Coupling of a population balance approach with the RPI wall boiling model. Part I: Model formulation & homogeneous MUSIG-RPI validation.

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Outline

- Motivation
- Coupling between wall boiling modelling and population balance method (MUSIG)
  - Mathematical formulation
- Validation study (homogeneous MUSIG)
  - Discretization independence analysis
    - Spatial
    - Bubble class
  - Comparison to results obtained with Kurul & Podowski correlation
- Conclusions & Outlook

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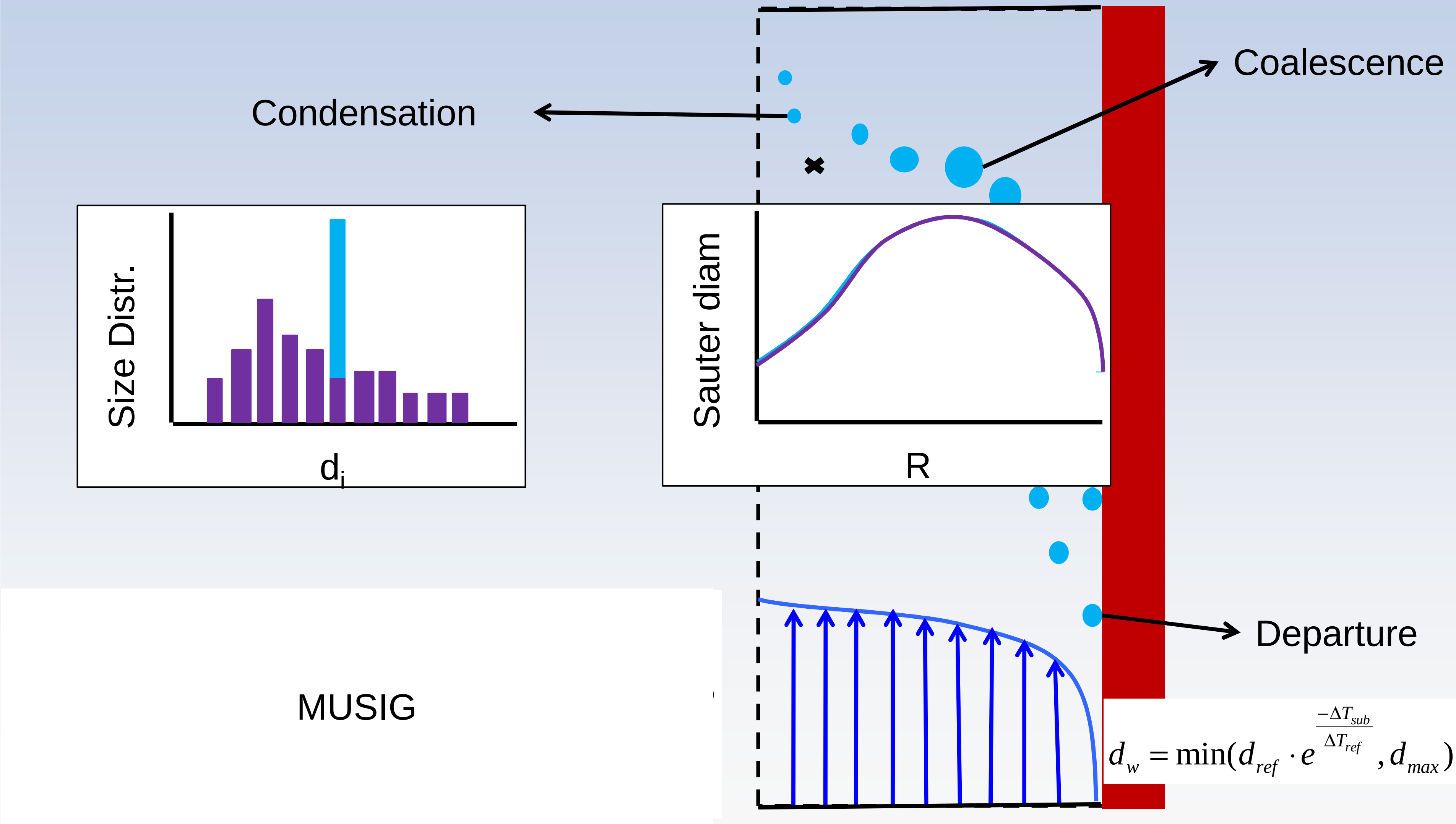
Motivation



$$d_w = \min(d_{ref} \cdot e^{\frac{-\Delta T_{sub}}{\Delta T_{ref}}}, d_{max})$$

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Modelling of Sub-cooled Boiling at a Heated Wall

The RPI Wall Boiling Model:

- Constant pressure → given T_{sat}
- Overall heat flux Q_w given
- Heat flux partitioning:

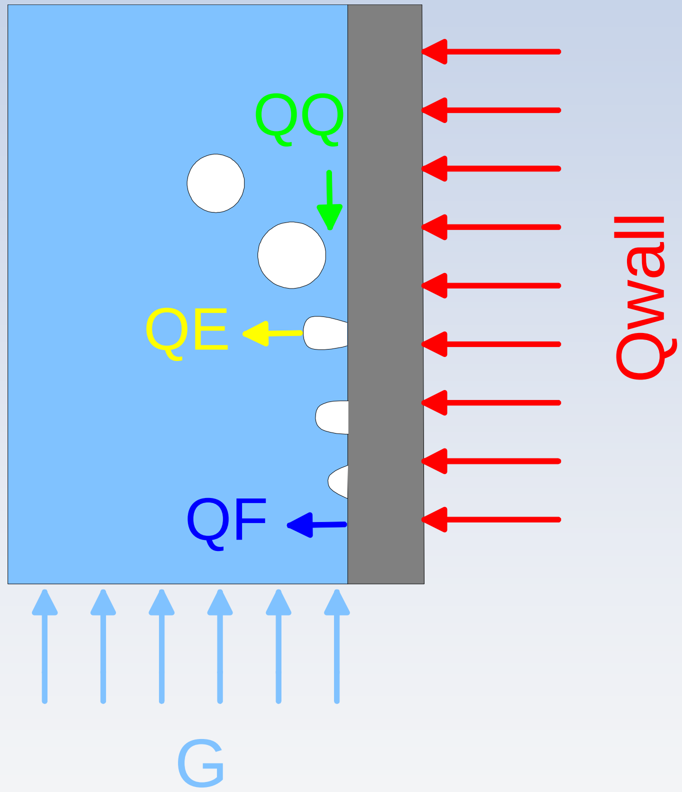
$$Q_w = Q_f + Q_e + Q_q$$

Q_f - single phase convection

Q_e - evaporation

Q_q - quenching

(departure of a bubble from the heated surface → cooling of the surface by fresh water)



Coupling Between Wall Boiling Modelling and Population Balance

- Size fraction equations derived from mass balance

Std. MUSIG

Mass transfer due to phase change extension

$$\frac{\partial}{\partial t}(\rho_i r_d f_i) + \frac{\partial}{\partial x^j}(\rho_i r_d U_i^j f_i) = S_{B_B} - S_{D_B} + S_{B_C} - S_{D_C} + S_i$$

- RPI wall heat partitioning

$$Q_{wall} = Q_{convl} + Q_{quench} + \dot{m}_{evap} h_{lg}$$

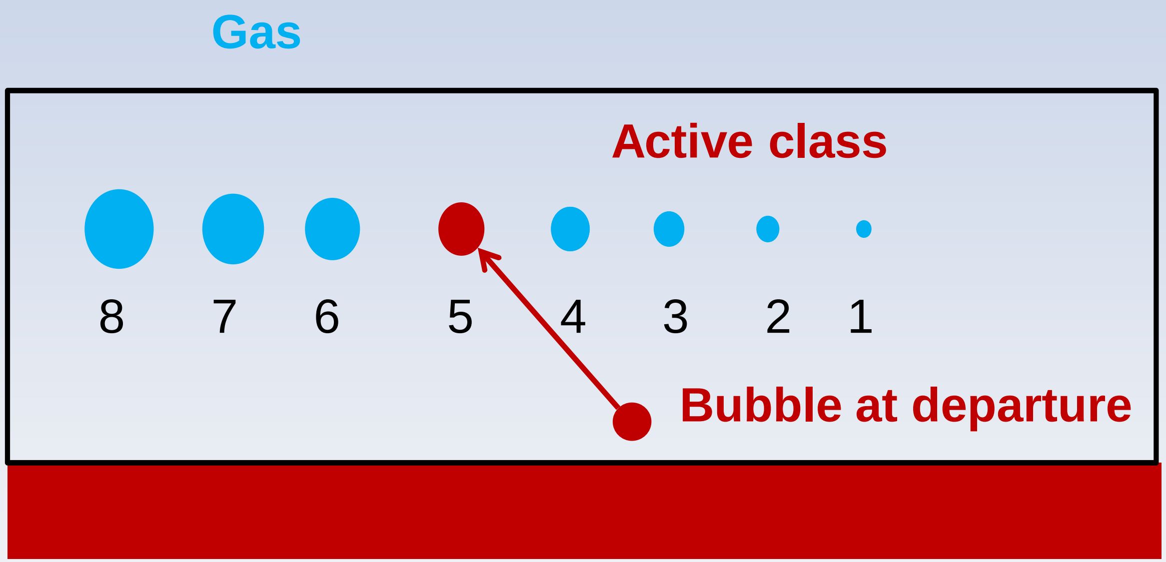
- At the heated walls one more source term is added to one size fract. Eq

$$S_W\left[kg/m^3 s\right] = \dot{m}_{evap}[kg/m^2 s]\frac{S[m^2]}{V[m^3]}$$

RPI: Evaporation rate

Coupling Between Wall Boiling Modelling and Population Balance

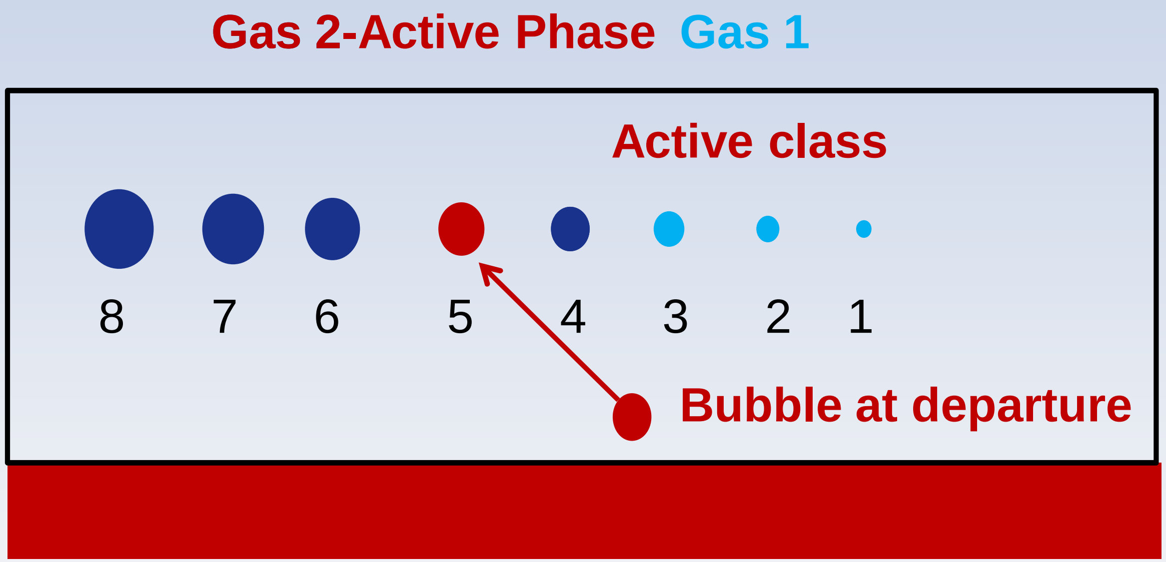
- Homogeneous MUSIG:



- $\dot{m}_{evap}$ → Size fraction class 5
- $\dot{m}_{evap}$ → Mass conservation Gas
- Derived Source Terms → Momentum Gas

Coupling Between Wall Boiling Modelling and Population Balance

- Inhomogeneous MUSIG:



- $\dot{m}_{evap}$ → Size fraction class 5
- $\dot{m}_{evap}$ → Mass conservation Gas 2
- Derived Source Terms → Momentum Gas 2

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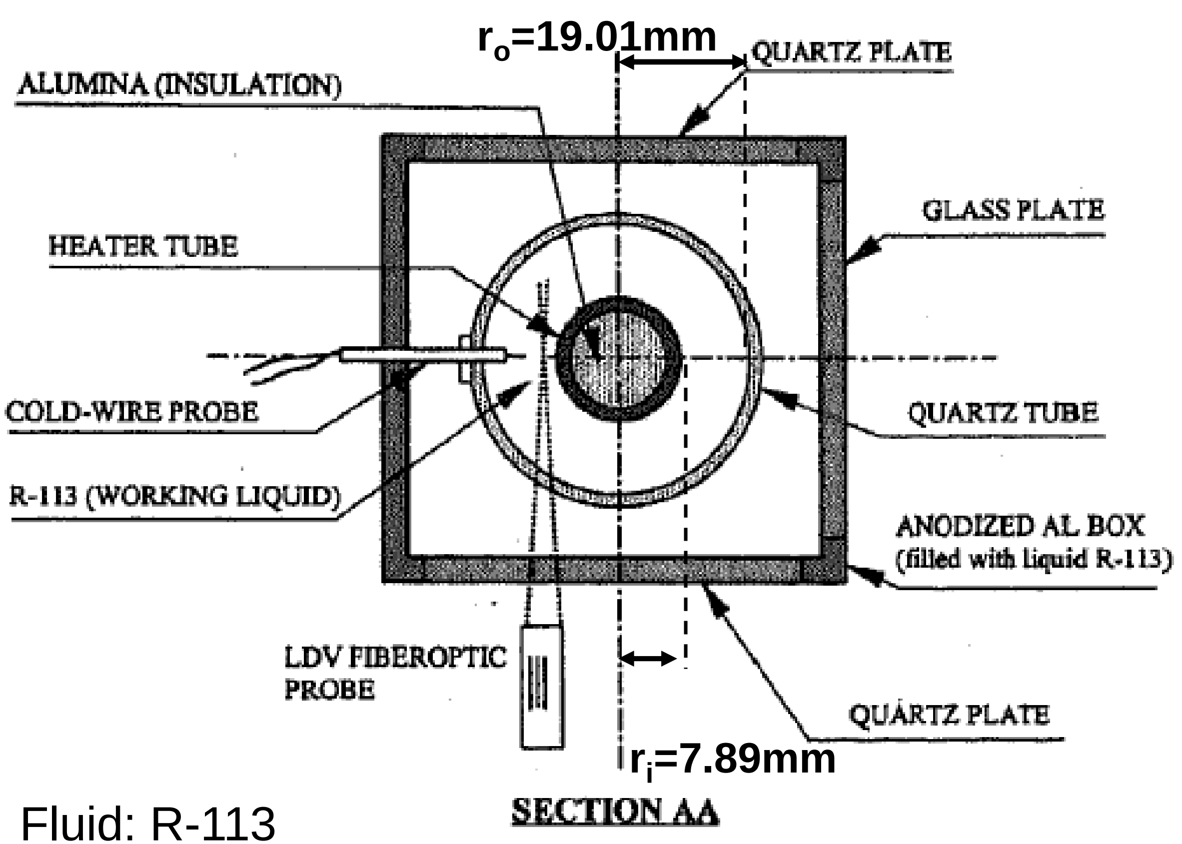
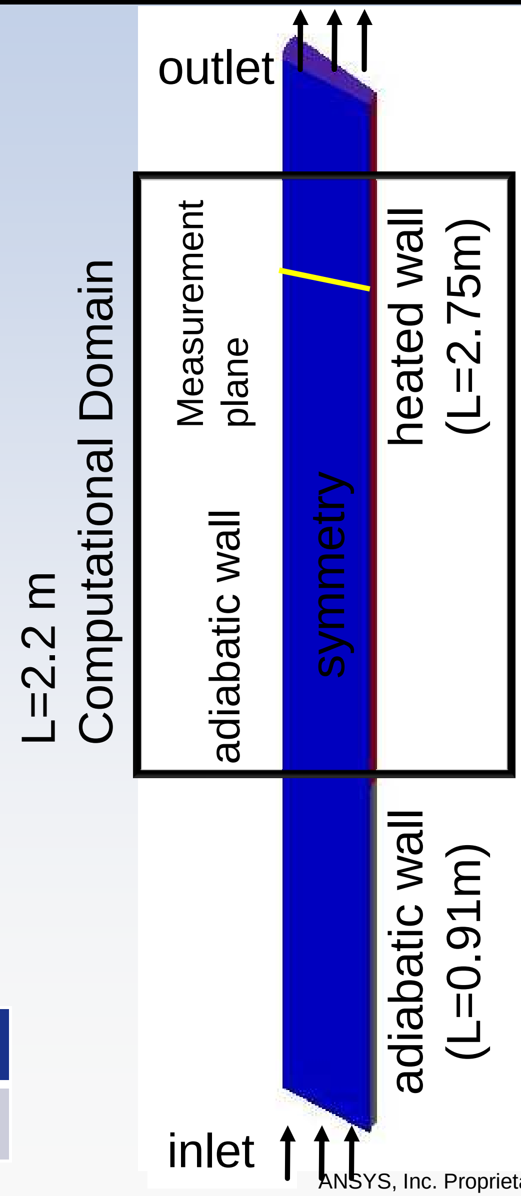
Validation Study

Test geometry (Roy et al., 2002)



Fluid: R-113

Pressure	Inlet Temp.	Mass Flux	Power
2.69 bar	50.2 C	784 kg m^{-2} s^{-1}	116 kW m^{-2}



Validation Study

Main setup parameters:

- Steady state
- High resolution advection scheme
- Turbulence model: SST
- Morel model for source terms in turb. eq.'s ($C_{\varepsilon,3} = 1.0$)
- Turbulent dispersion (FAD) & drag force
  → Grace with correction coefficient -0.5
- Constant value for wall roughness $k_r = \eta d_W \left(1 - \frac{Q_{convl} + Q_{quench}}{Q_{wall}}\right)^{\zeta} = 0.575mm$
- Wall Contact Model: $AF_{liquid} = 1$; $AF_{gas} = 0$
- Heat transfer correlation: Tomiyama

Validation Study

Main setup parameters:

- RPI model & bubble departure diameter: 1.3 mm
- Homogenous MUSIG model, 15 bubble classes
  - d_{min} = 0.25 mm, d_{max} = 3.75 mm
  - Prince/Blanch for coalescence (F_C=4); no breakup (F_B=0)
- For comparison: monodisperse simulation with Kurul & Podowski assumption on $d_B=f(T_{Sub})=f(T_{Sat-}T_L)$

Spatial Grid Independence Analysis

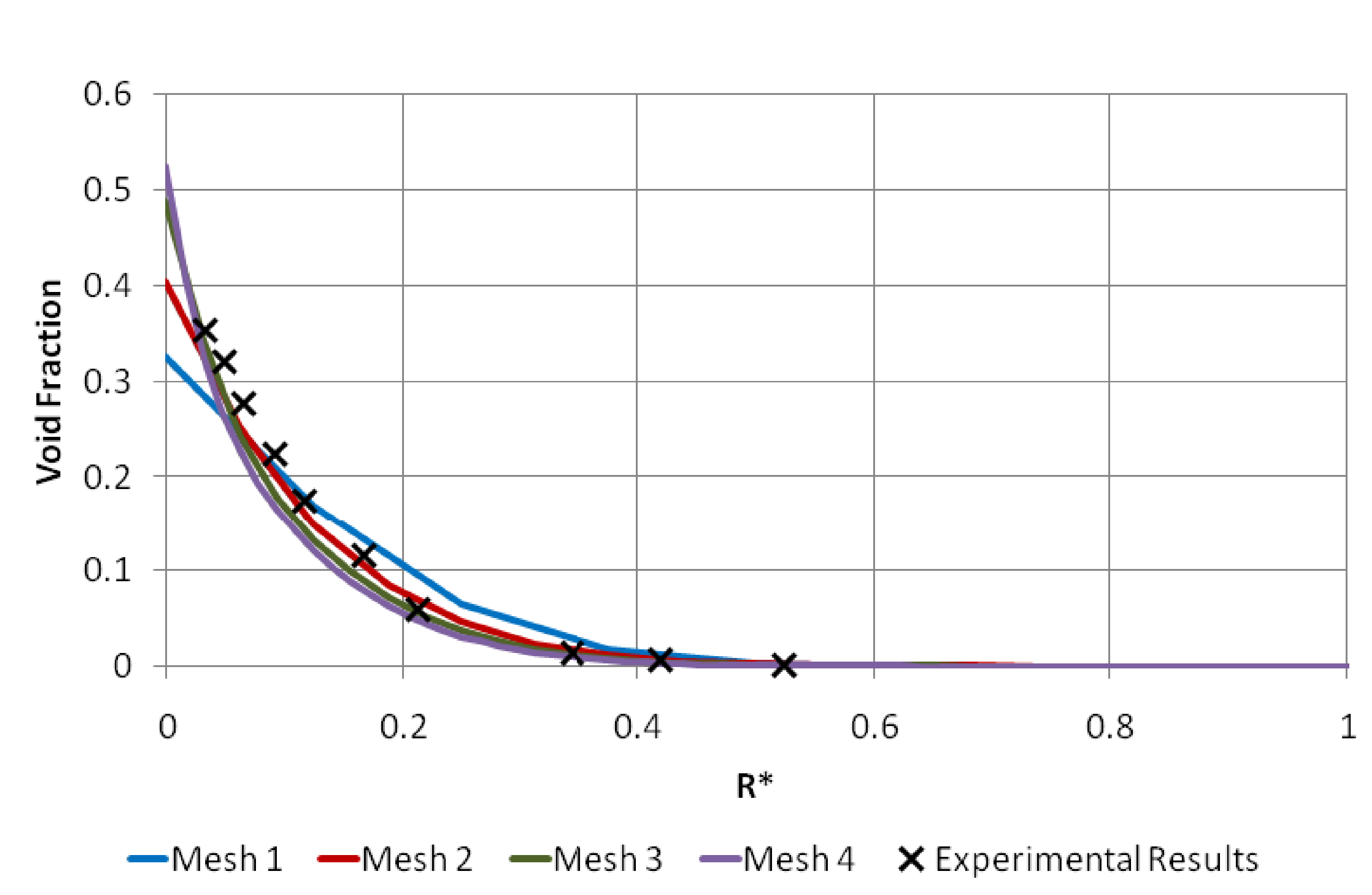
- Spatial grid hierarchy:

	Mesh 1	Mesh 2	Mesh 3	Mesh 4
Radial cells	8	16	32	64
Axial cells	220	440	880	1760
Total Cells	1760	7040	28160	112640
y^+_{max}	381	199	104	86

Mesh3	Single phase
y^+_{max}	34

R* dimensionless radius $$R^* = \frac{R - R_i}{R_o - R_i}$$

Spatial Grid Independence Analysis



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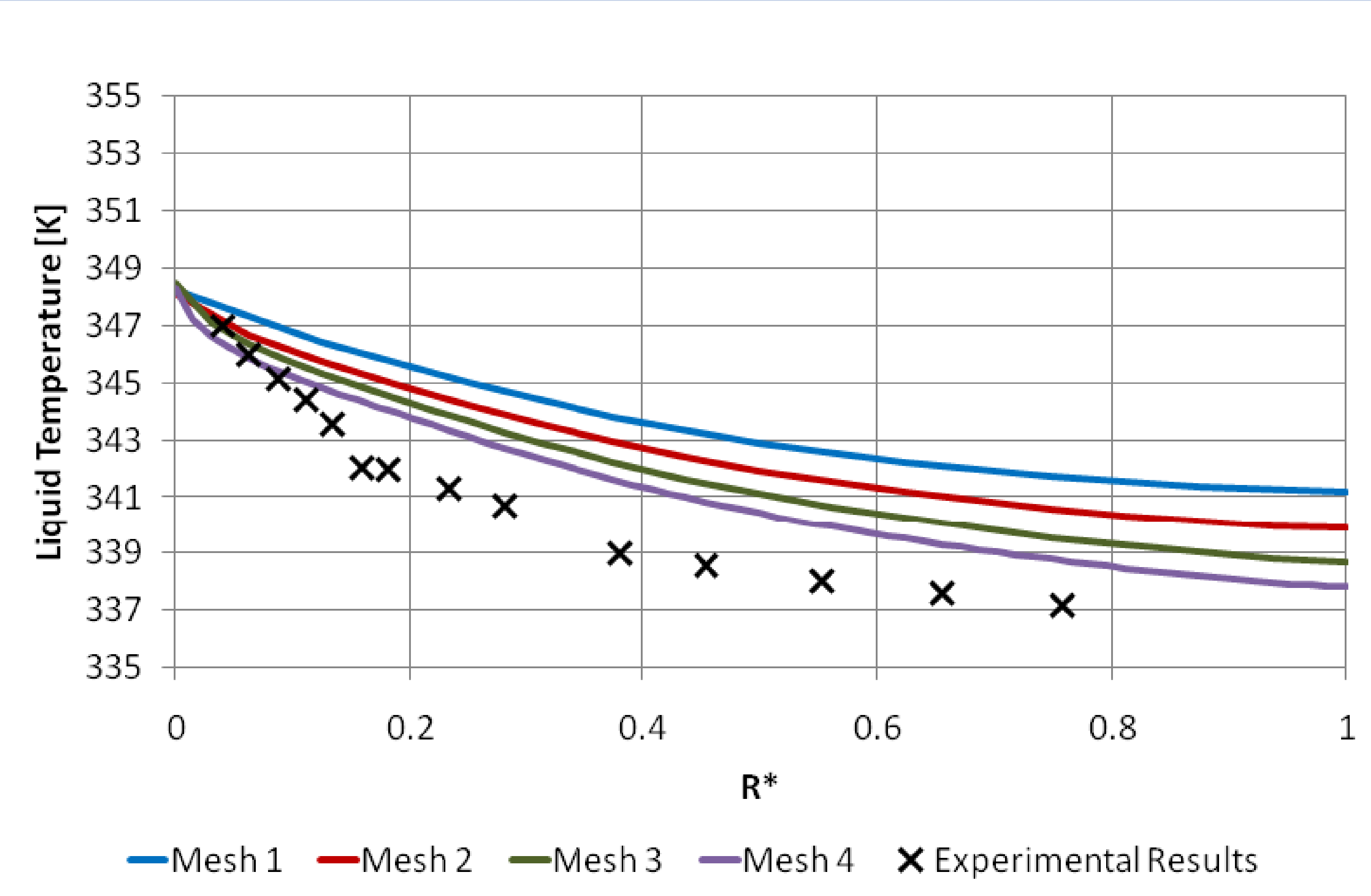

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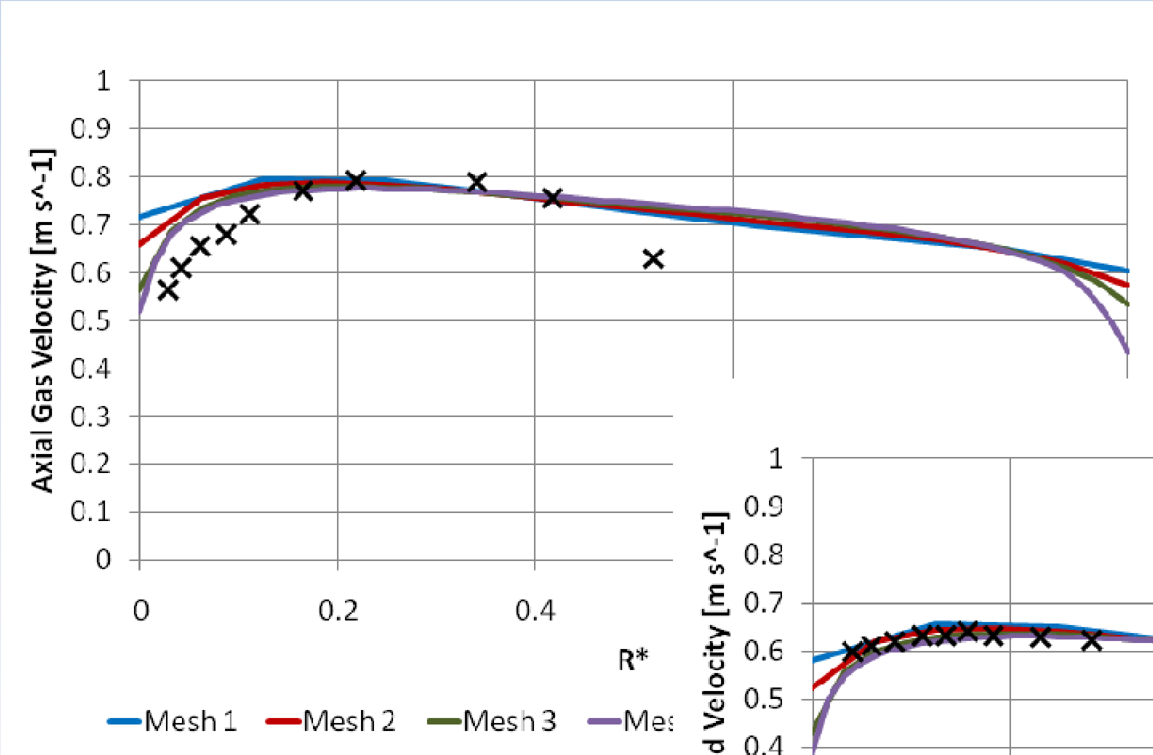
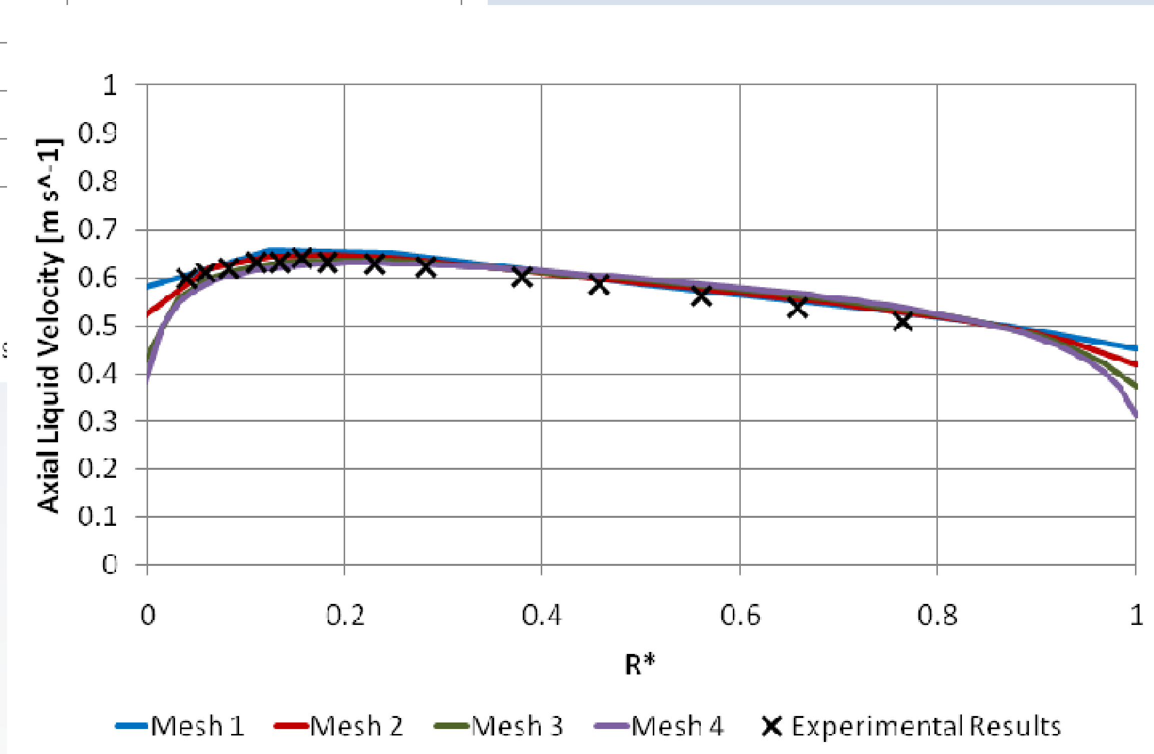


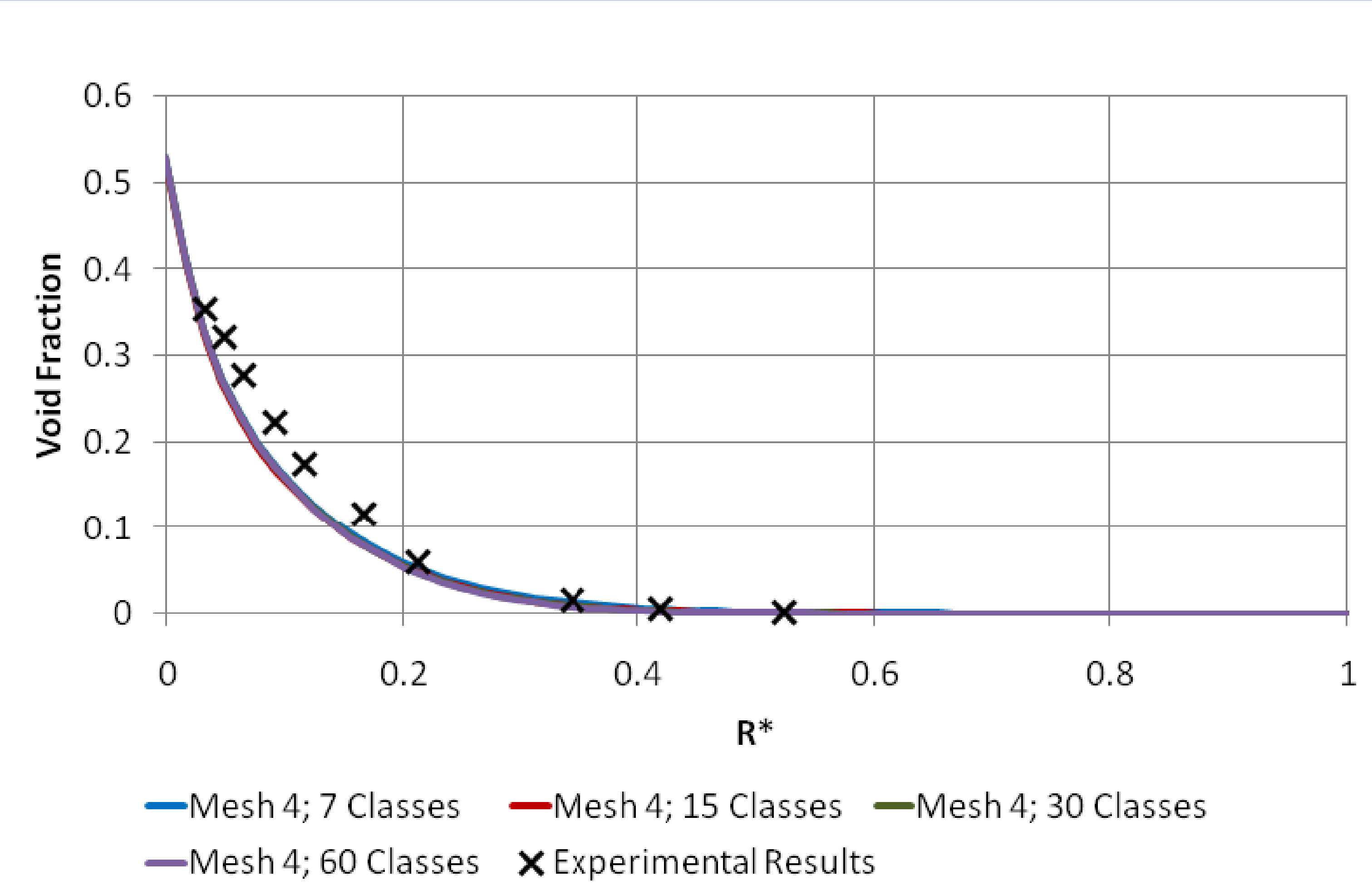


Analysis of Independence from Bubble Size Class Discretization

- Bubble size class discretization hierarchy:

	Discret. 1	Discret. 2	Discret. 3	Discret. 4
Number of classes	7	15	30	60
Diameter step [mm]	0.50	0.23	0.12	0.06

Analysis of Independence from Bubble Size Class Discretization



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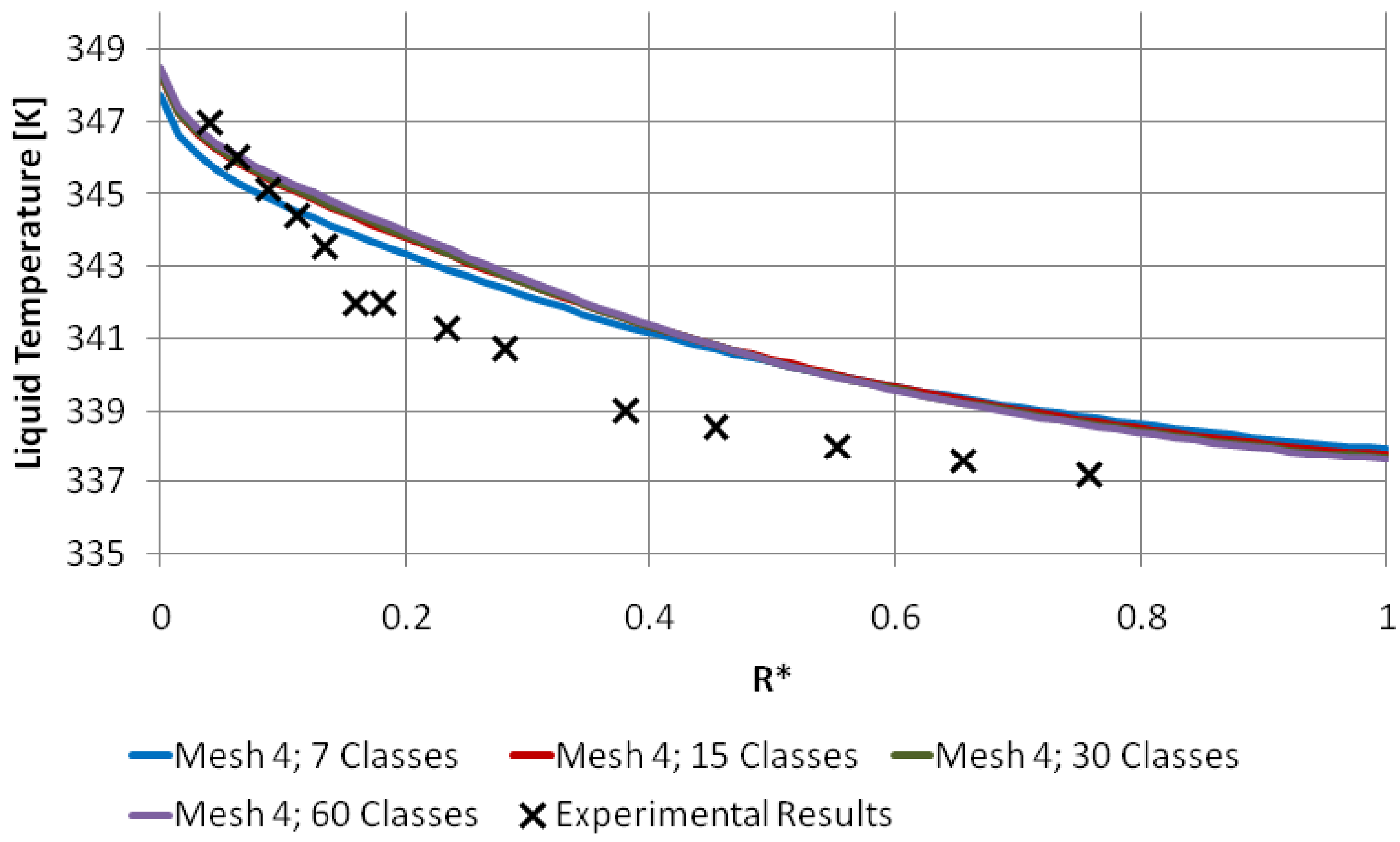

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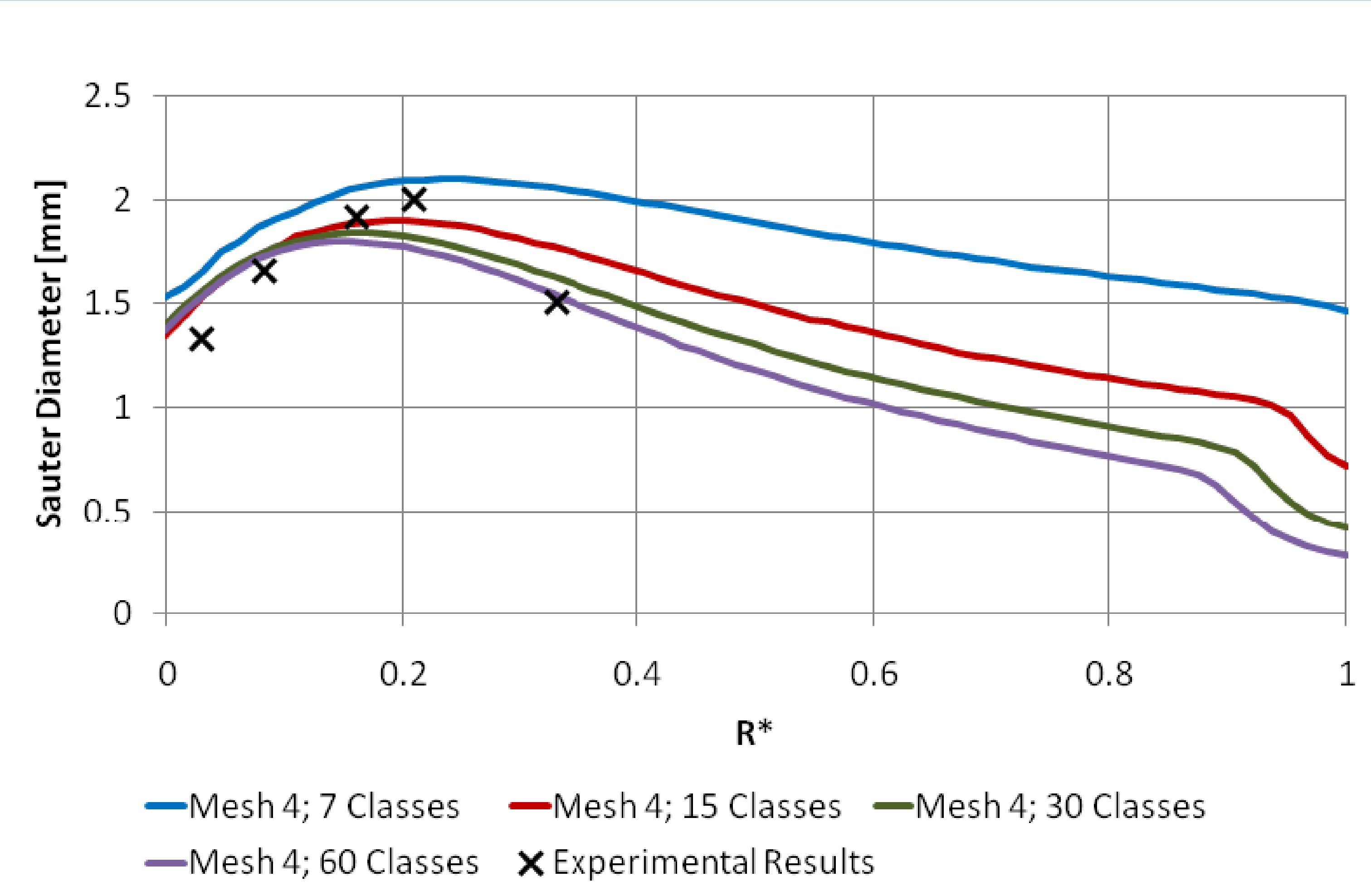

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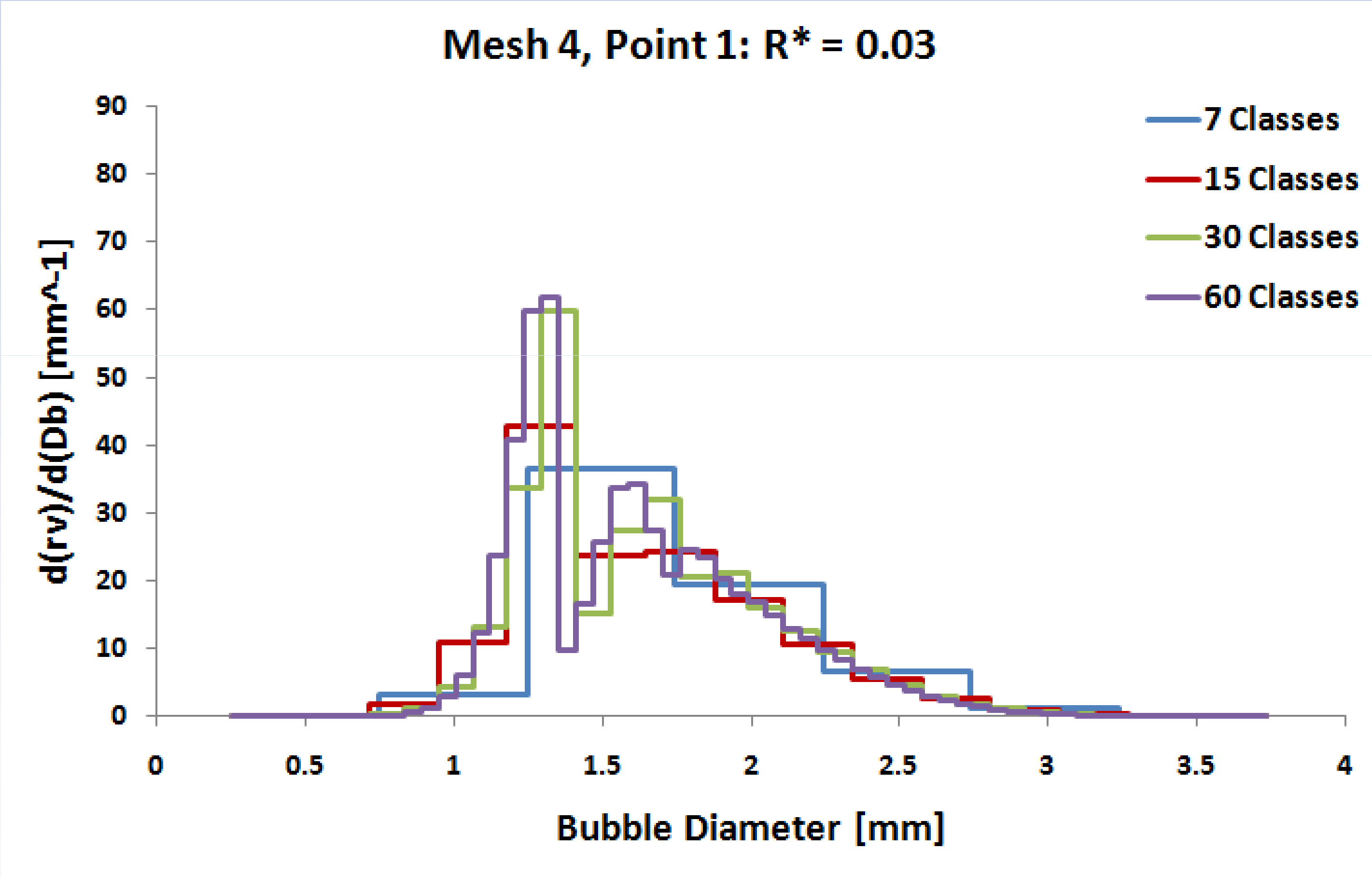

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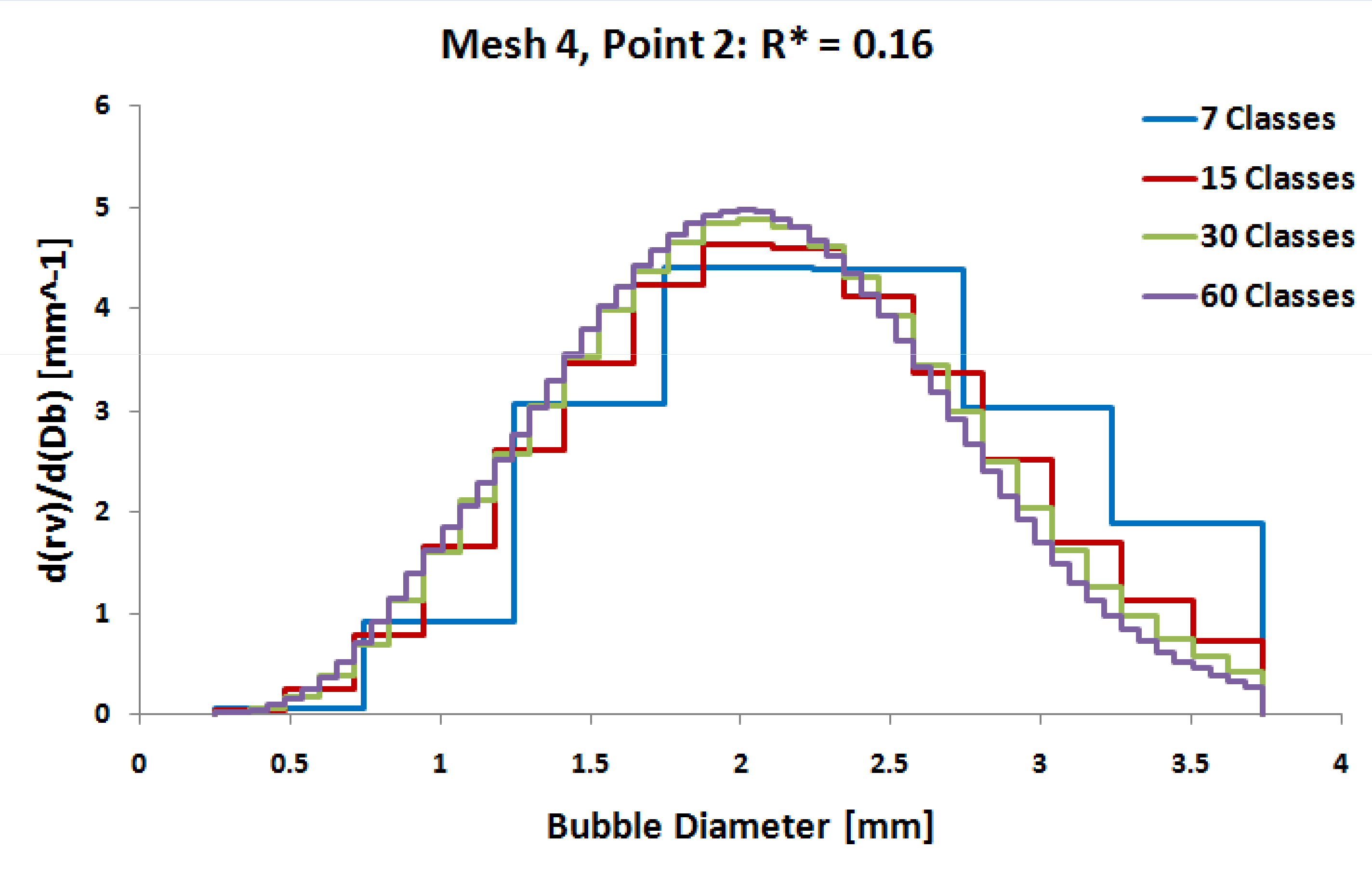
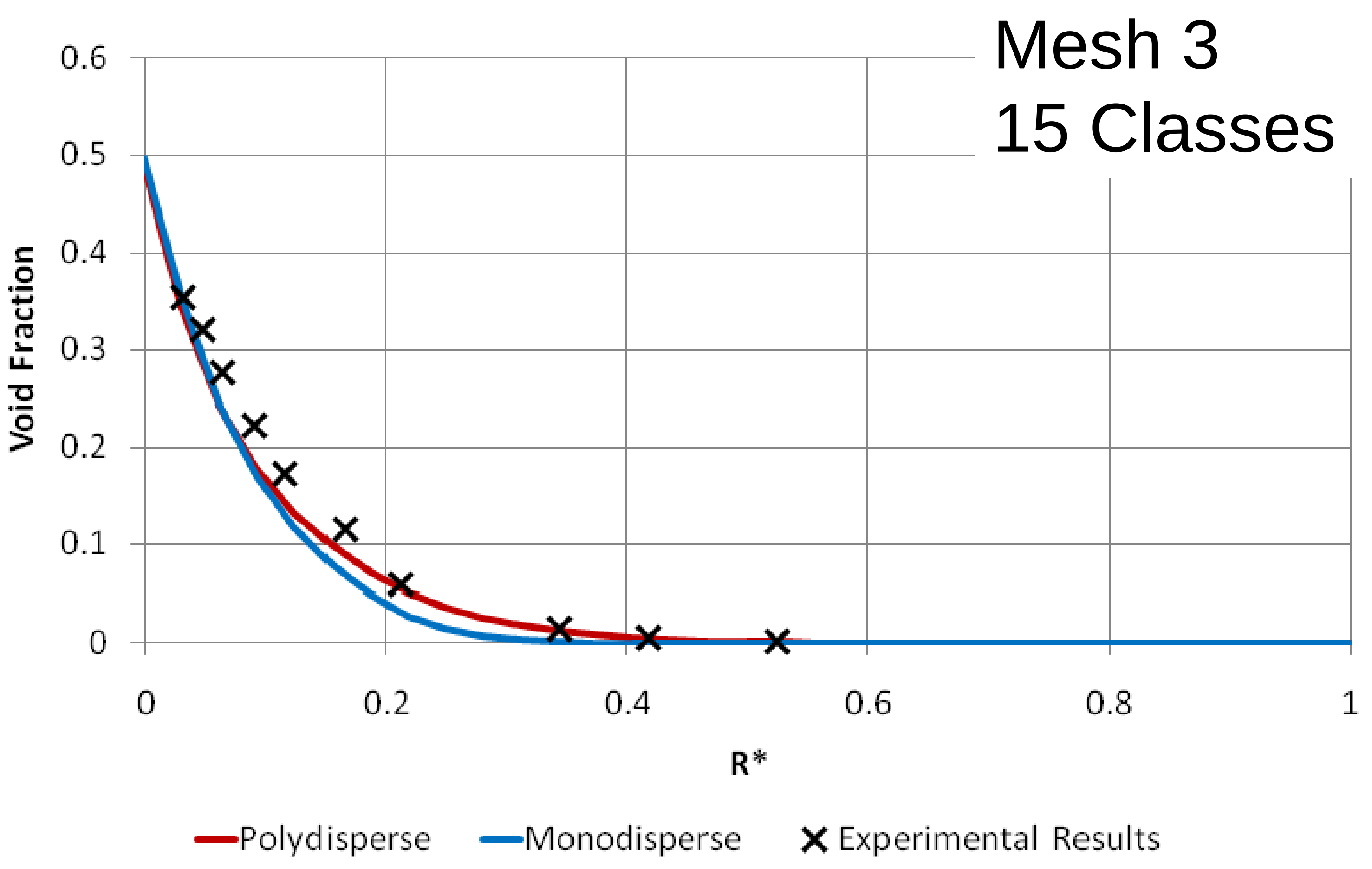


Comparison to K&P correlation



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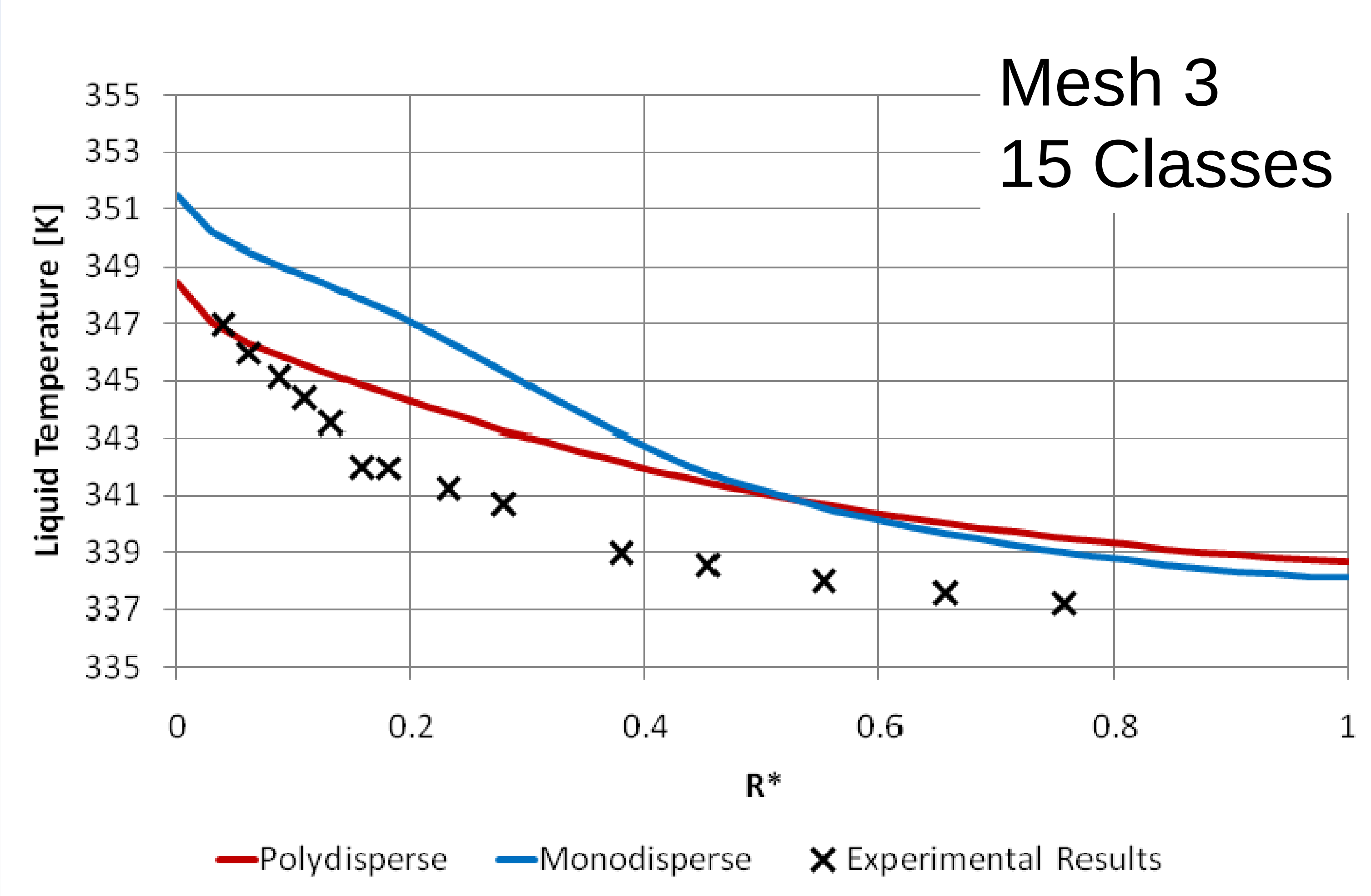

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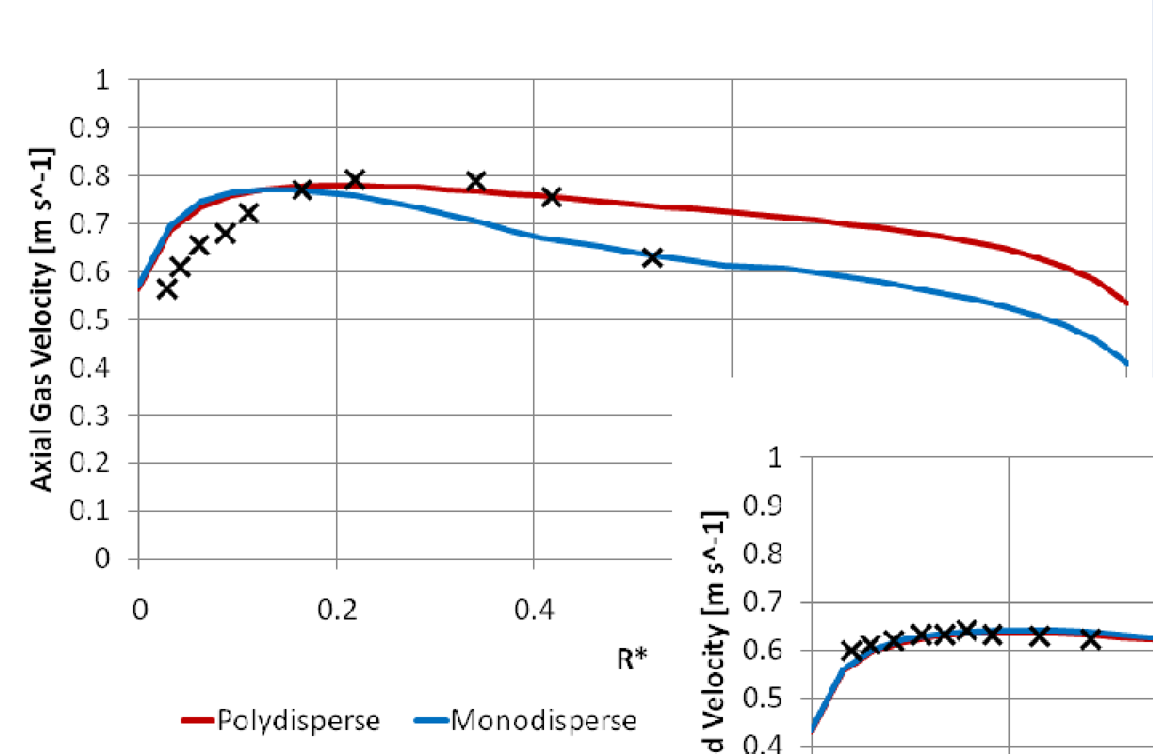
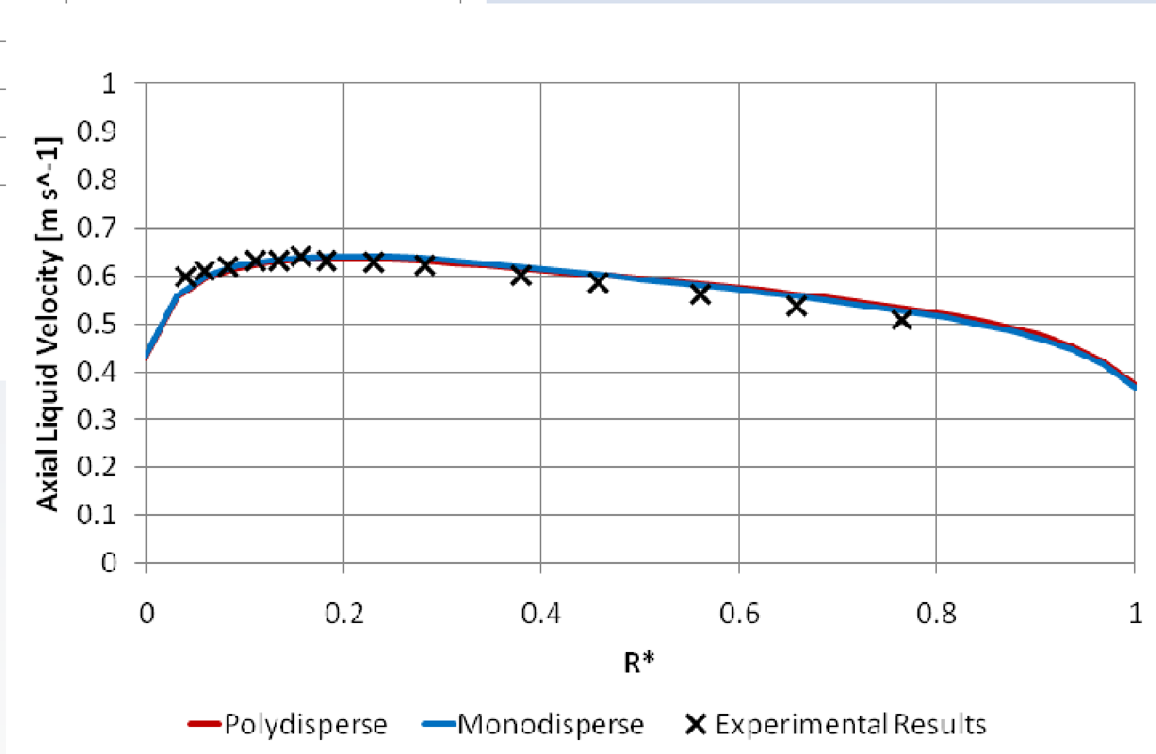
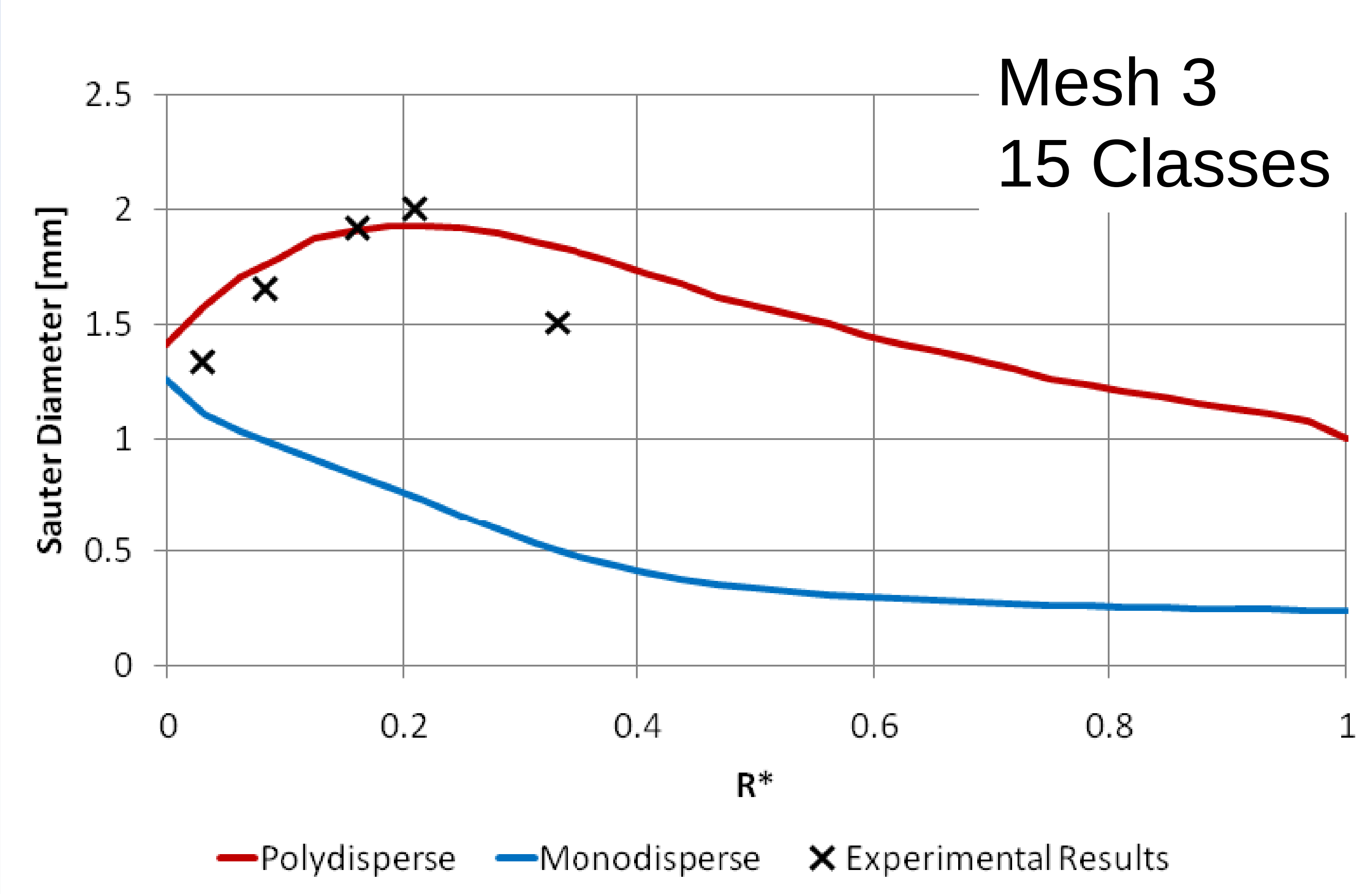




Mesh 3
15 Classes

Comparison to K&P correlation



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Conclusions & Outlook

- MUSIG-RPI coupling
  - In ANSYS CFX implemented (available in release 14, already PV3)
  - improves the accuracy of the simulations
  - provides more detailed information about bubble size distribution
- Homog. model was validated
- Consider two adjacent bubbles classes at the wall
- Include further phenomena in the wall heat partitioning
  - Non equilibrium RPI (convection to gaseous phase)
  - Sliding bubbles
- Improve wall treatment for two-phase flows

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