Validation of the CFX inhomogeneous MUSIG model

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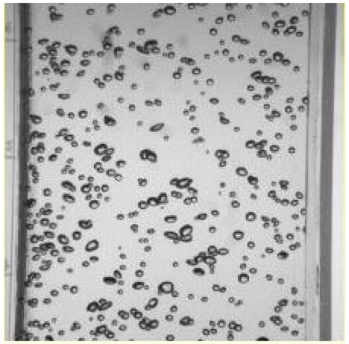
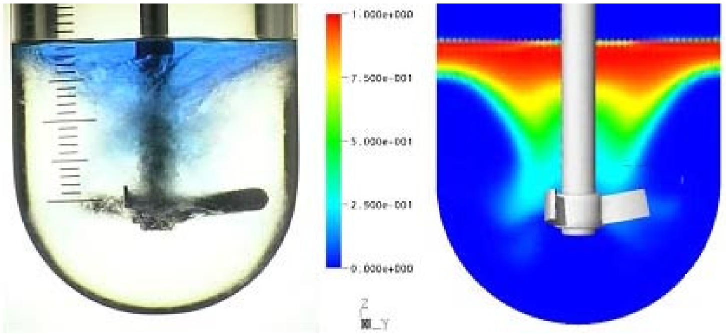
Multiphase Flow: Simulation, Experiment and Application
FZ-Rossendorf 26.-29. June 2006

Two phase flow

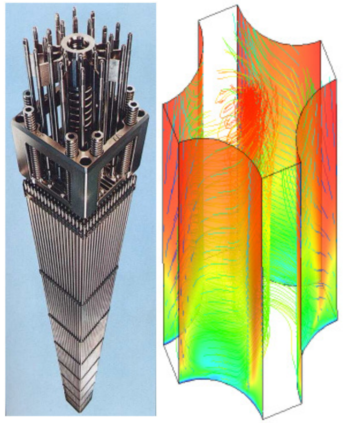
Examples for two phase flow



Bubble columns



Stirred vessel reactors



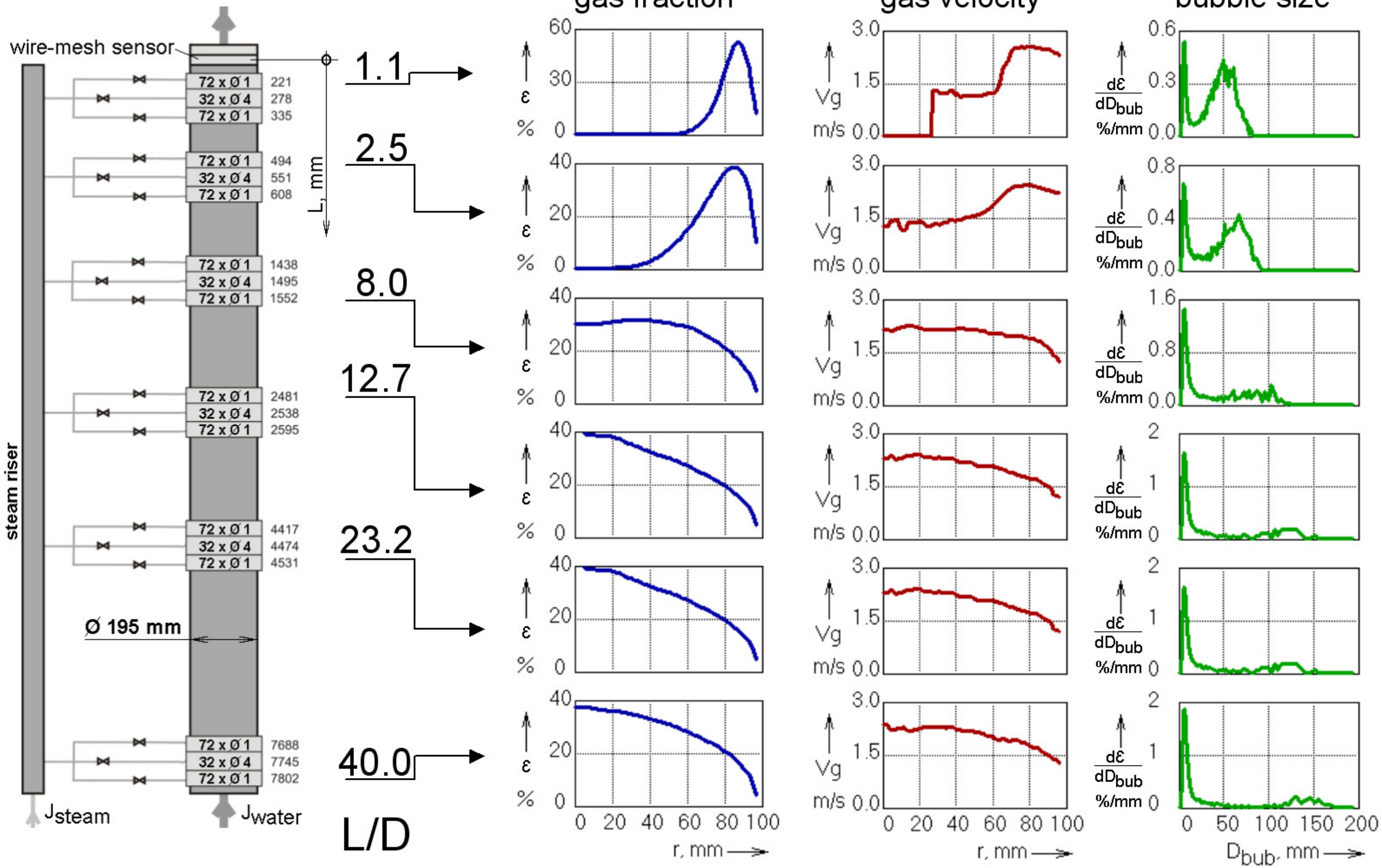
Hot channels
in nuclear reactors

Goal: Qualification of CFD-Codes modelling two phase flow

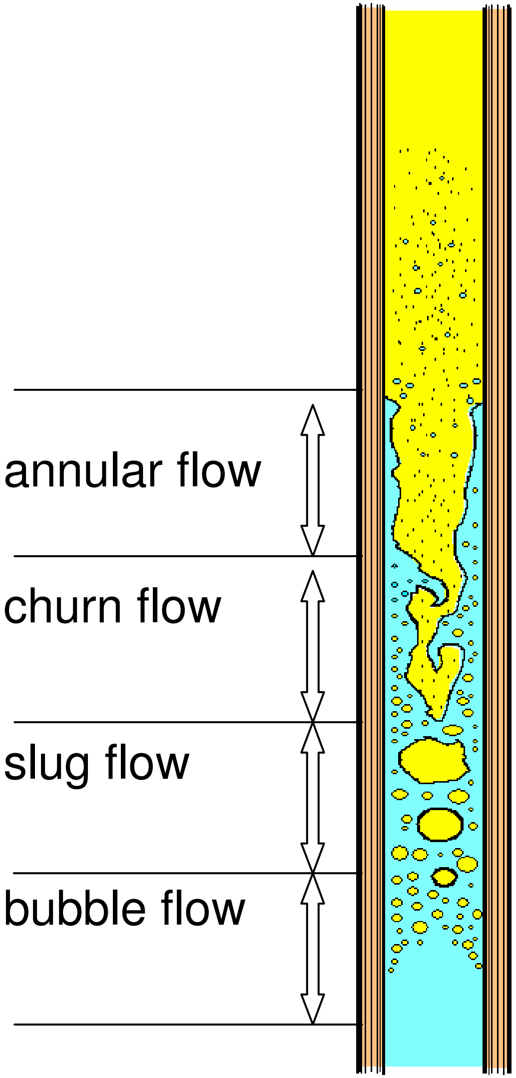
Procedure:

- Experiments at TOPFLOW using innovative measuring technique
- Model setup for momentum-, heat-, and mass transfer in the two phase flow
- Implementation into CFX (ANSYS-CFX®)
- Code validation using TOPFLOW and other experiments

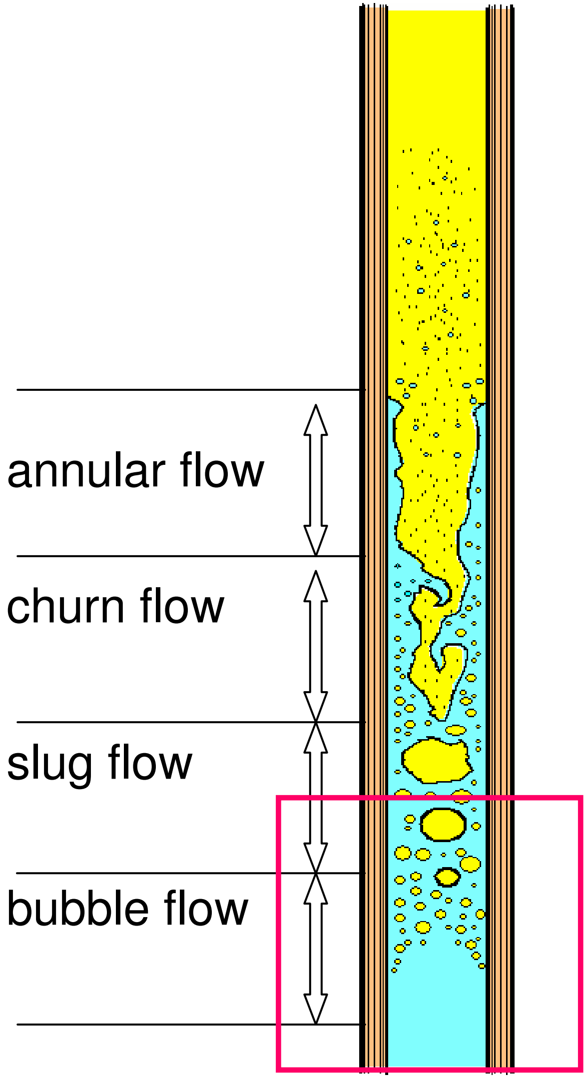
Experimental basis: TOPFLOW



Flow pattern in a gas liquid flow increasing the gas volume fraction



Euler/Euler-Approach – at actual level of application limitation to low gas volume fractions



Bubble forces

No simulation of single bubbles (DNS), but of average forces dependent on the local flow field

- **Drag**: flow resistance in flow direction
  - determines bubble rising velocity (vertical)
  - but also essential for velocity of bubble redistribution in lateral direction

- **Nondrag**: Forces perpendicular to the flow direction
  - influence on the flow pattern
  - determines the cross sectional distribution of the gaseous phase
  - Measuring of the cross sectional distribution → Validation of the model approaches

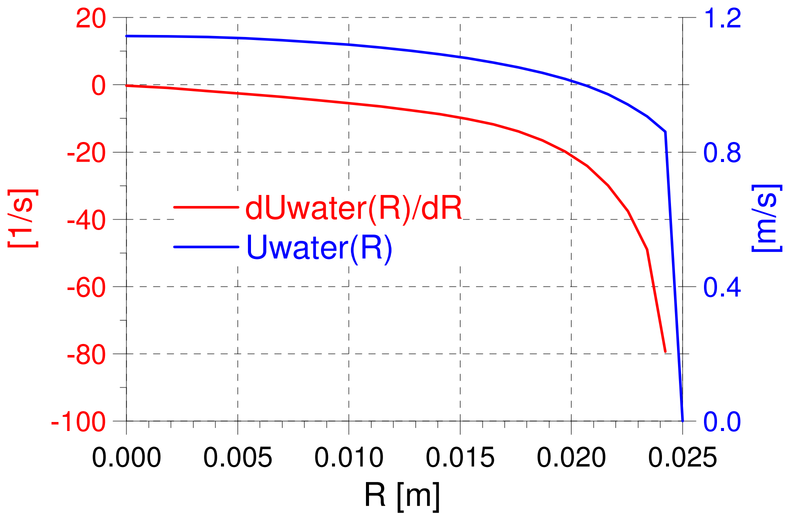
Non drag forces: Lift

$$F_{lift} = -C_{lift}\,\rho_W\,(\vec{U}_G - \vec{U}_W) \times rot\,\vec{U}_W$$

cylindrical co-ordinates:

$$F_{lift} = -C_{lift}\,\rho_W\,(U_G - U_W)\,\frac{dU_W}{dR}$$

→ With $C_{lift} > 0$ the bubbles are moved in the direction of negative ∇U_L



Tomiyama (1998):

- For air/water C_{lift} changes the sign for BD ca. 5.8 mm
- Experimental fitted

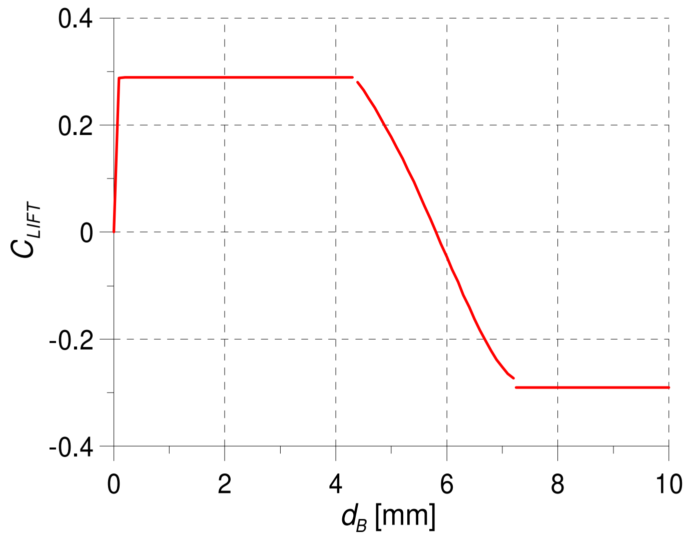
Non drag forces: Lift

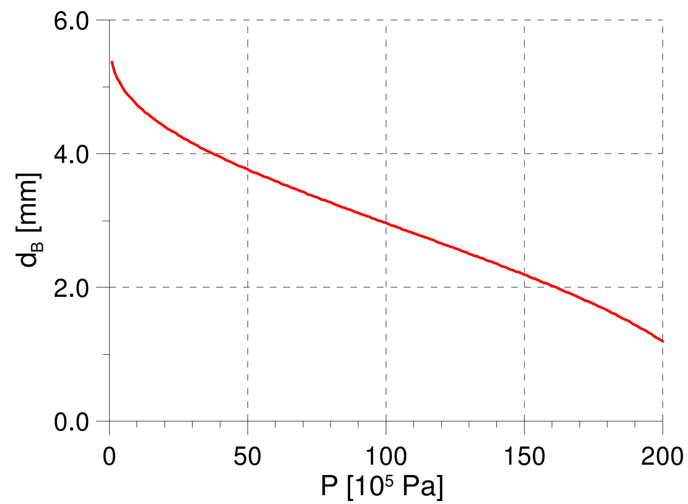
Tomiyama (1998):

- For **air/water** C_{LIFT} changes the sign for d_B ca. 5.8 mm
- Experimental fitted

Steam/Water-Flow:

- Correlation by Tomiyama
- Experiments at TOPFLOW
  → With higher pressure smaller critical d_B





Non drag forces: Wall Force

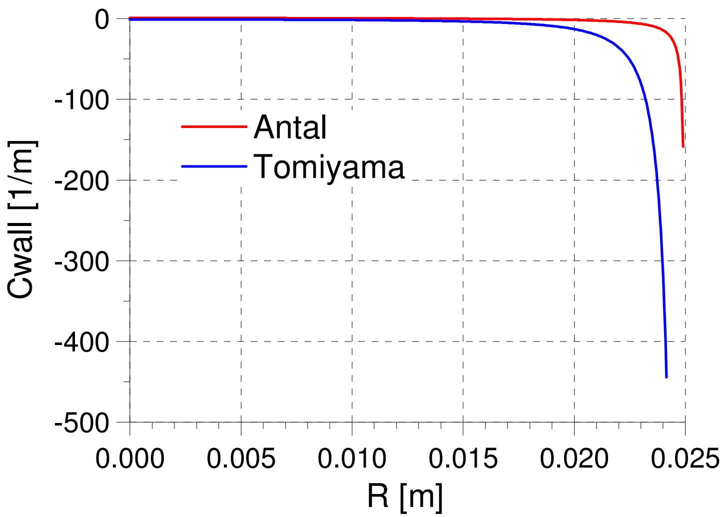
$$F_{wall} = -\rho_W \left| U_G - U_W \right|^2 \vec{n} C_{wall}$$

- Antal (1991):

$$C_{wall} = \min\left\{0, -\frac{C_{W1}}{d_B} - \frac{C_{W2}}{y_{wall}}\right\}$$

- Tomiyama (1998):

$$C_{wall} = C_W \frac{d_B}{2} \left(\frac{1}{y_W^2} - \frac{1}{(D - y_{wall})^2} \right)$$



→ Bubbles are pushed away from the wall

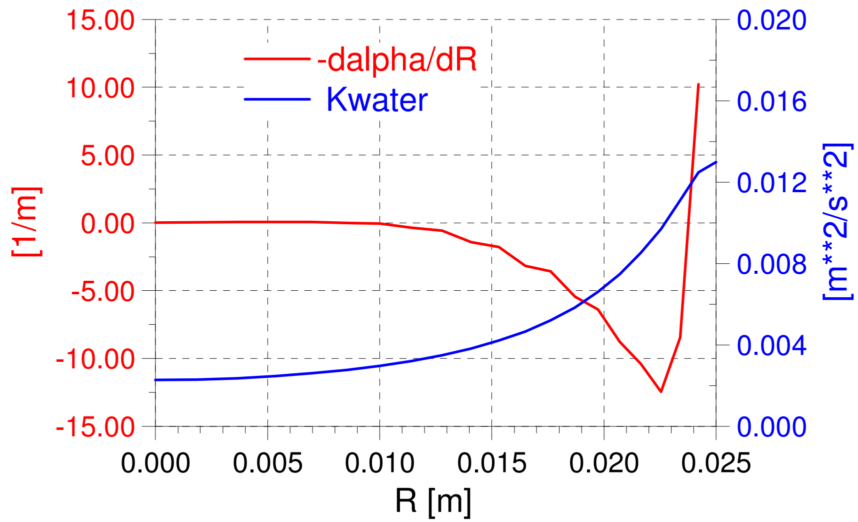
→ F_{wall} acts only near the wall

Non drag forces: Turbulent Dispersion

- Lopez de Bertodano:

$$F_{disp} = -C_{disp}\rho_W K_W \nabla\alpha$$

→ Equalization of the volume fraction distribution

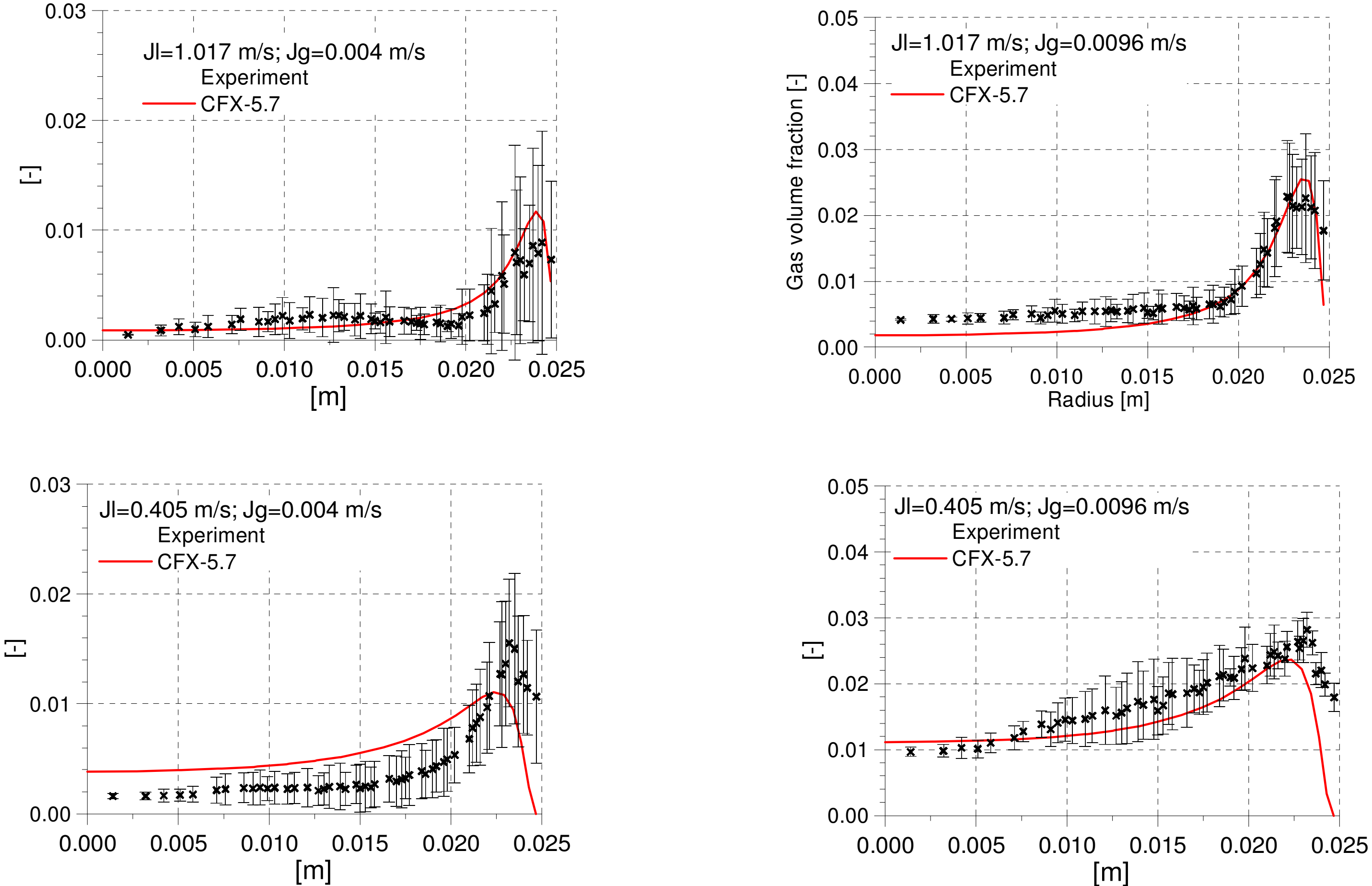


- Favre average of the interfacial drag forces

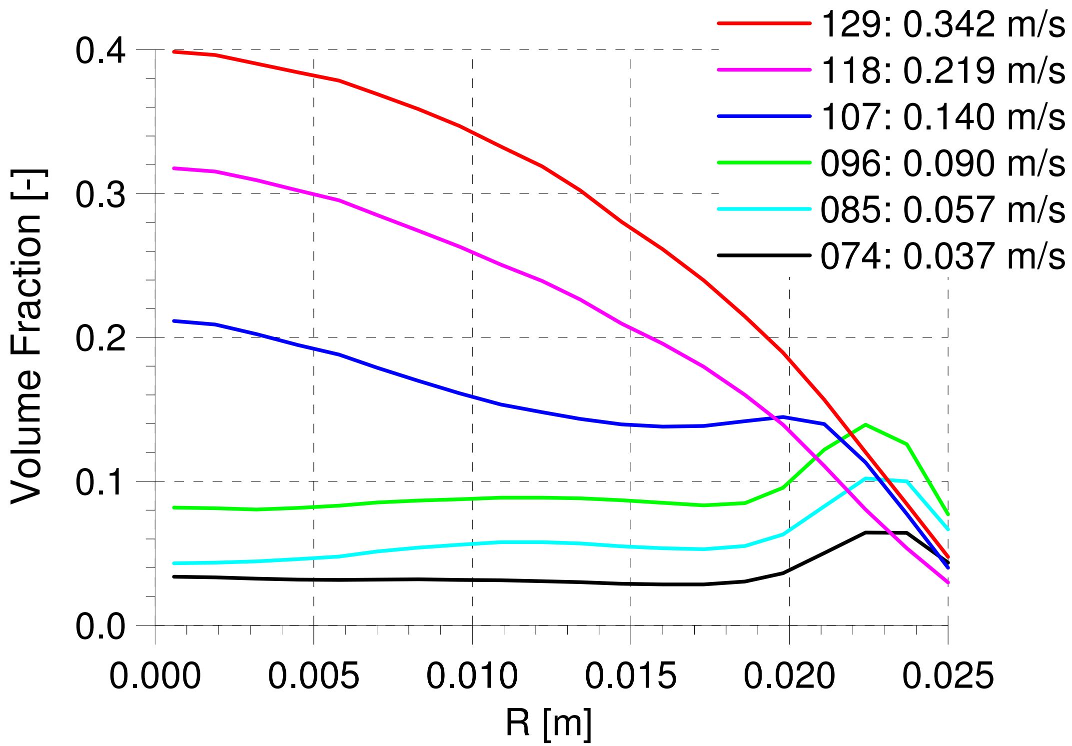
$$F_{disp} = -\frac{3C_D \nu_W}{4d_B \Pr}\rho_W \left|U_G - U_W\right| \nabla\alpha$$

Validation of non drag forces (examples for bubbly flow)

monodispersed bubble size distribution



Measured Volume fraction profile with enhancement of the superficial gas velocity

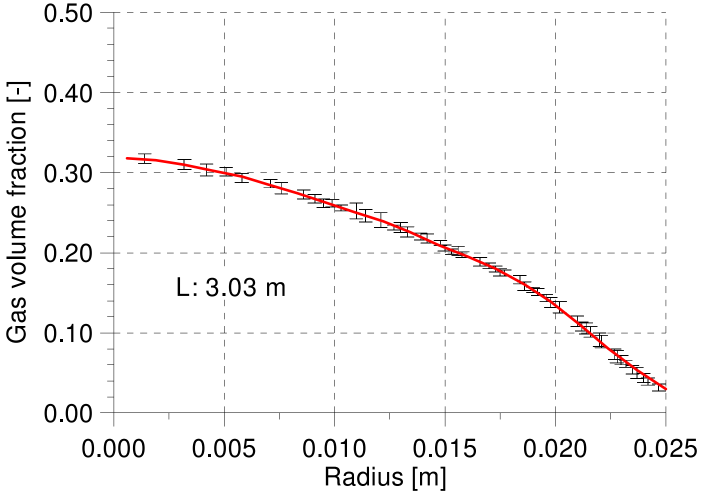


- sign change of the lift force

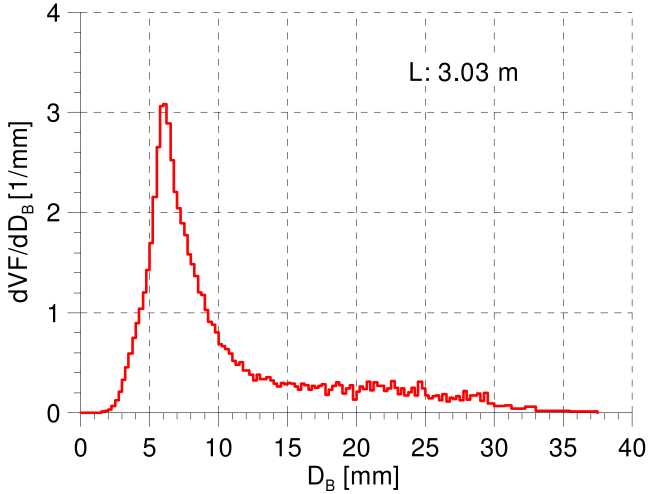
→ consideration of different dispersed phases necessary

Measurements: FZR118: J_l = 1.017 m/s; J_g = 0.2194 m/s

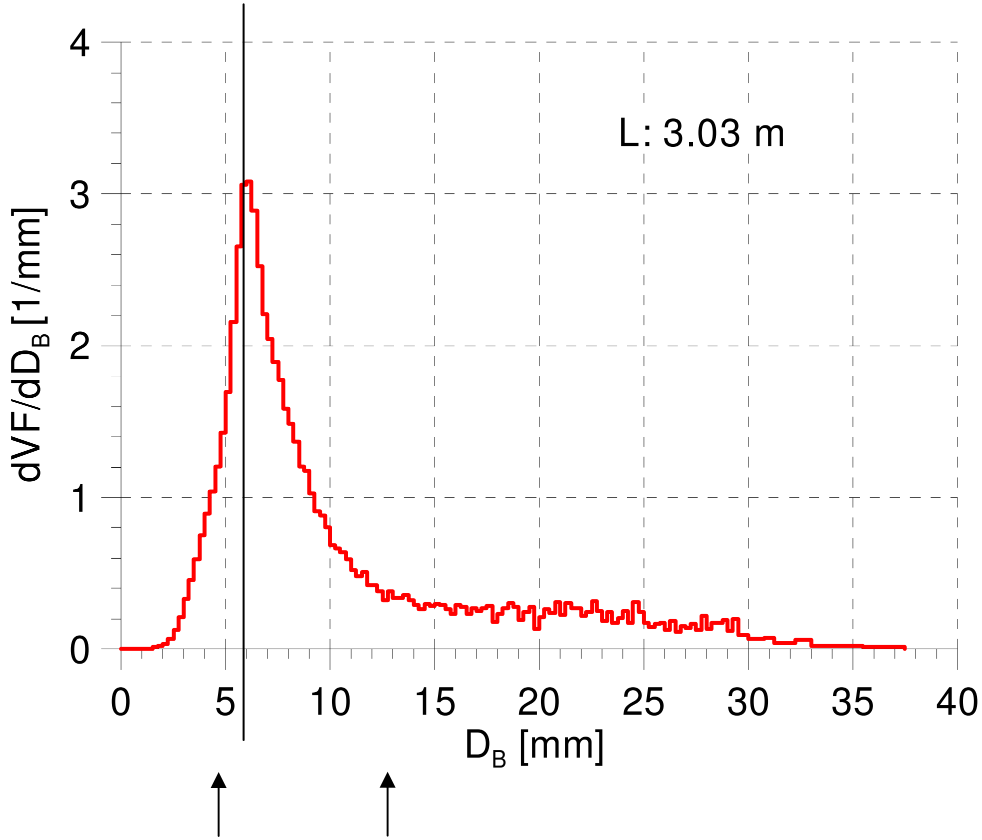
Radial gas fraction profile



Bubble size distribution



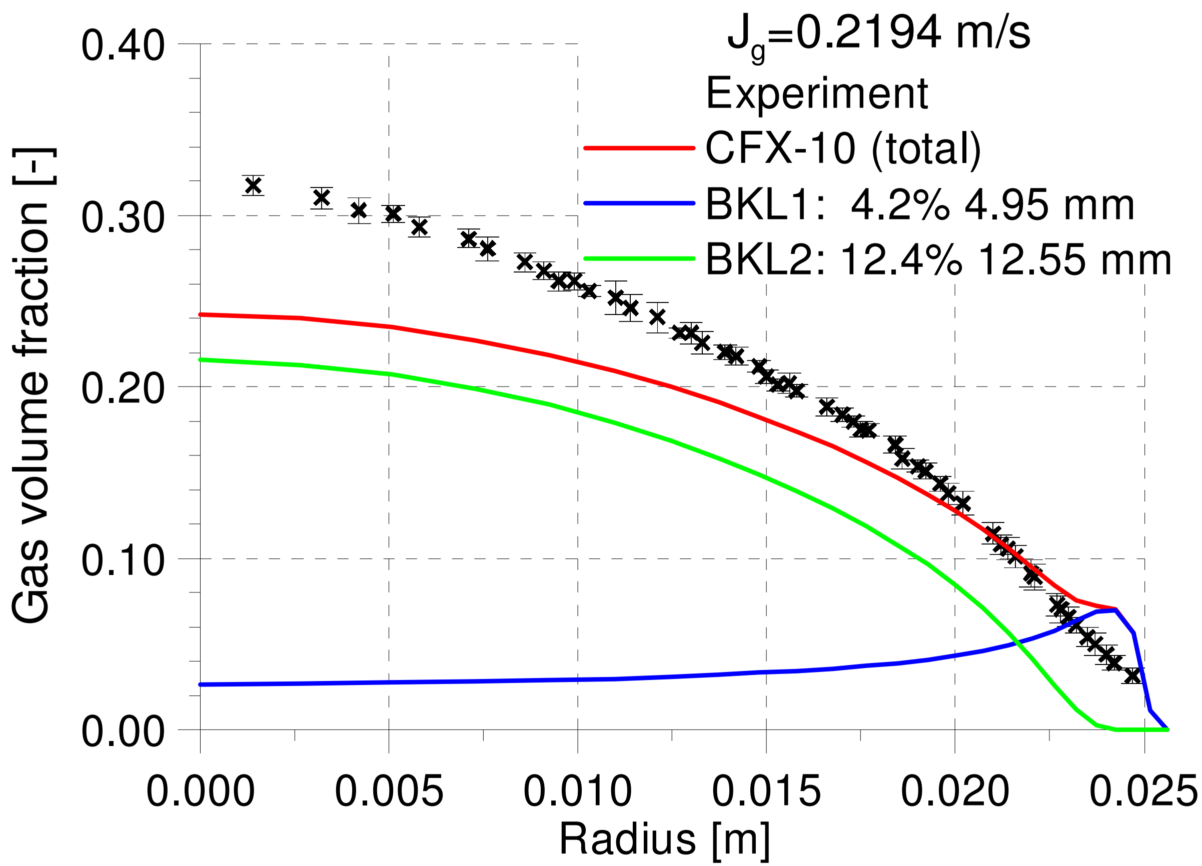
Simulation of several dispersed gas phases



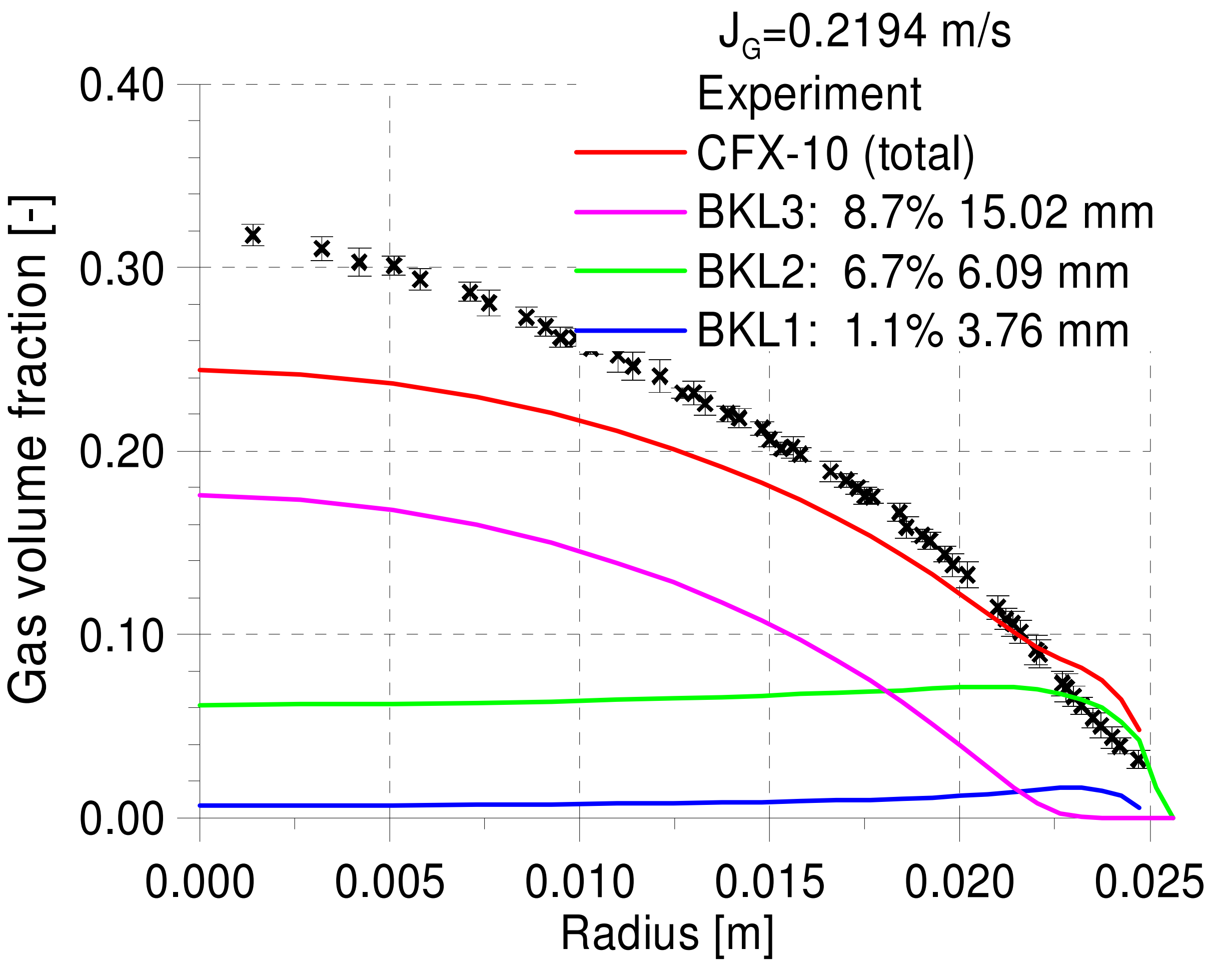
BKL1:
4.185%
4.95 mm

BKL2
12.36%
12.55 mm

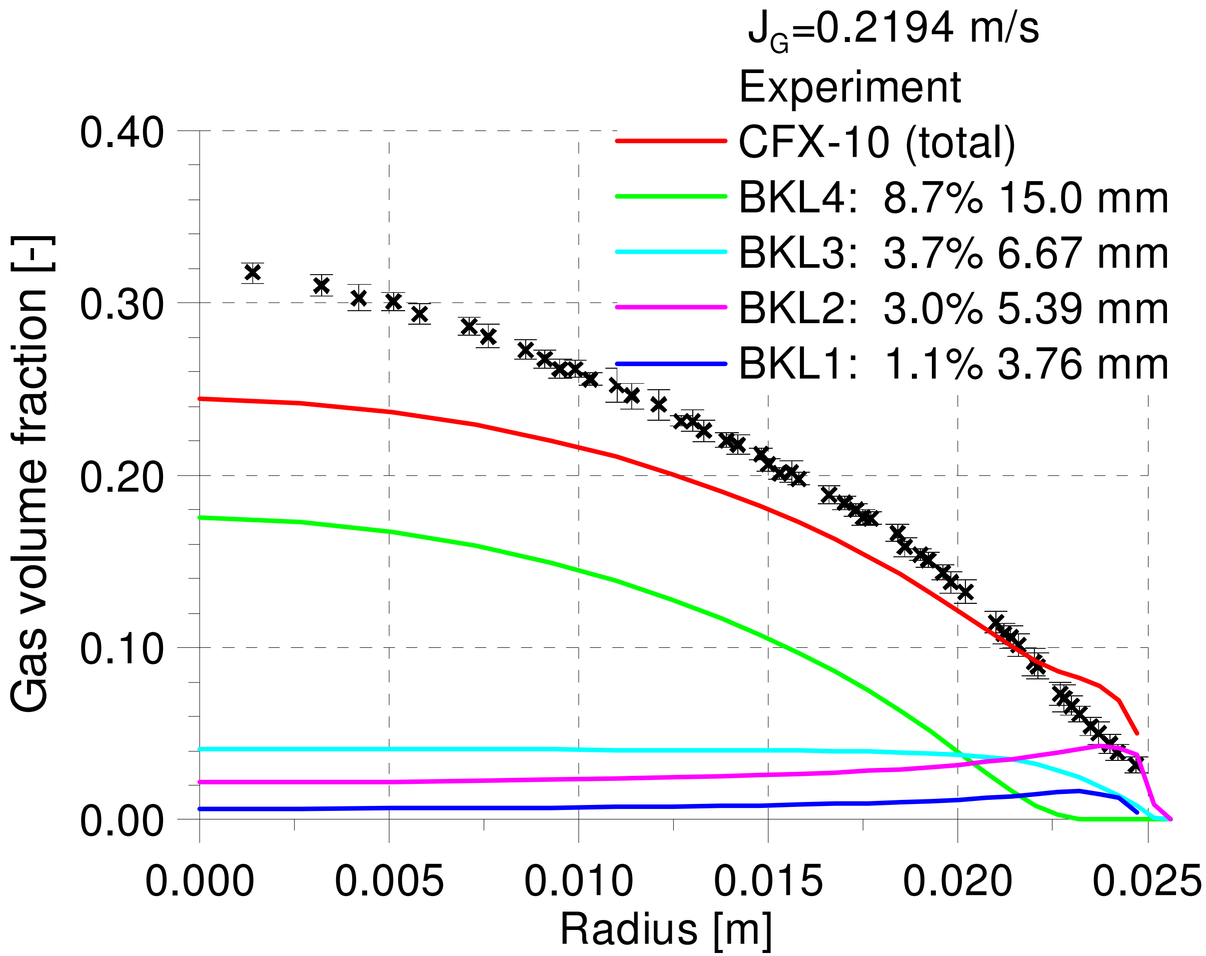
2 Bubble size classes



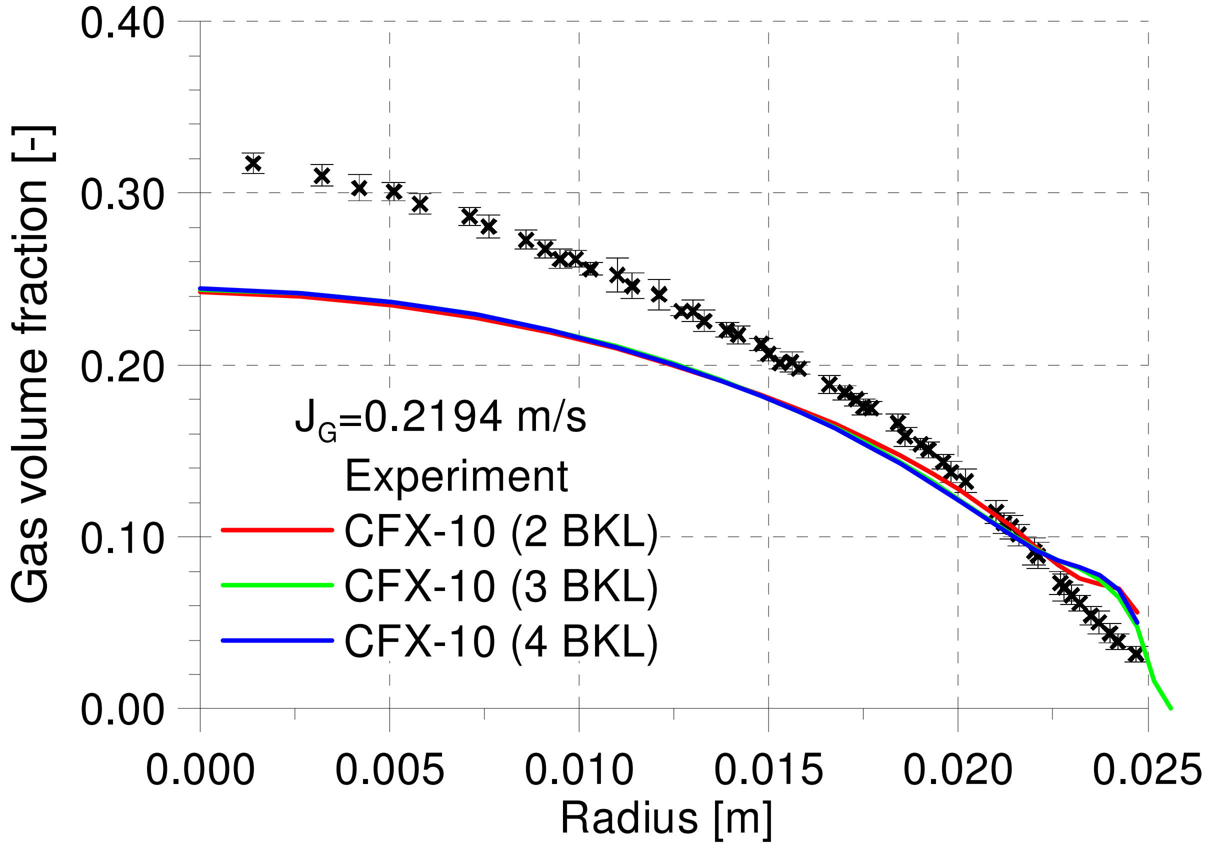
3 Bubble size classes



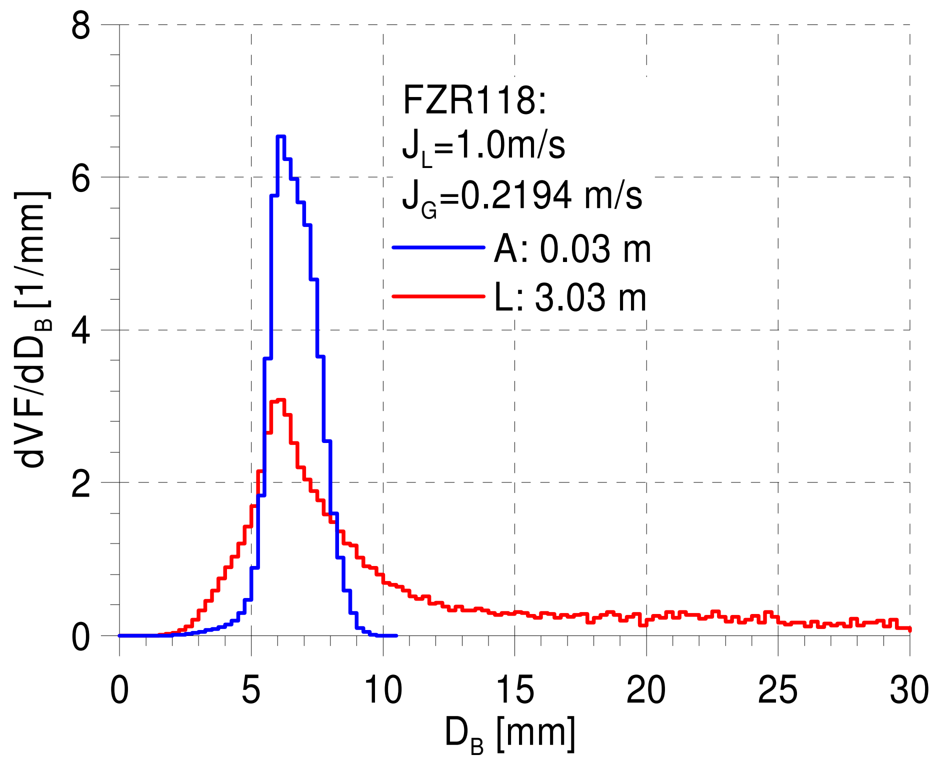
4 Bubble size classes



How many classes are necessary?

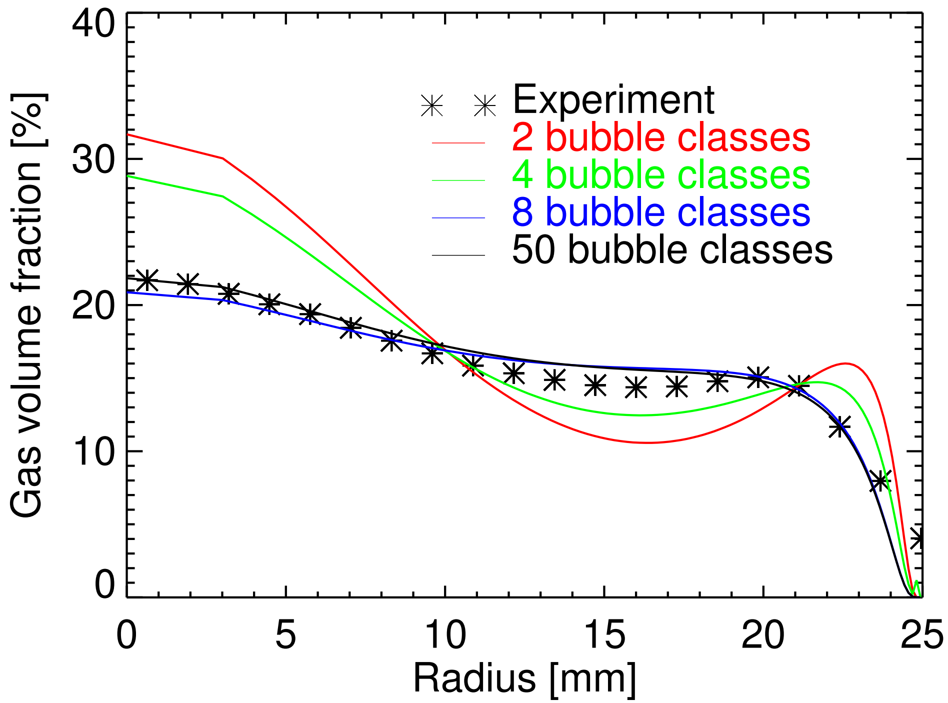


Measured bubble size distribution at different distances from gas injection



- Consideration of bubble coalescence and bubble fragmentation necessary

Simulation only the radial profile of the flow in the vertical tube



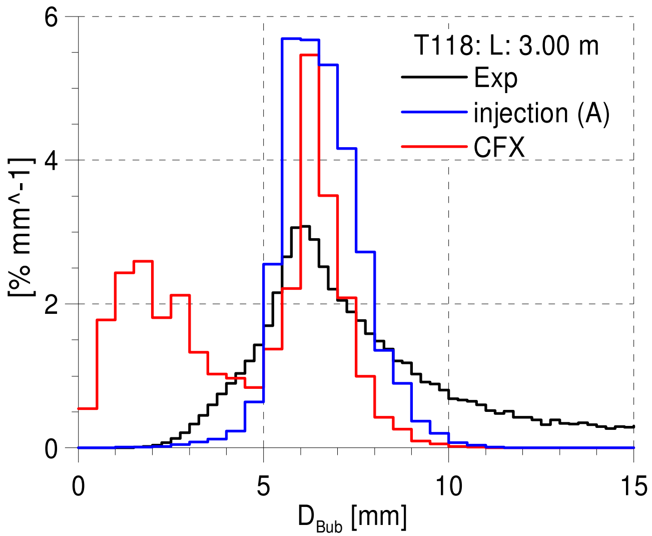
→Decades of bubble size classes would be necessary
→strong increasing numerical effort

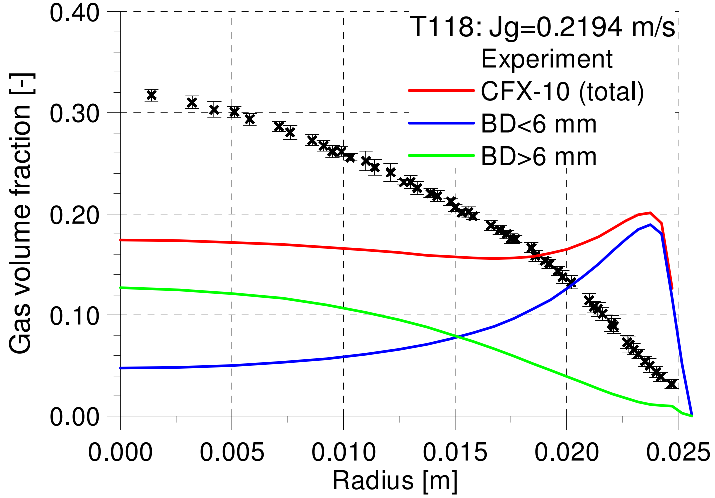
Concept for improving of the MUSIG model

Fluid	Phases	MUSIG groups
Gas	3	n
		...
		4
		3
	2	2
		1
Liquid	1	

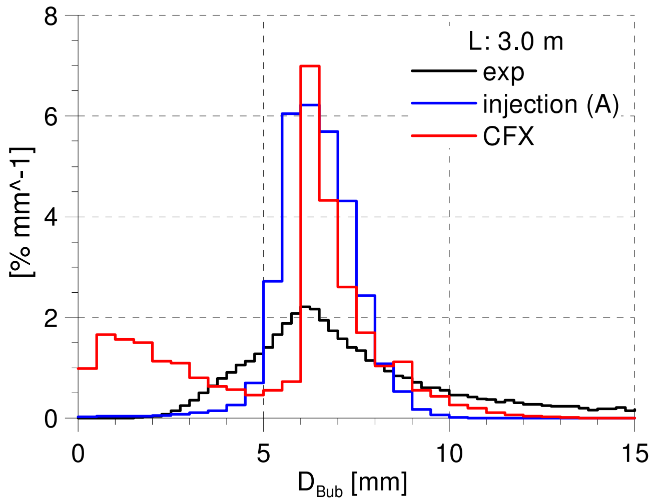
- The momentum equation are solved for at least two gas phases → description of the radial separation of small and large bubbles
- Bubble coalescence and break-up over all MUSIG groups

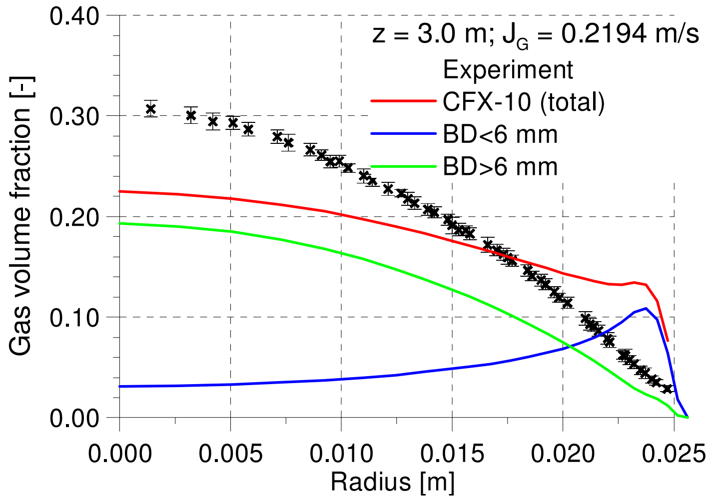
FZR-118: J_L=1.0 m/s, J_G=0.2194 m/s
2 dispersed Phases, 34 Musig-Groups
FB = 1; FC=0.05





FZR-118: J_L=1.0 m/s, J_G=0.2194 m/s
2 dispersed Phases, 34 Musig-Groups
FB = 1; FC=0.5





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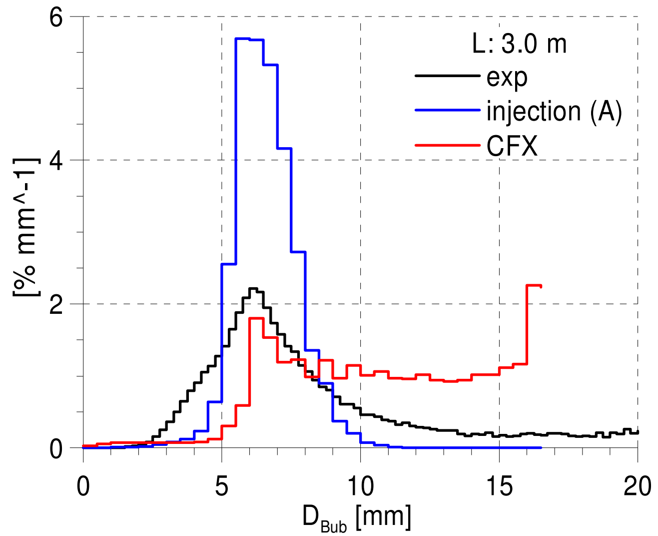
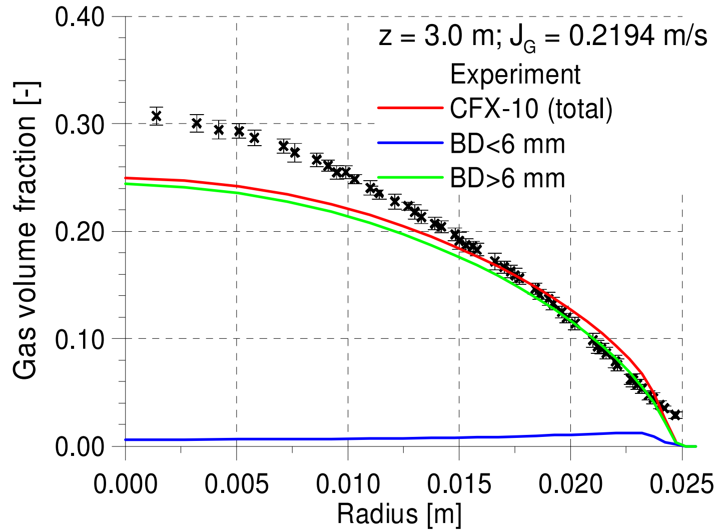
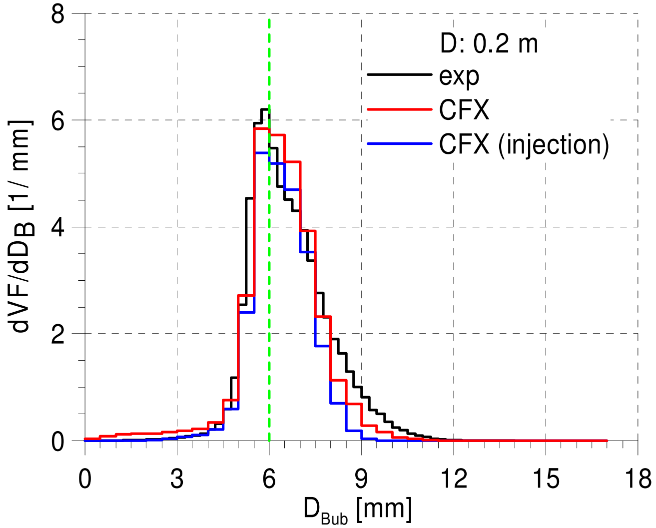
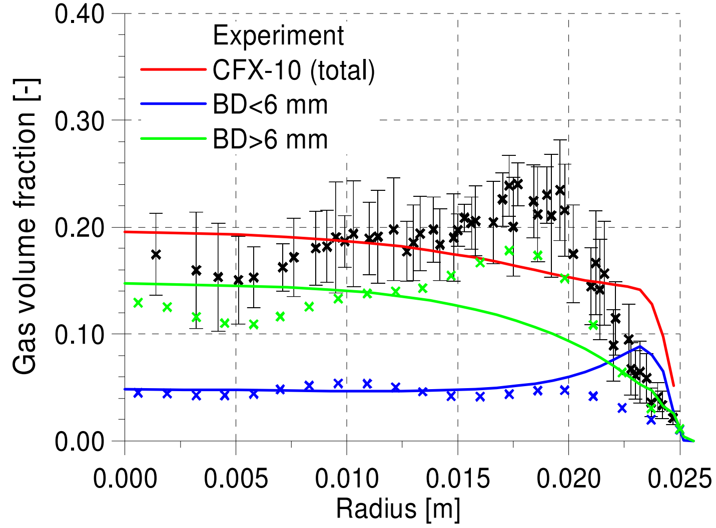
2 dispersed Phases, 34 Musig-Groups
FB=0.05; FC=0.5





FZR-118: J_L=1.0 m/s, J_G=0.2194 m/s
2 dispersed Phases, 34 Musig-Groups
FB = 0.25; FC = 0.05





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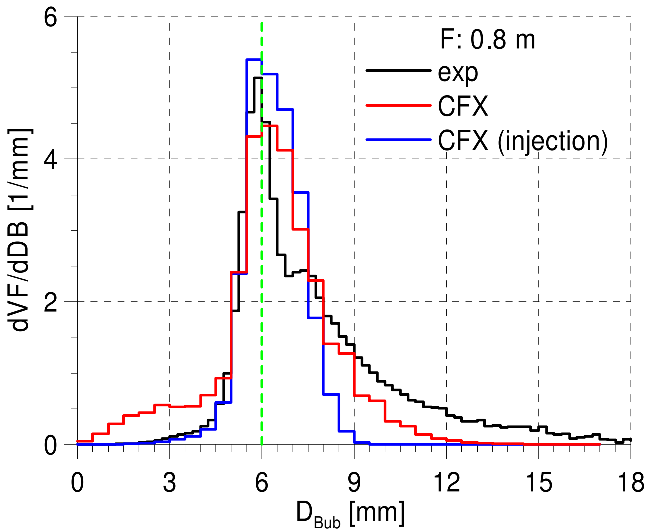

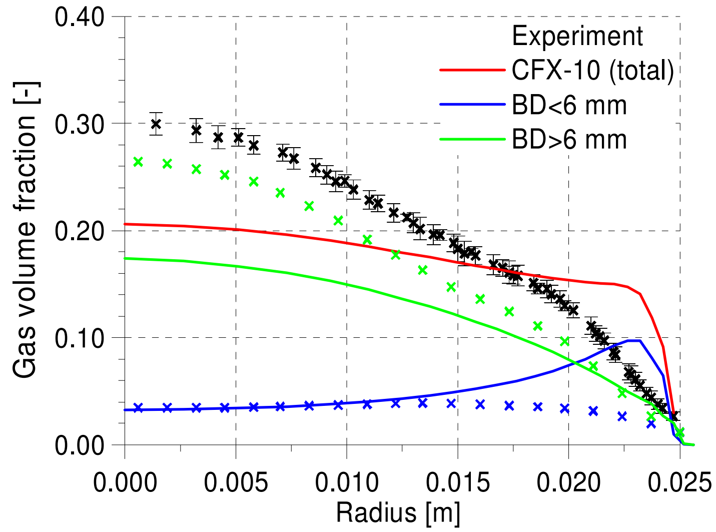

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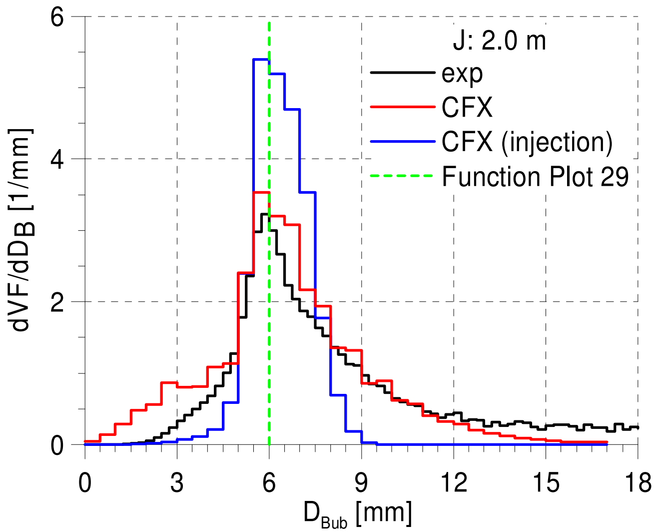

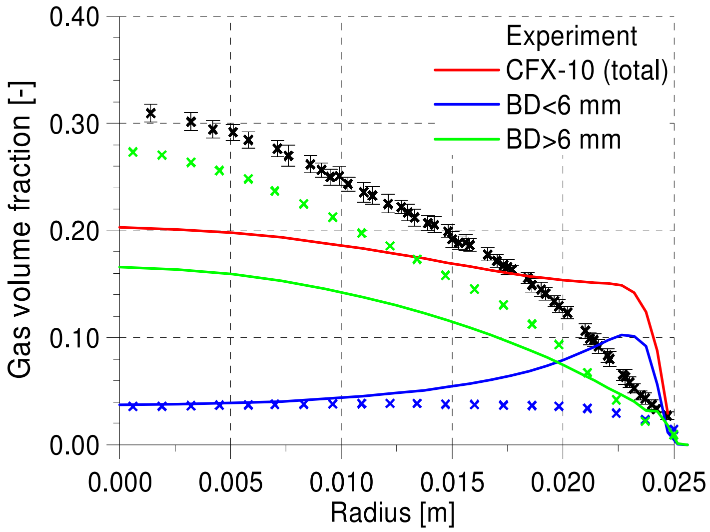

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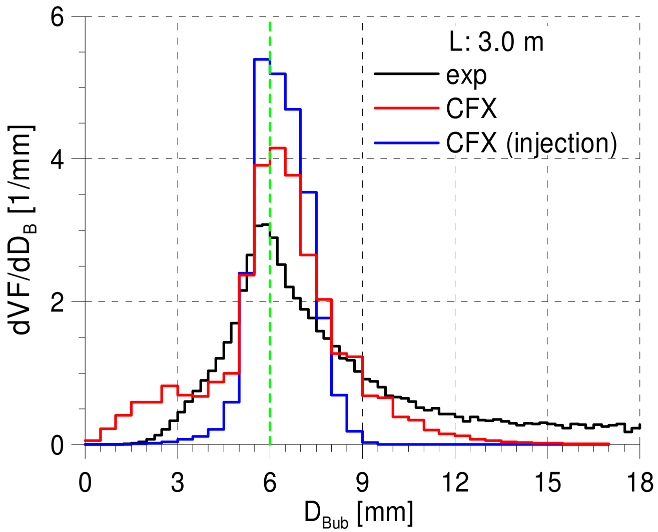
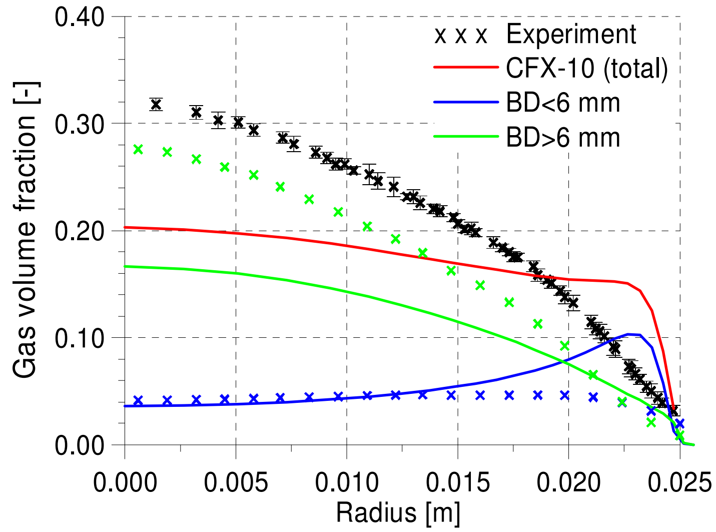
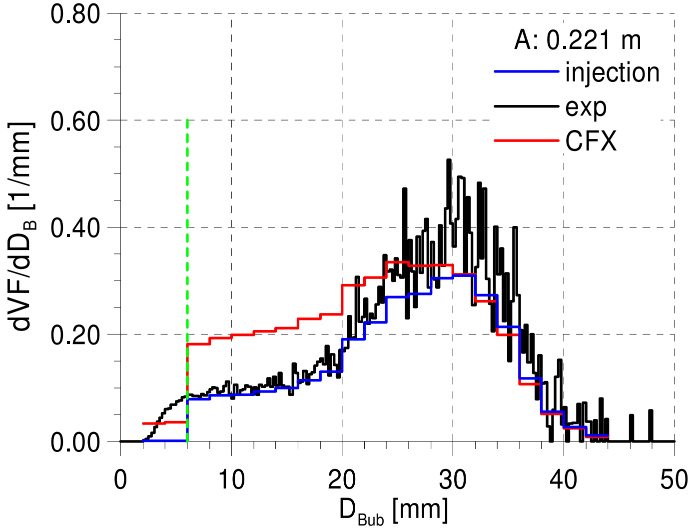
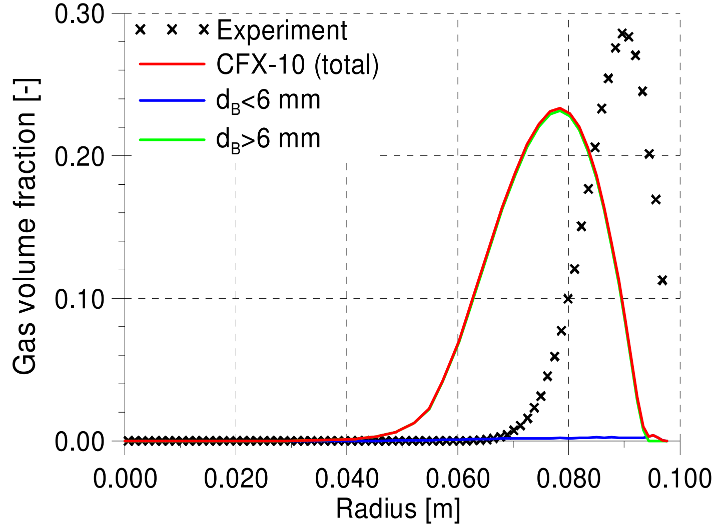




TOPFLOW: J_L=1.0 m/s, J_G=0.14 m/s
2 dispersed Phases, 21 Musig-Groups
FB = 0.25; FC = 0.05





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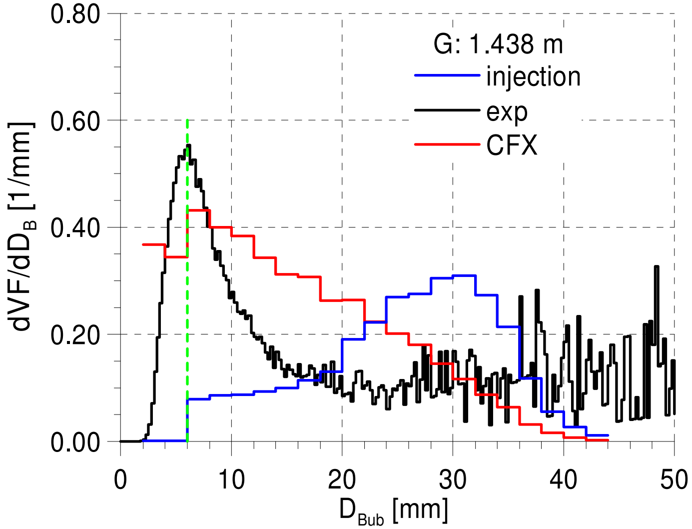

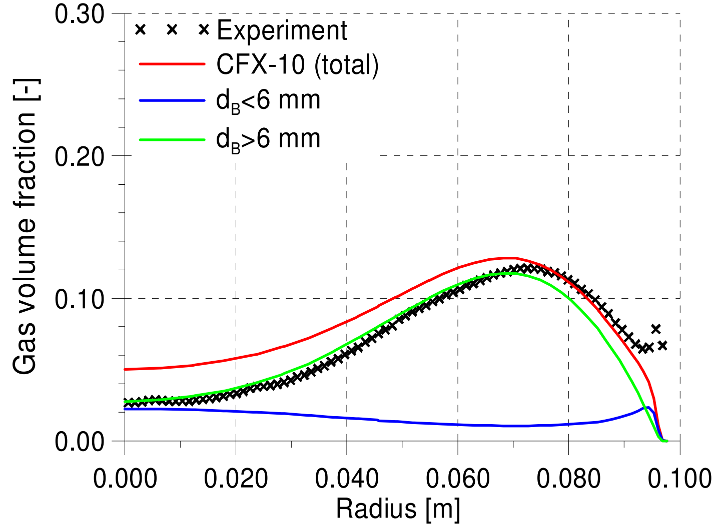

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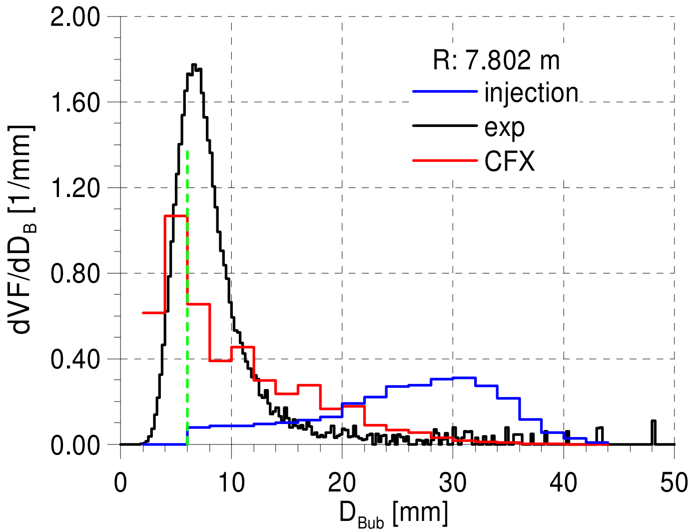
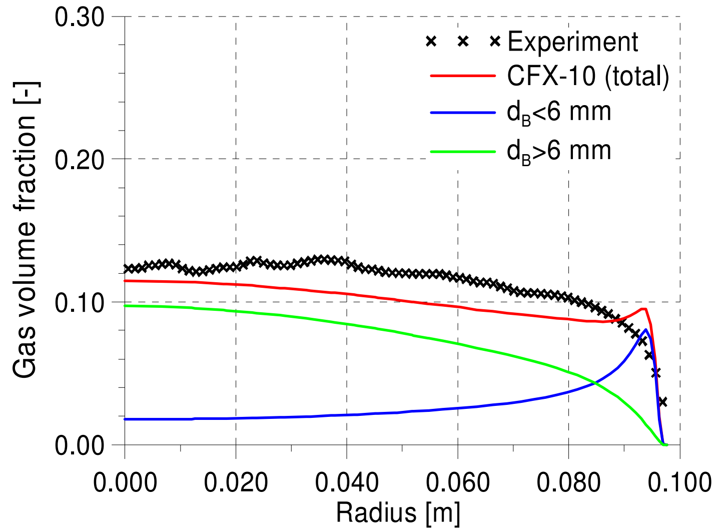
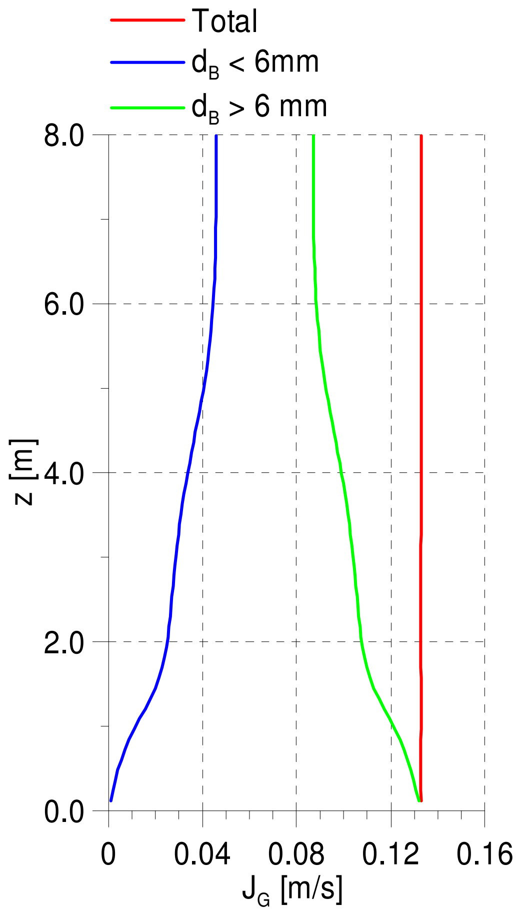
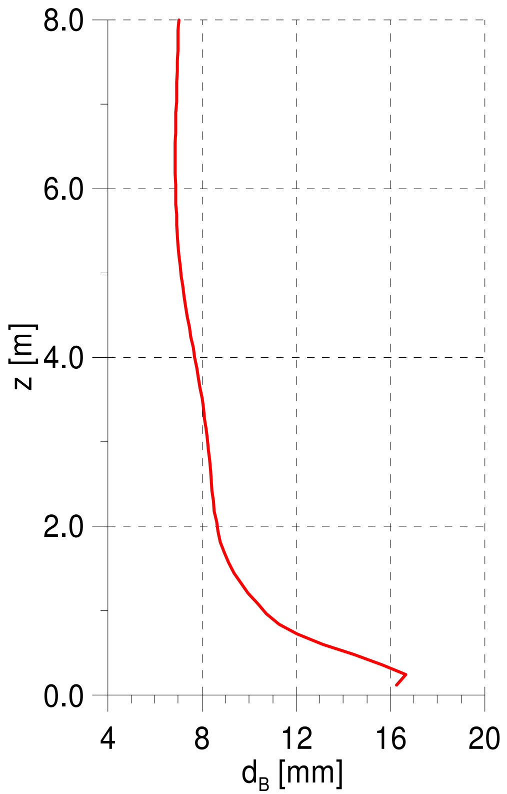




TOPFLOW: J_L=1.0 m/s, J_G=0.14 m/s
2 disperse Phasen, 21 Musig-Gruppen



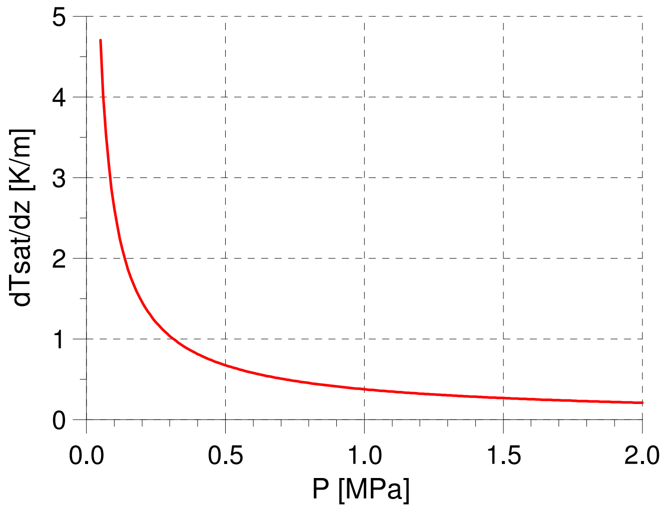
gas superficial velocity



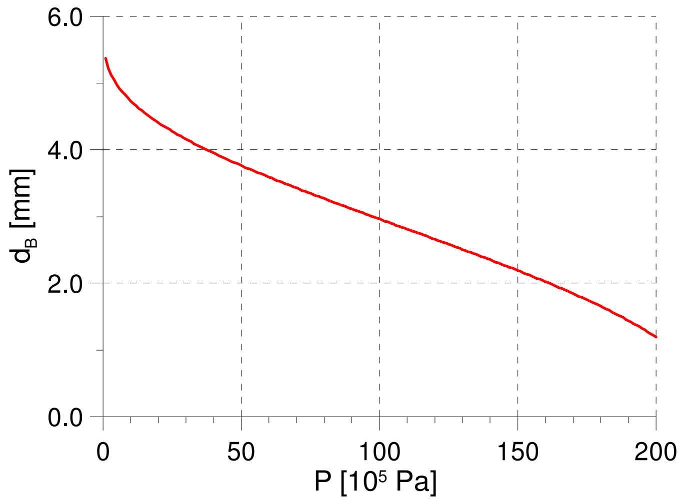
mean sauter diameter

Steam water flow at saturation conditions → limited mass transfer

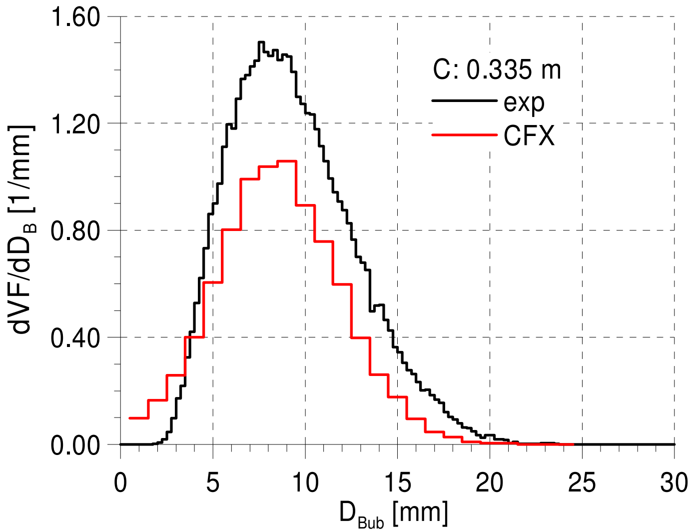
hydrostatic height gradient of T_{sat} at different pressure

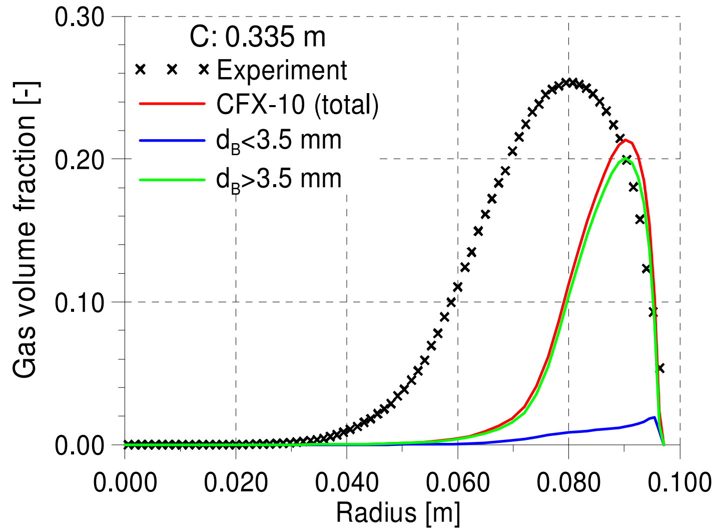


dependence of the critical bubble size of C_{lift} sign change on the pressure



TOPFLOW, Steam Water at 6.5 MPa: J_L=1.0 m/s, J_G=0.14 m/s
2 disperse phases, 25 Musig-Groups
FB = 0.02; FC = 0.05





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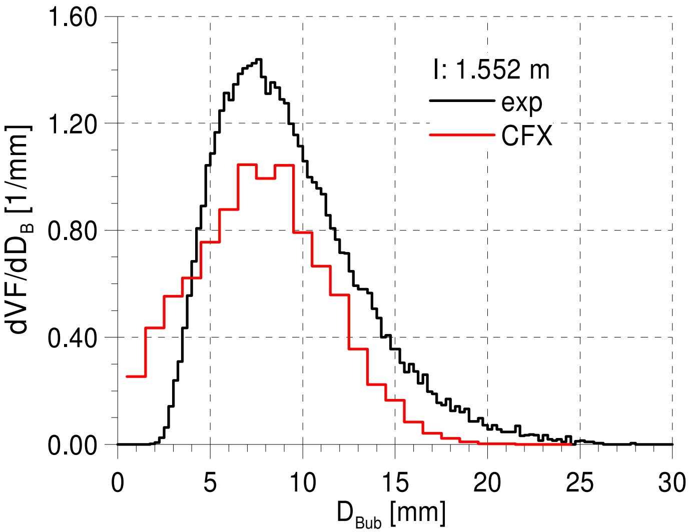

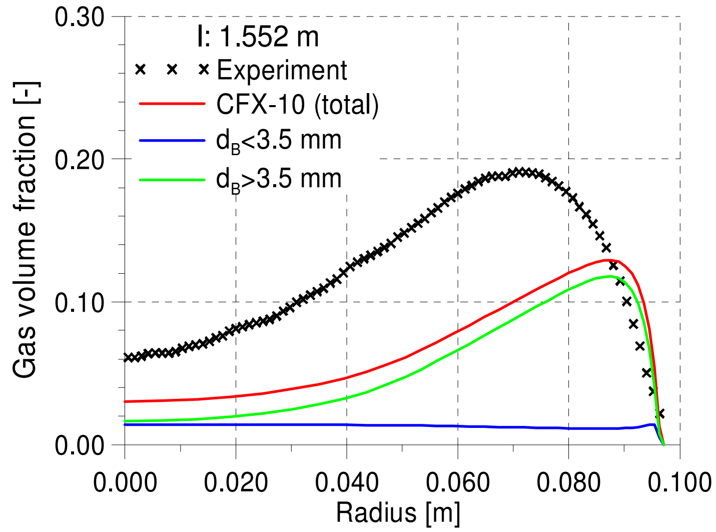

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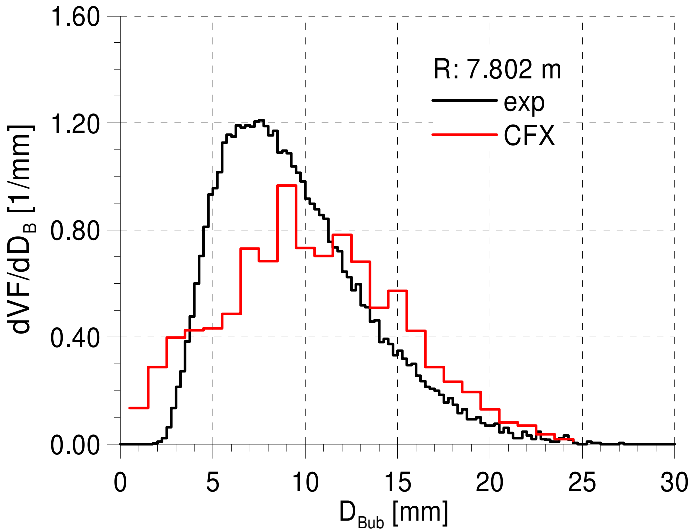

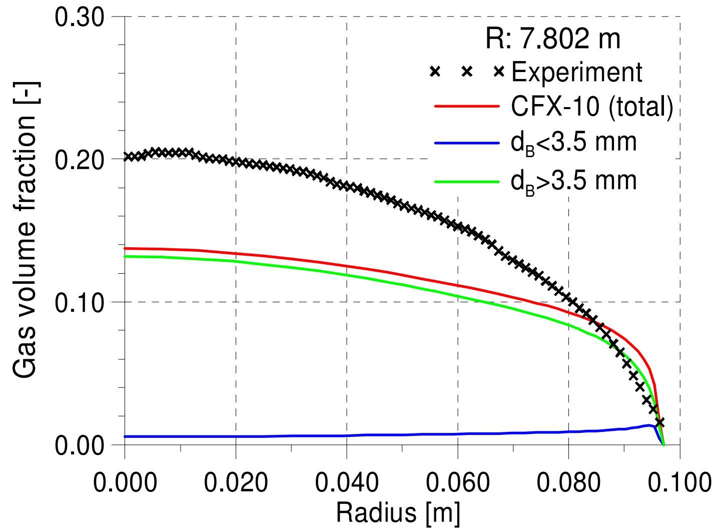

Summary

- Correct function of the heterogeneous MUSIG model and ability of the approach to describe bubbly flow with higher gas volume fraction confirmed
- Most weak point of the approach: Modeling of coalescence and fragmentation

→ Further work necessary