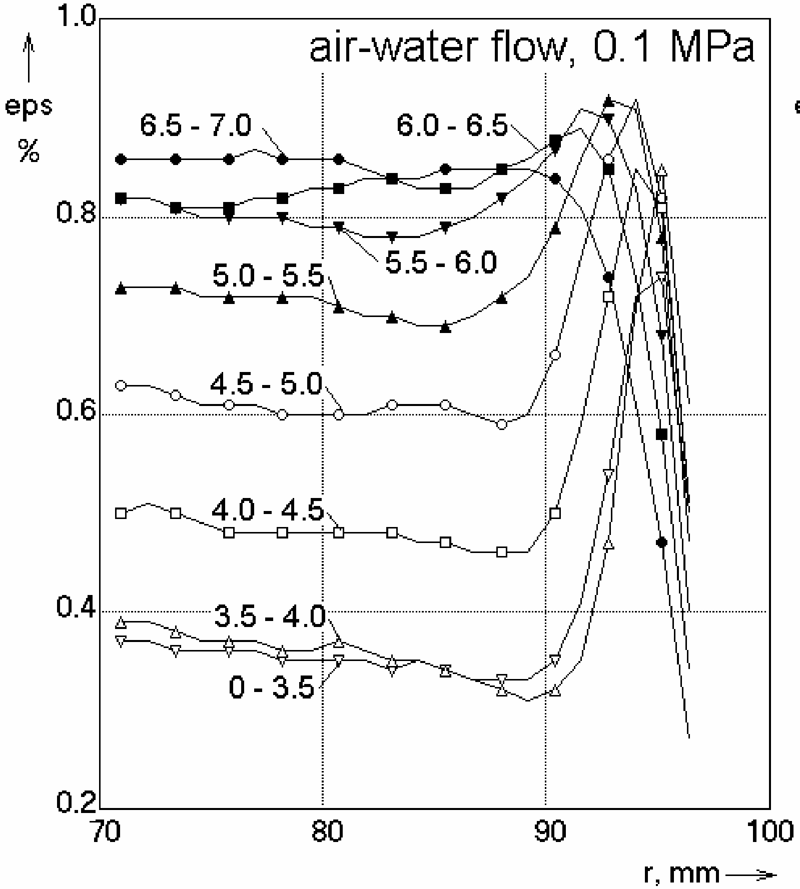


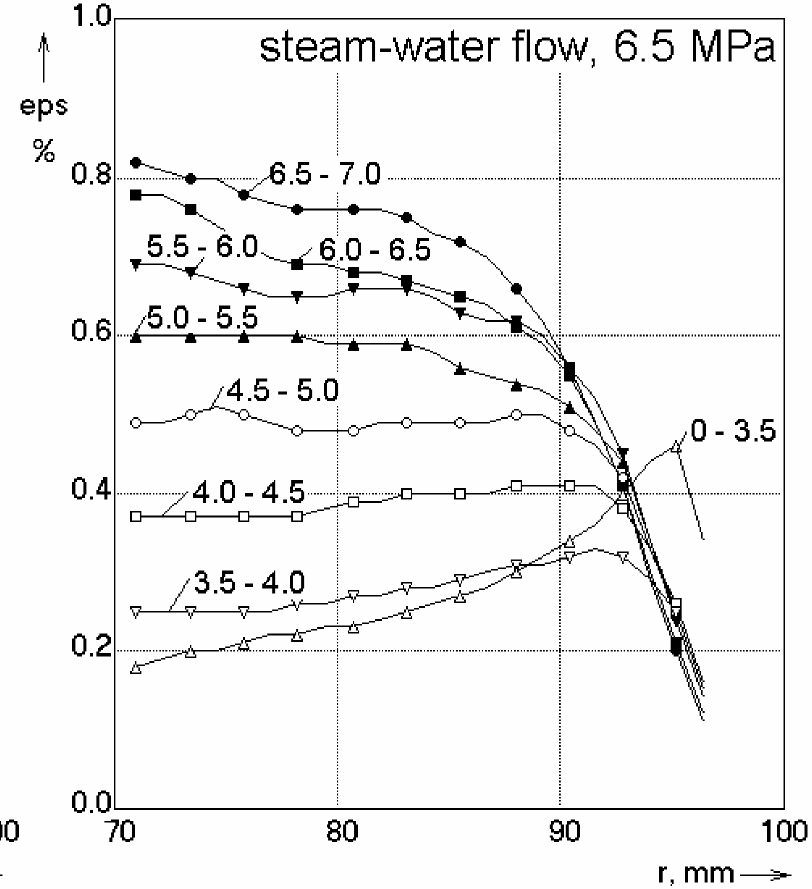
Measurements in FZD: Decomposition of the gas volume fraction distribution according bubble size



TOPFLOW experiments

J_L = 1 m/s and J_G = 0.22 m/s (FZR-118), L/D = 40, Injection valves: D_{inj} = 4 mm





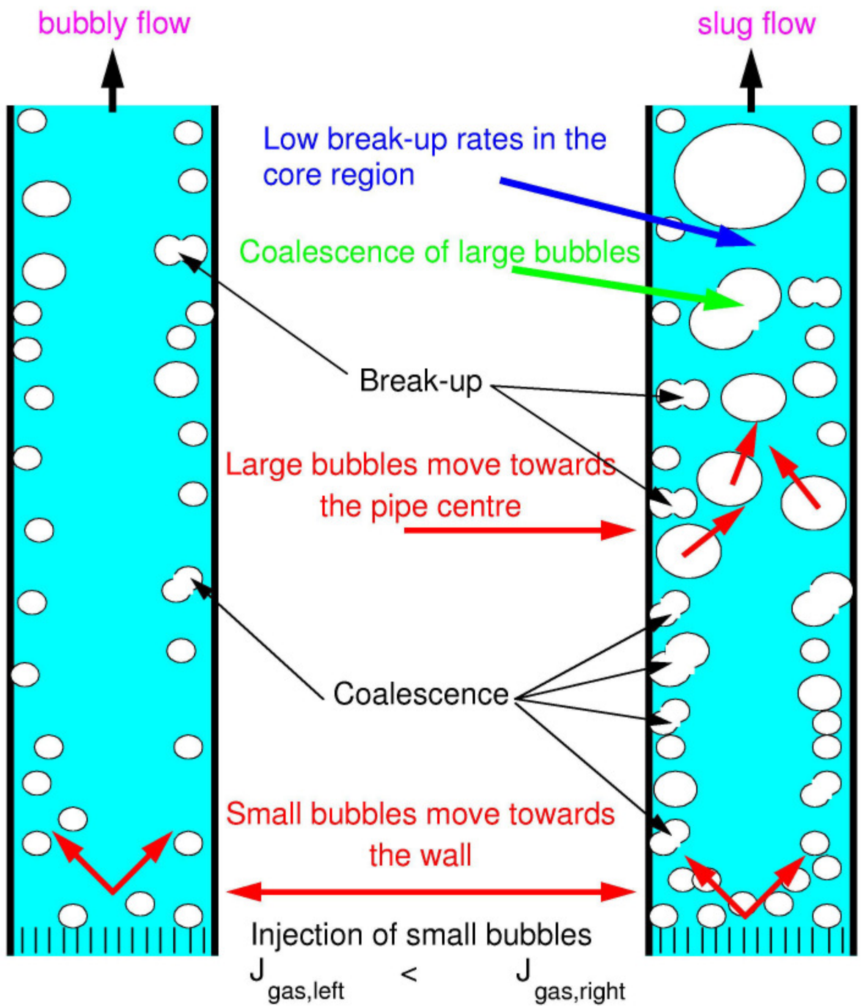
- *Horst-Michael Prasser et. al (2005): evolution of the structure of a gas-liquid two-phase flow in a large vertical pipe, NURETH-11, paper 399*

Influence of bubble forces on the flow regime in a vertical upward bubbly flow

- **Lift Force**:
  - small bubbles are pushed towards the wall
  - large bubbles are moved towards the centre
- **bubble break-up**
  - turbulent dissipation
  - only near the wall
- **bubble coalescence** :
  - at bubble accumulation

➢ radial phenomena have important influence on the flow regime

➢ a model approach has to be able to describe radial separation of small and large bubbles

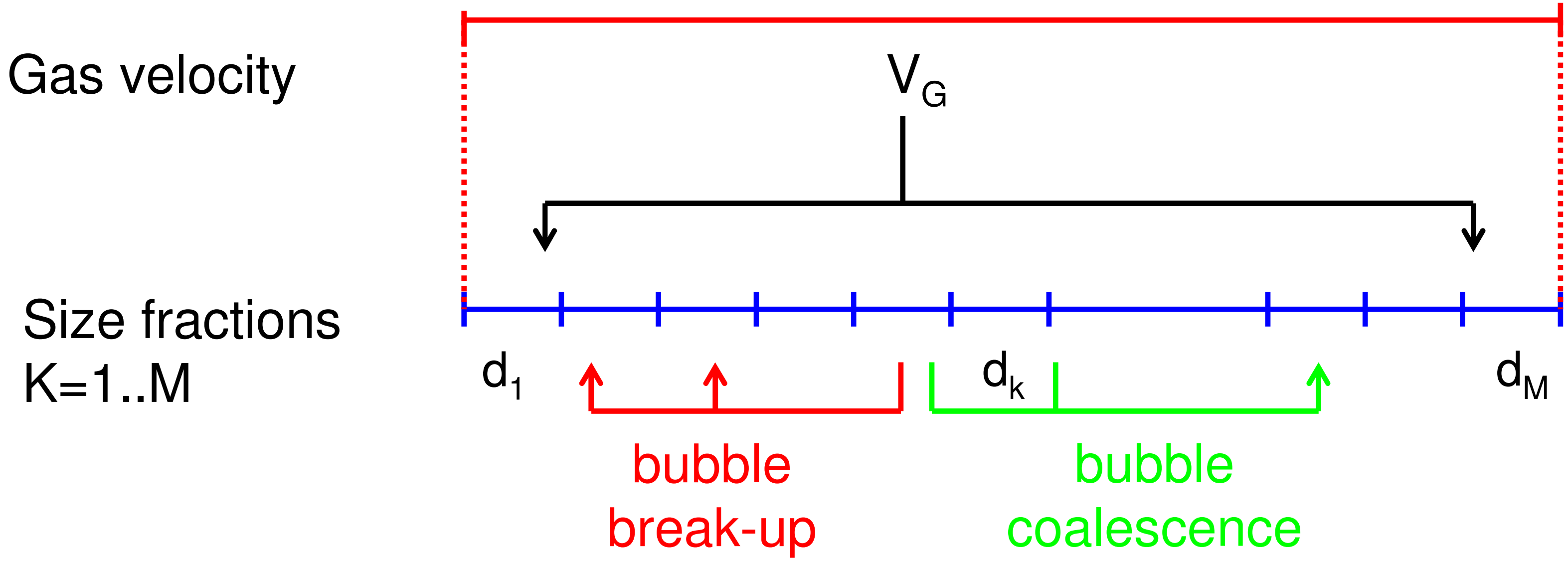


Population balance approach

- Definition of different bubble size classes
  - interact via models for bubble coalescence and bubble break-up
- In the Euler/Euler approach in principle the definition of several bubble classes is possible
- For the adequate description decades of bubble classes would be necessary (shown by separate investigations)
- Numerical problems: CPU time, convergence, stability

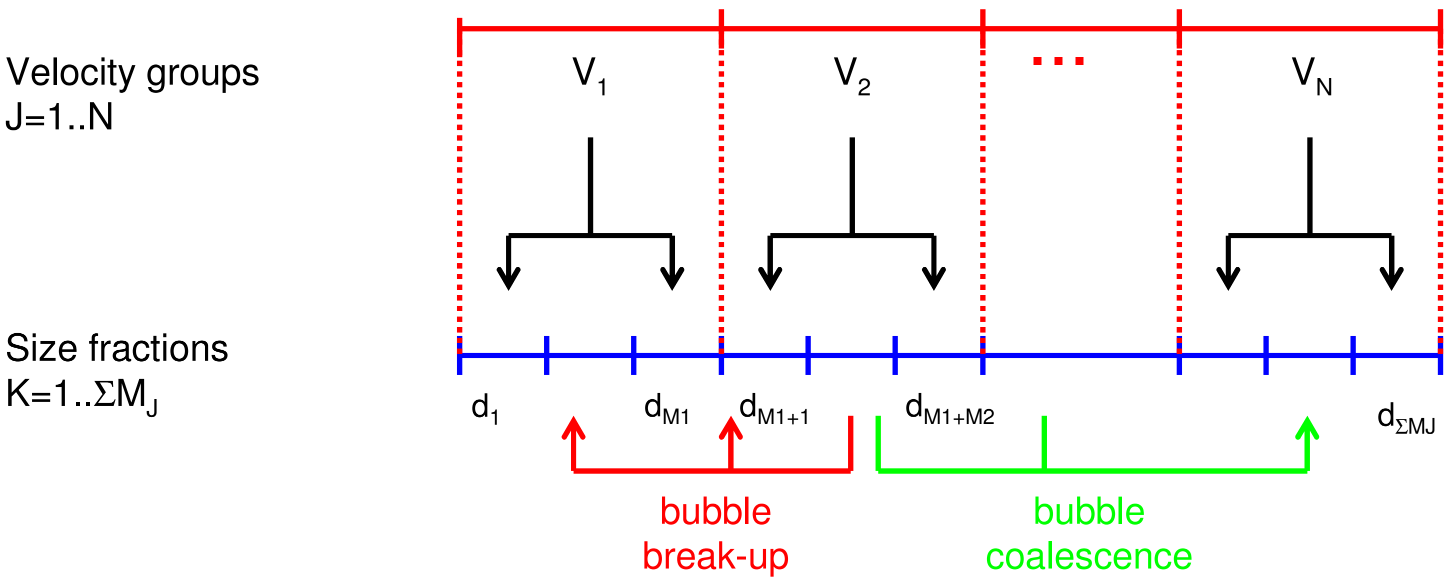
Multiple bubble **si**ze **g**roup model (MUSIG)

- S. Lo (1996 CFX-4):



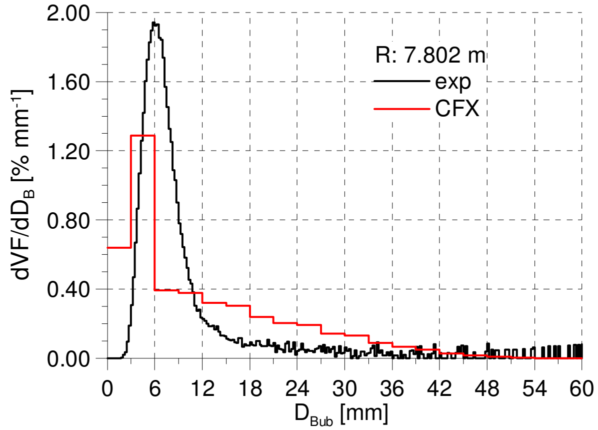
- for the gaseous phase only one velocity field
- only one momentum equation for the gaseous phase
- consideration of bubble break-up and coalescence only in the continuity equation

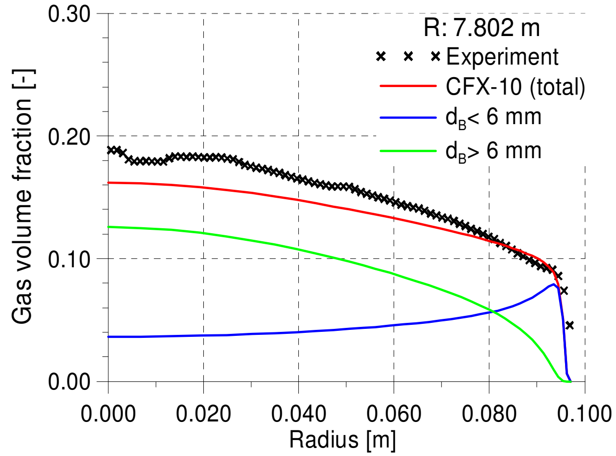
Concept for the improvement of the MUSIG Model

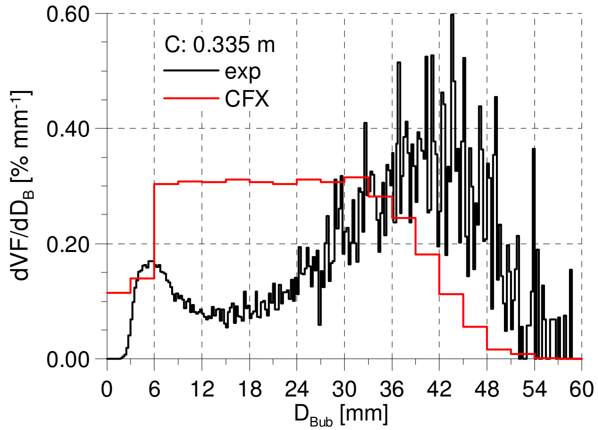


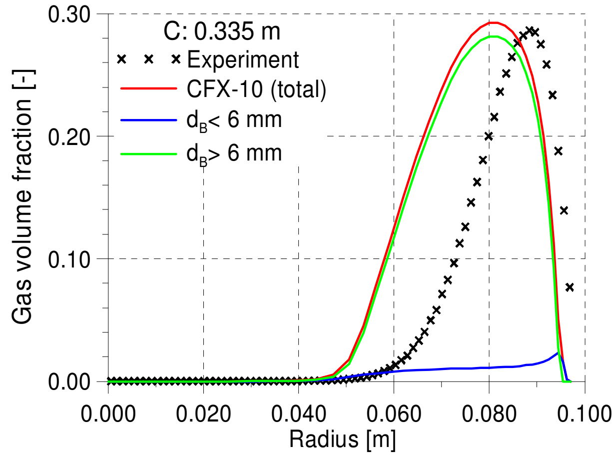
- The gaseous momentum equation is solved for at least two gaseous phases
- ➢ the description of the separation of small and large bubbles becomes possible
- simulation of bubble coalescence and break-up over all gaseous subsize fractions (continuity equation)

TOPFLOW FZR-118: J_L=1.0 m/s, J_G=0.2194 m/s
2 dispersed Phases, 34 sub-size fractions

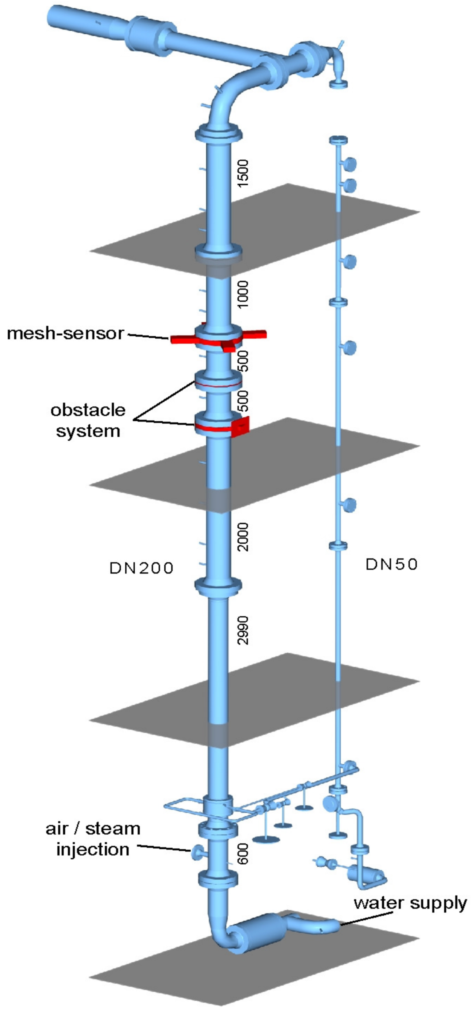


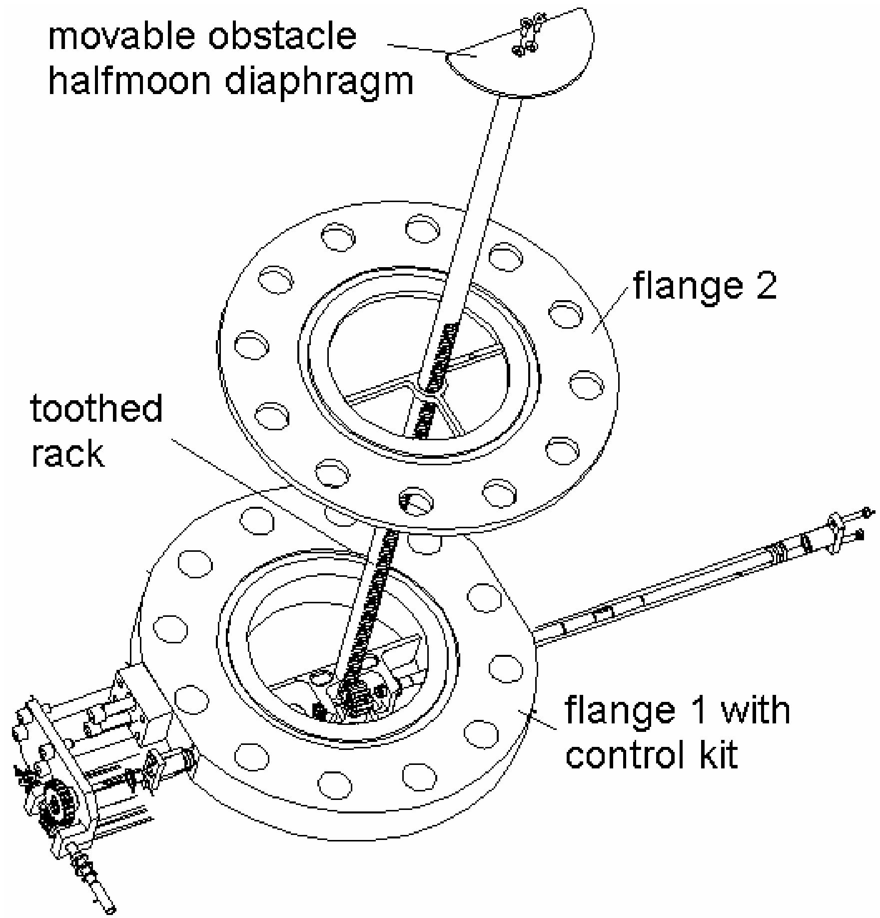






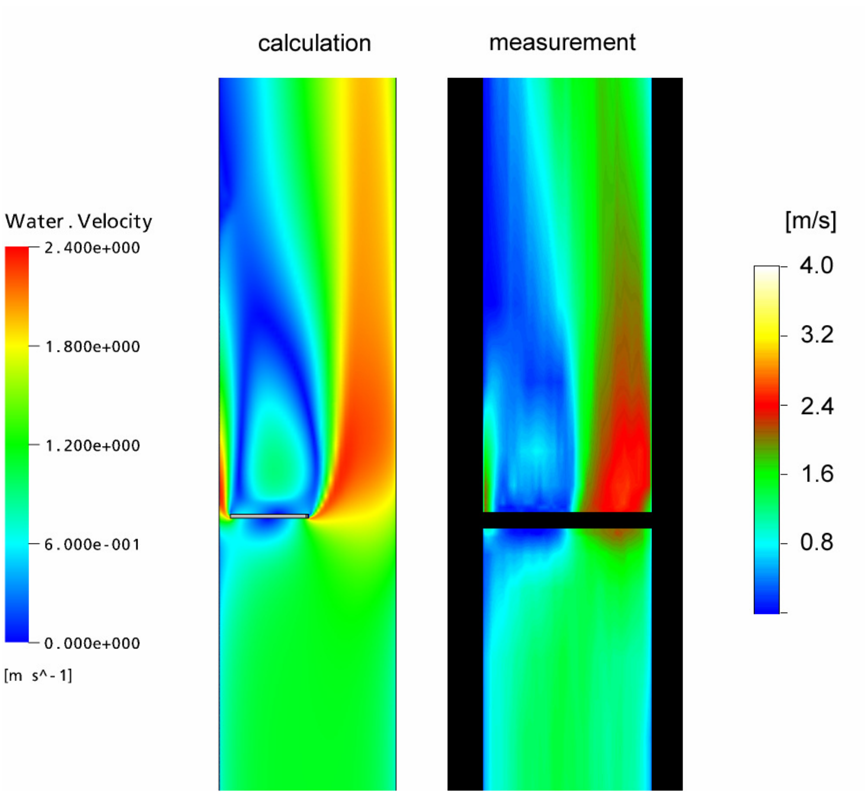
Investigation of a complex flow situation: Flow around an obstacle



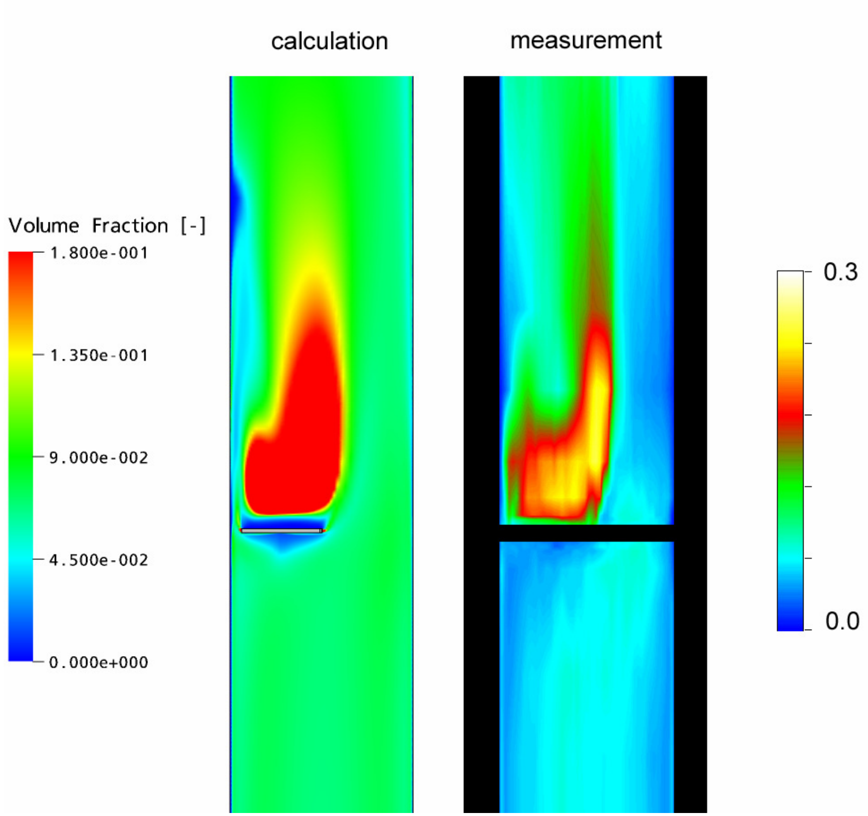


Comparison of calculated and measured timely averaged gas volume fraction and liquid velocity distributions

water velocity

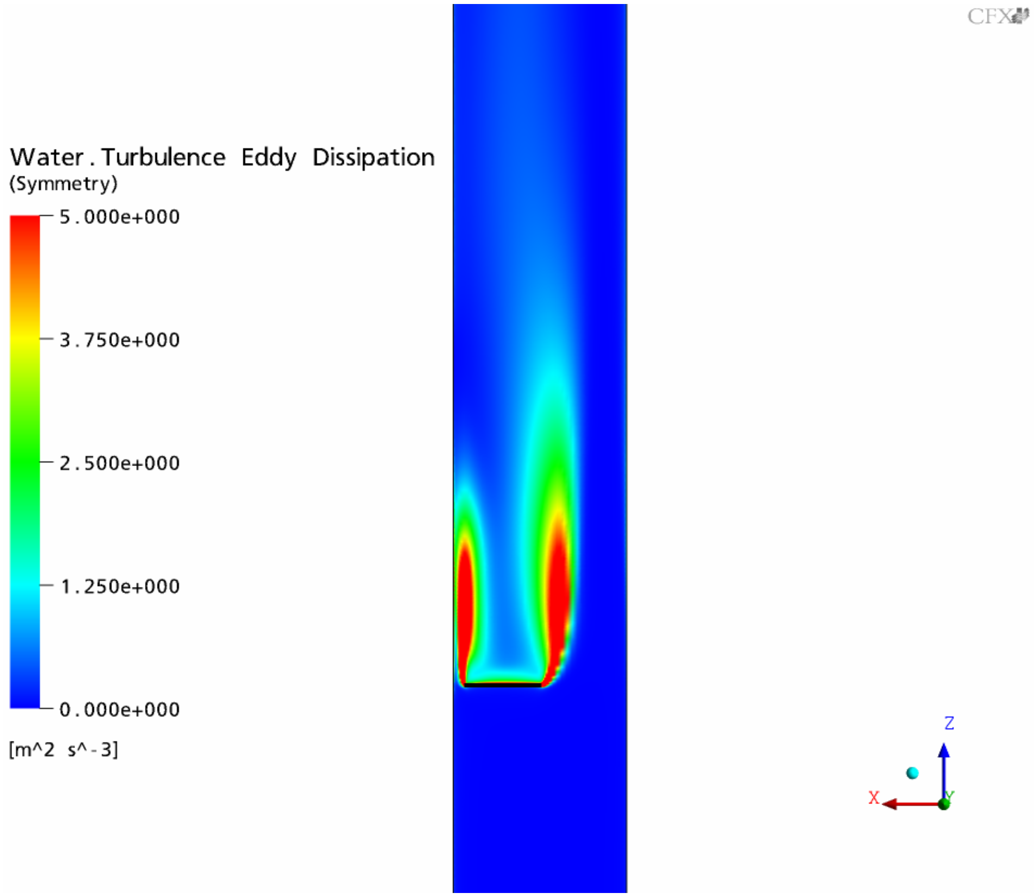


air volume fraction



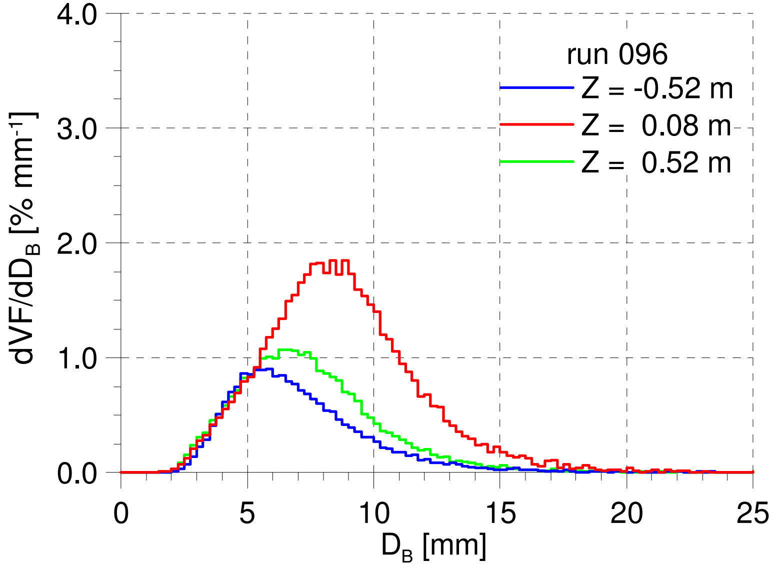
Run 096: J_L = 1.017 m/s; J_G = 0.0898 m/s

Calculated Turbulence Dissipation

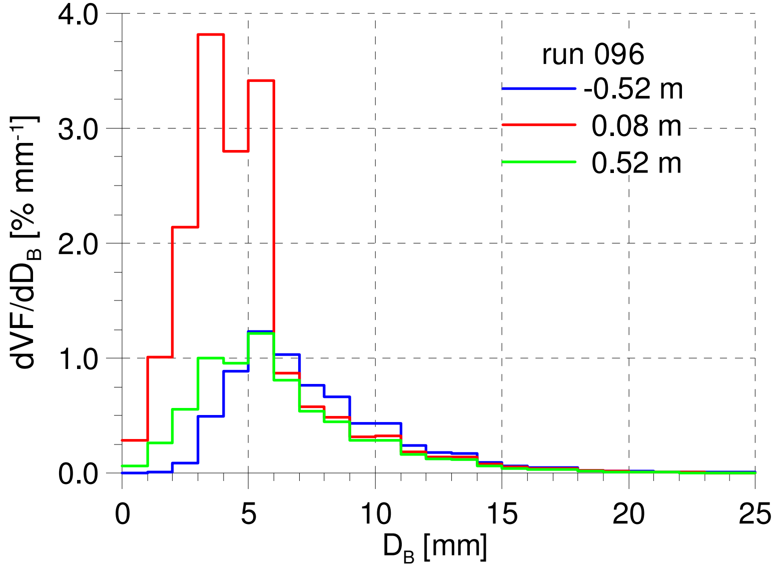


Comparison of measured and calculated cross sectional averaged bubble size distributions

Run 096 J_L = 1.017 m/s; J_G = 0.0898 m/s



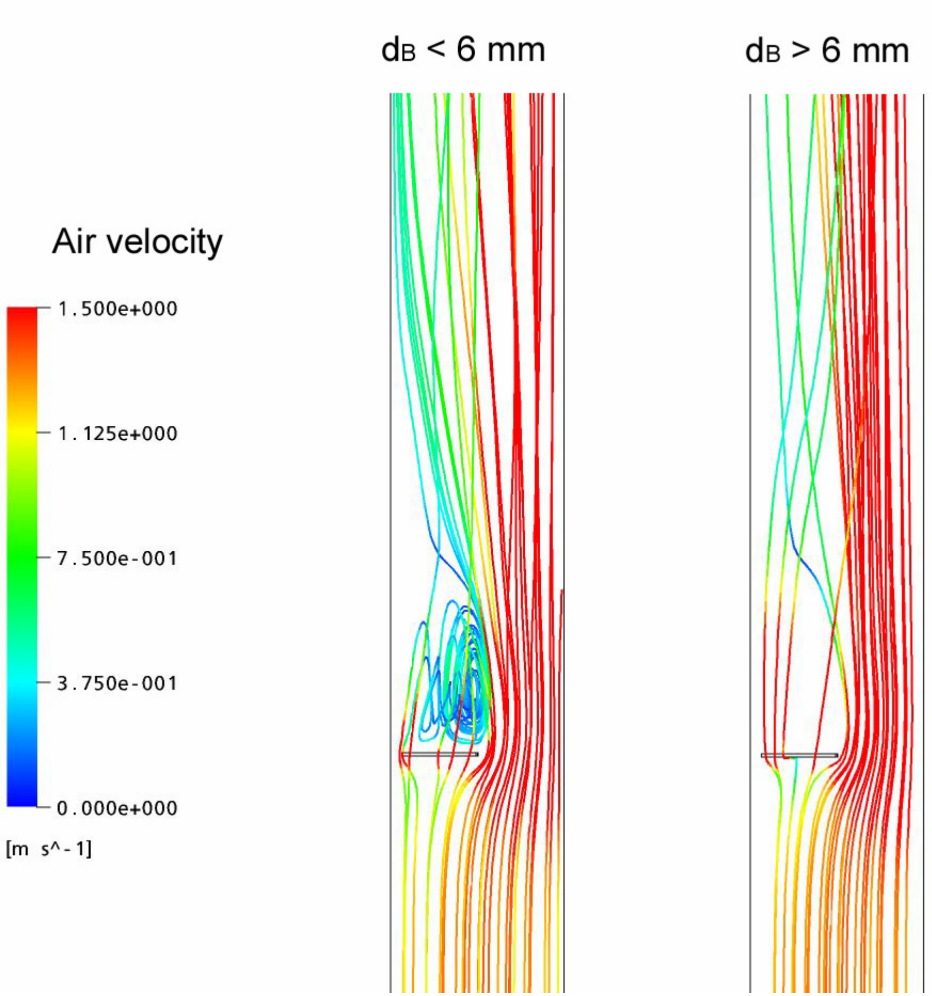
measurement



calculation

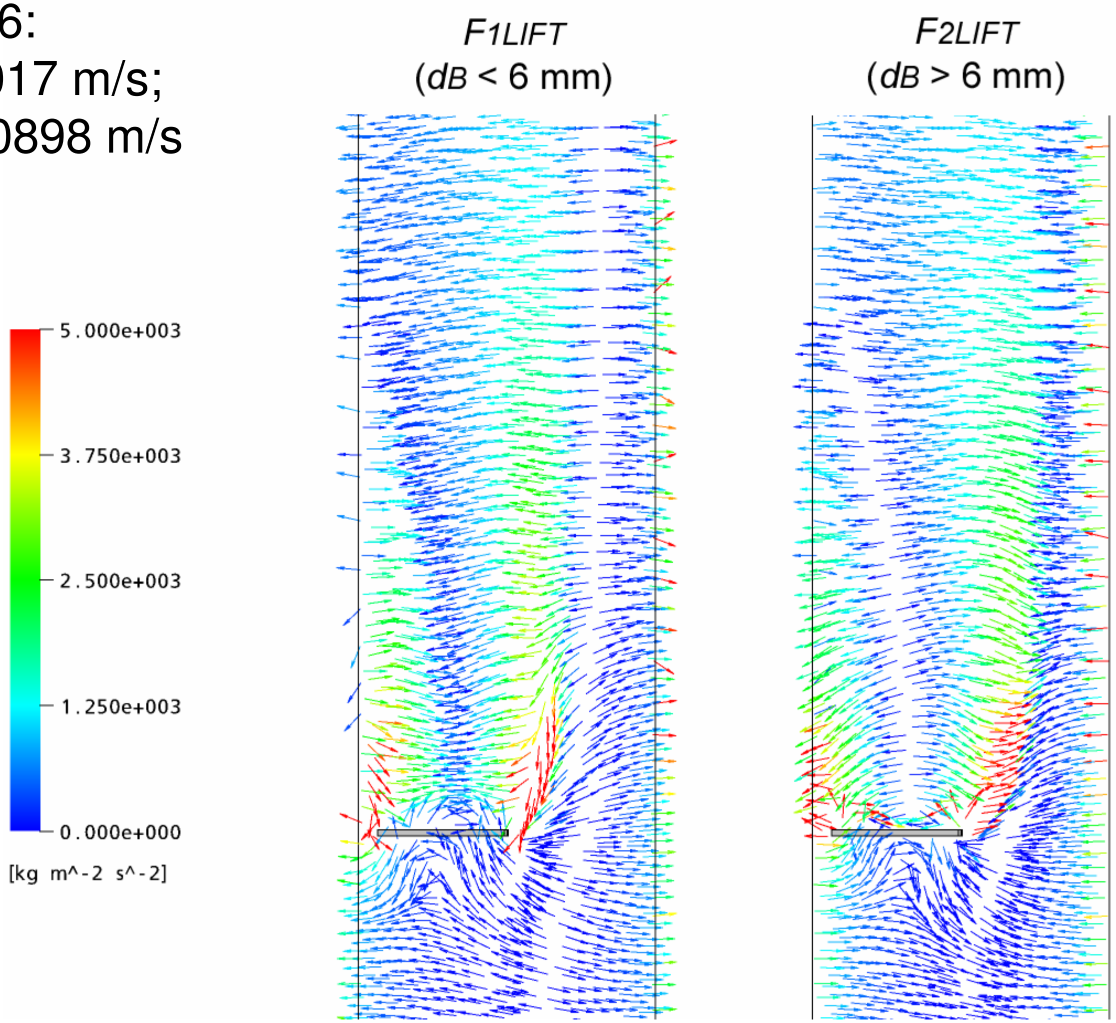
streamlines for large and small bubbles

Run 096:
J_L = 1.017 m/s;
J_G = 0.0898 m/s



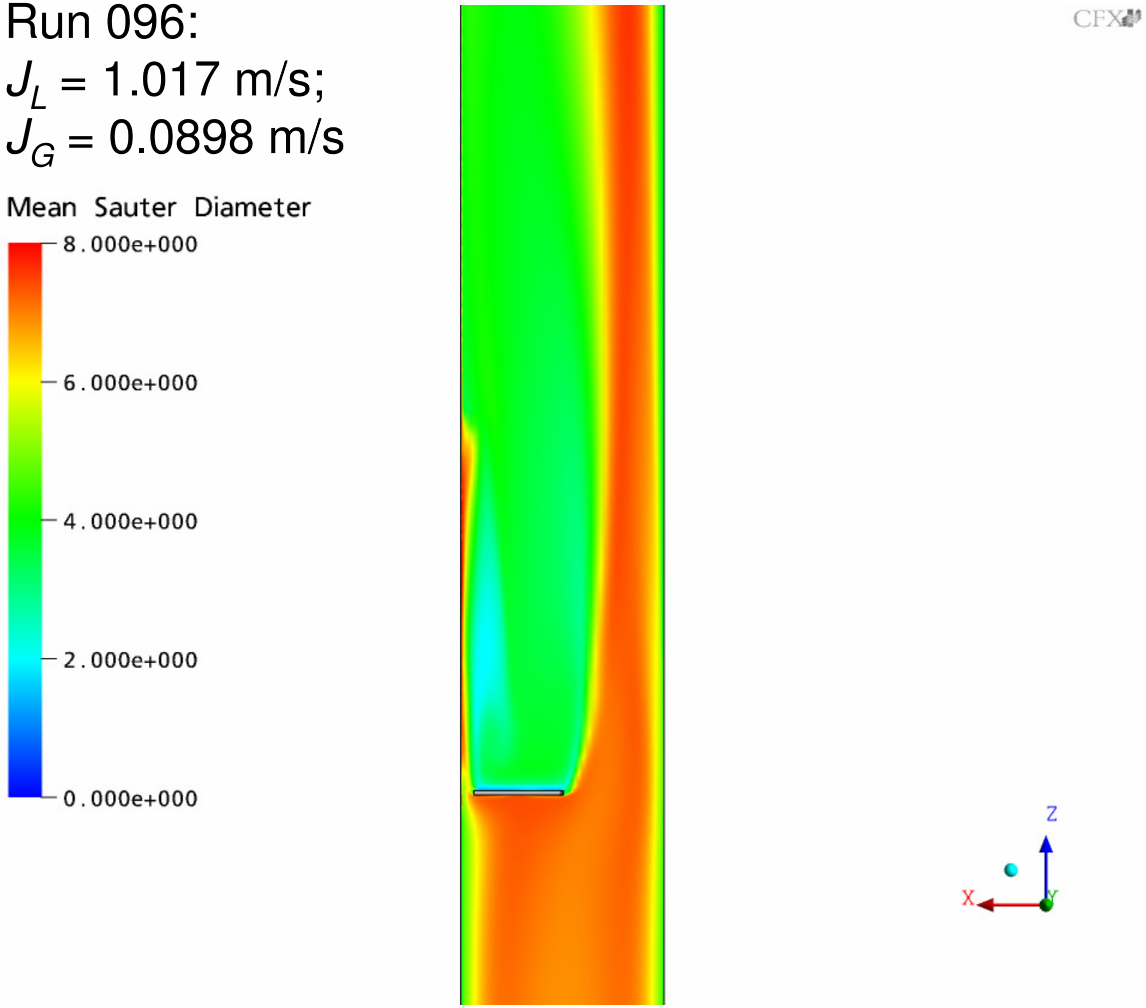
Lift forces

Run 096:
J_L = 1.017 m/s;
J_G = 0.0898 m/s

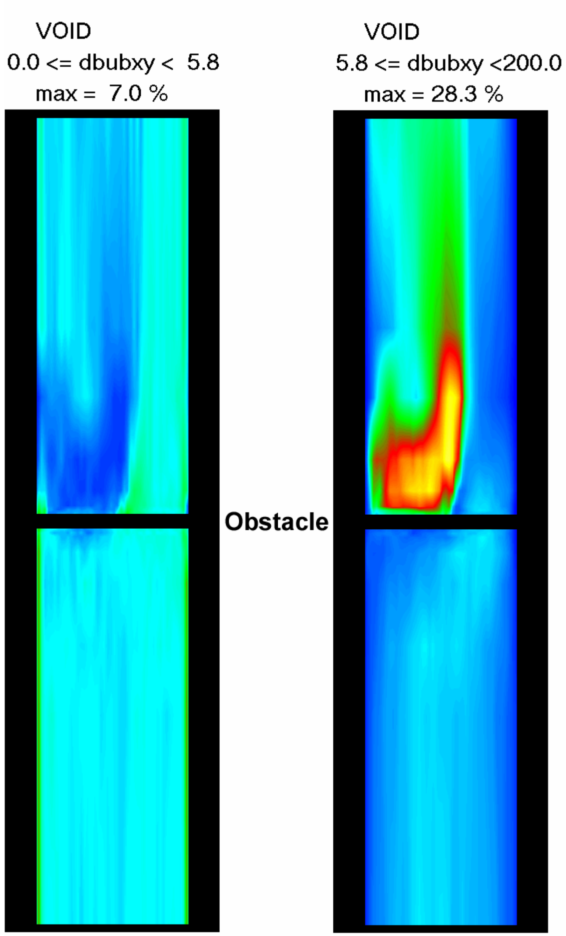


mean sauter bubble diameter

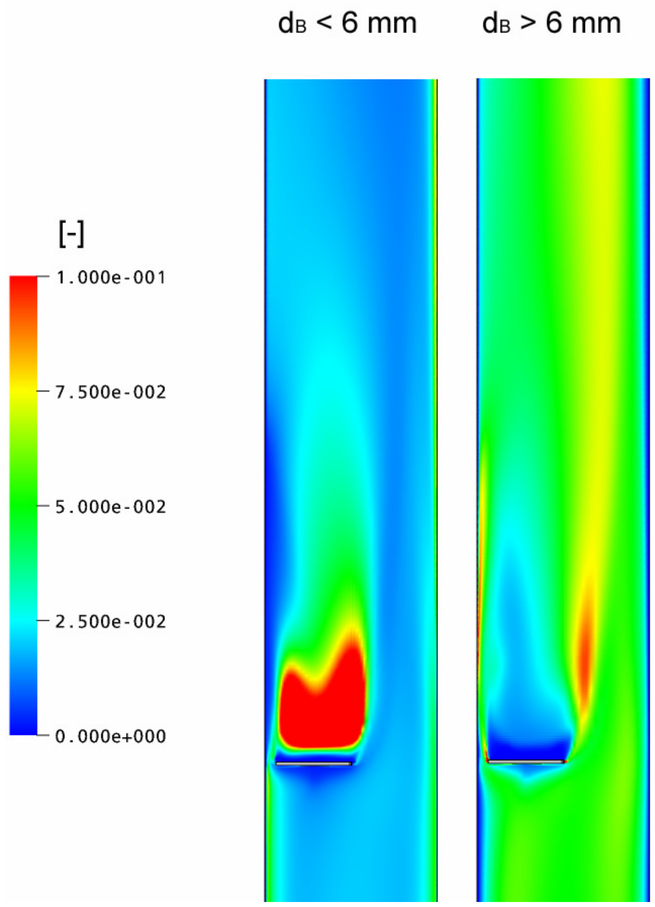
Run 096:
J_L = 1.017 m/s;
J_G = 0.0898 m/s



Gas distributions for different bubble size classes run 096 (J_L = 1.017 m/s; J_G =0.0898 m/s)



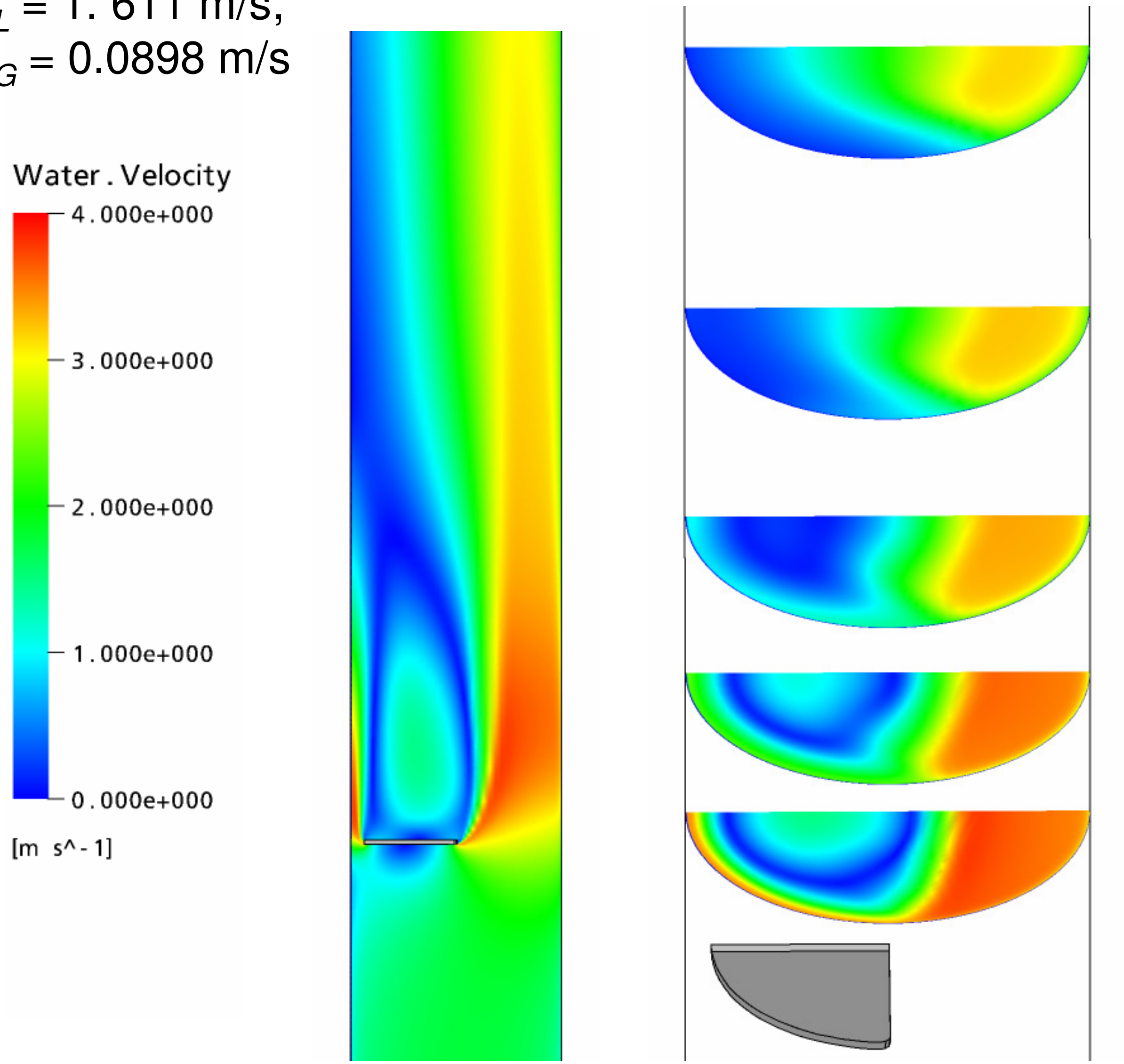
measurement

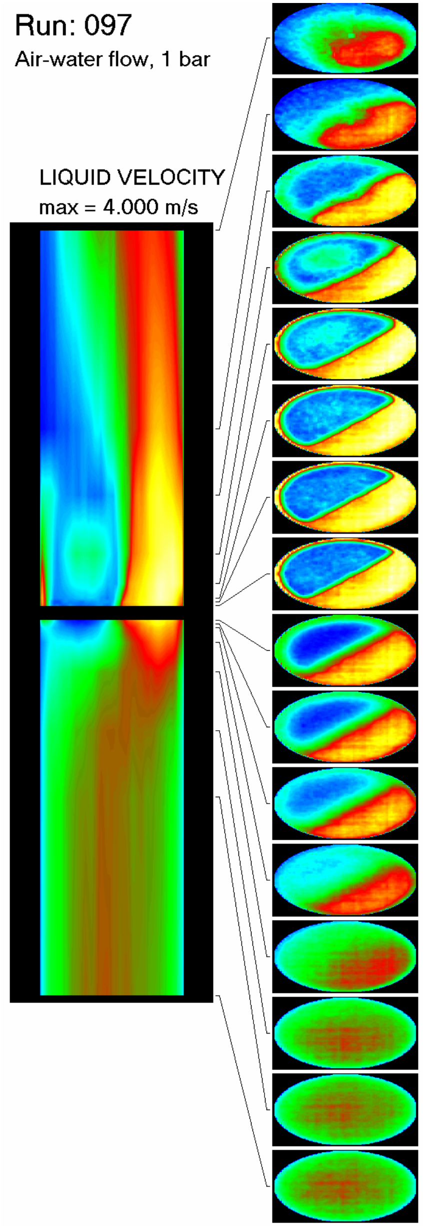


calculation

Run 097:
J_L = 1. 611 m/s;
J_G = 0.0898 m/s

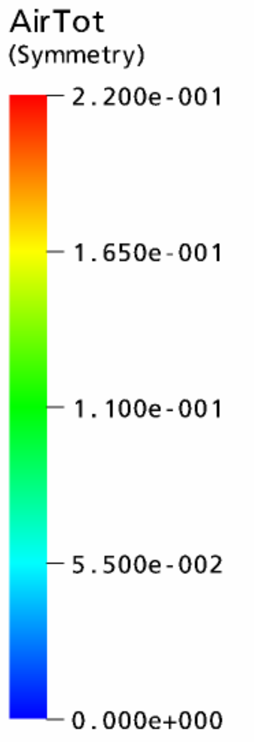
Water Velocity

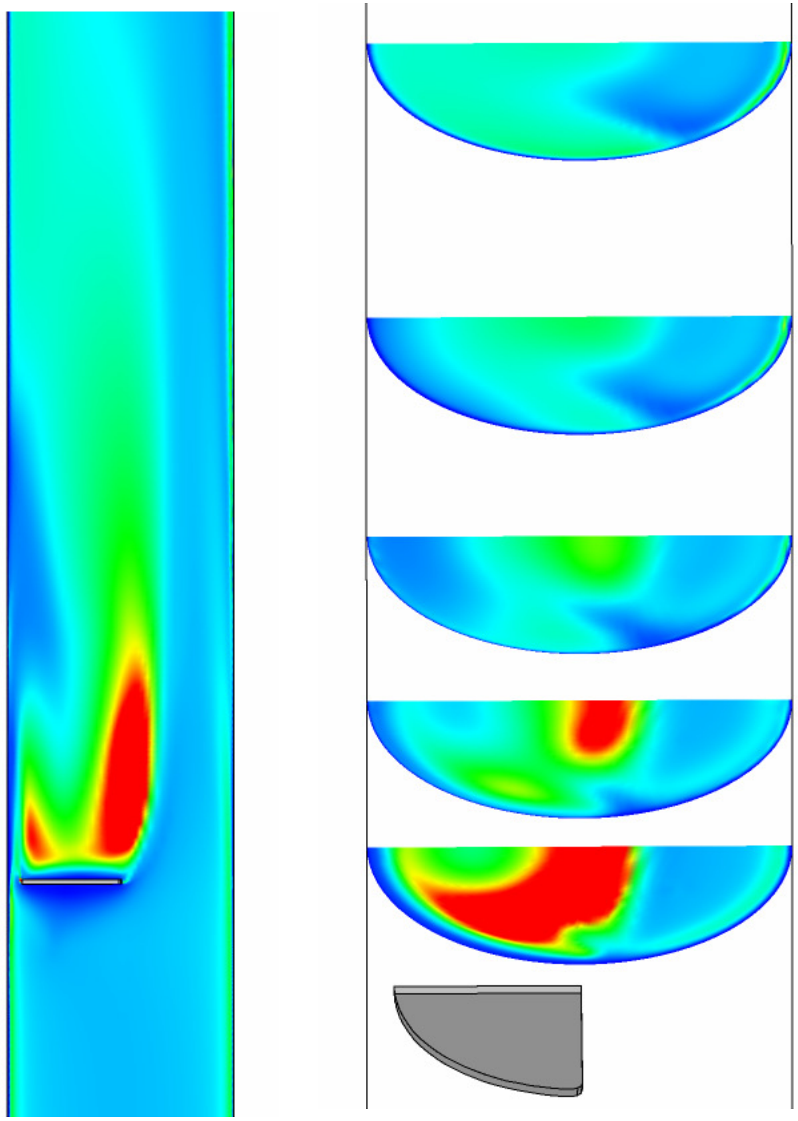


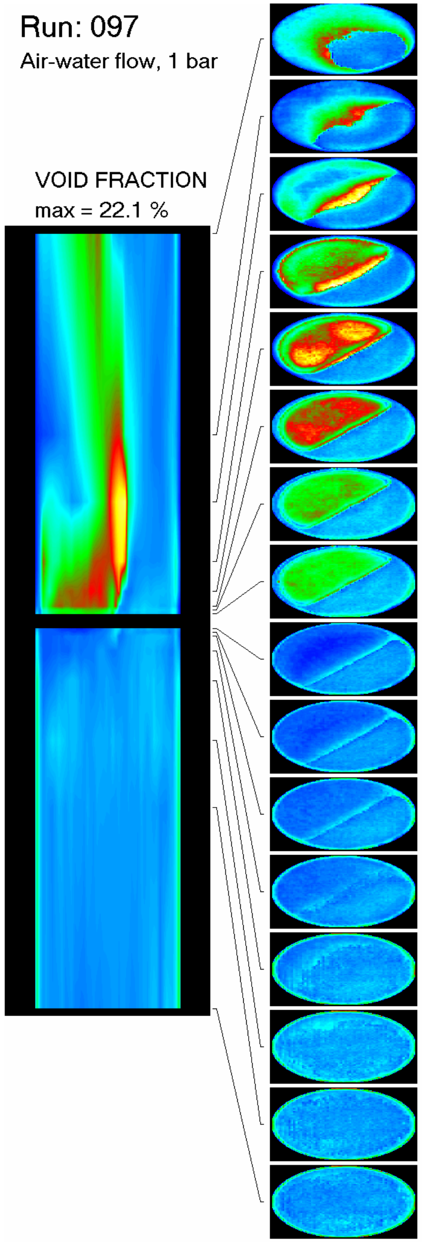


Run 097:
J_L = 1. 611 m/s;
J_G = 0.0898 m/s

Total Air Volume Fraction

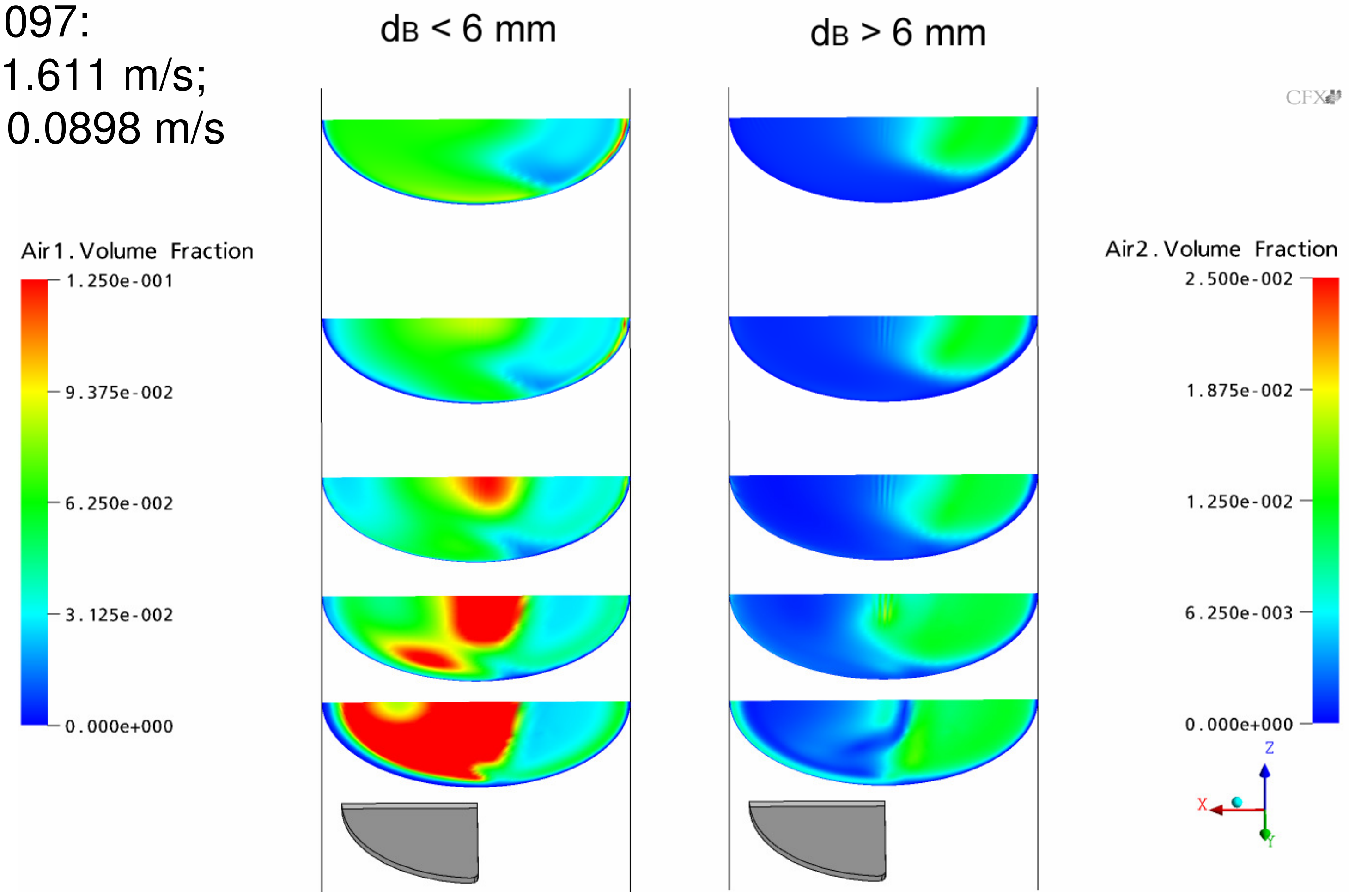






Gas distributions for different bubble size classes

Run 097:
J_L = 1.611 m/s;
J_G = 0.0898 m/s



Obstacle: Summary of observations

1. Phenomena in the wake of the obstacle
   - Small bubbles are transported behind the obstacle (lift force)
   - Bubble accumulation behind the obstacle causes coalescence
   - in the measurements behind the obstacle mainly large bubbles are found
2. Phenomena in the jet beside the obstacle in the non-obstructed cross sectional area
   - Generated large bubbles are rejected into the jet beside by the obstacle
   - Near the jet margin large shear rates are found
     - fragmentation of large bubbles (not considered in the calculations)
     - small bubbles are rejected out of the jet (lift force)

Summary

- correct function of the inhomogeneous MUSIG model approach confirmed
- thoroughly understanding of the complex flow situation
- closure models for bubble forces in agreement with experiment
- most weak point: Models for simulation of bubble coalescence and bubble break-up
  - With the actual implemented models tuning coefficients are necessary:
    - air/water in vertical tube: $F_B = 0.25$; $F_C = 0.05$
    - steam/water in vertical tube: $F_B = 0.02$; $F_C = 0.05$
    - complex flow: tuning factors depend on flow situation
- Further work is considered for future investigations