Ongoing Validation Efforts in Gas-Liquid Flows with Phase Change in System and CFD Codes

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Overview

- Two-fluid model
- Challenges
- Experimental facility
- Multiphase instrumentation
- Validation approach
- Other ongoing experiments

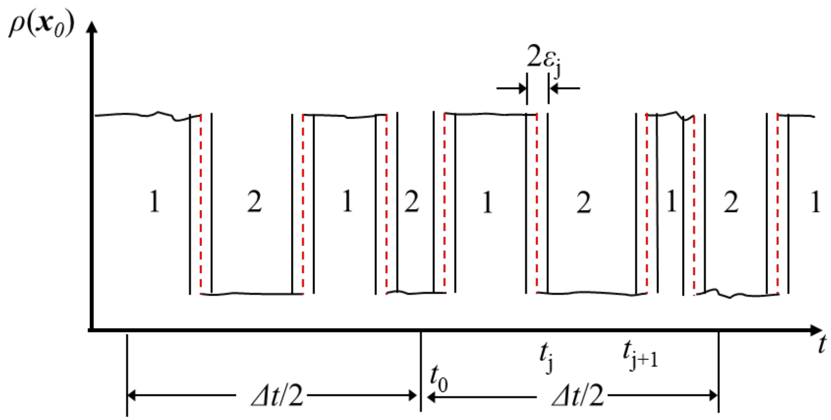
Two-fluid model with IATE

Two-fluid Model:

$$\frac{\partial\left(\alpha_k \rho_k\right)}{\partial t}+\nabla .\left(\alpha_k \rho_k v_k\right)=\Gamma_k$$

$$\frac{\partial\left(\alpha_k \rho_k v_k\right)}{\partial t}+\nabla .\left(\alpha_k \rho_k v_k v_k\right)=-\alpha_k \nabla p_k+\nabla .\left[\alpha_k\left(\overline{\tau_k}+\tau_k^T\right)\right]+\alpha_k \rho_k g_k+v_{ki} \Gamma_k+M_{ik}$$

$$\frac{\partial\left(\alpha_k \rho_k h_k\right)}{\partial t}+\nabla .\left(\alpha_k \rho_k v_k h_k\right)=-p_k \frac{D_k}{D t} \alpha_k+\nabla .\left[\alpha_k\left(\overline{q_k}+q_k^T\right)\right]+a_i q_{ki}^{''}+\phi_k+h_{ki} \Gamma_k$$



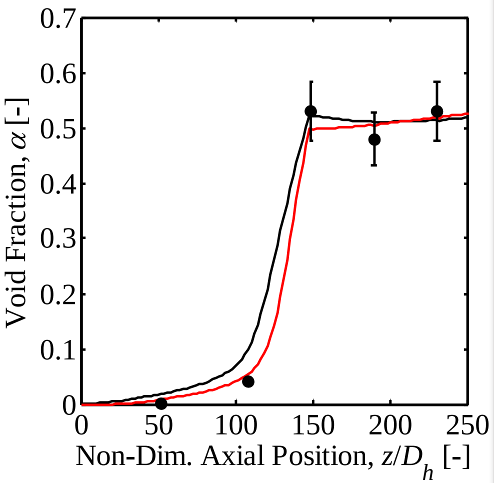
$I_k = a_i$ x *Mean Interfacial Driving Flux*

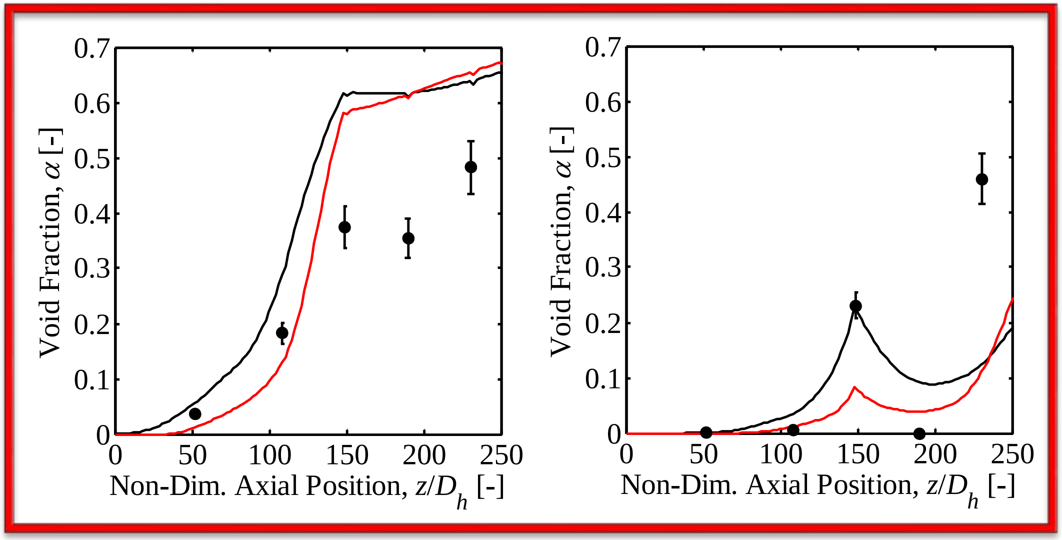
$$a_i \equiv \frac{1}{\Delta t} \sum_j \frac{1}{v_{ni,j}}$$

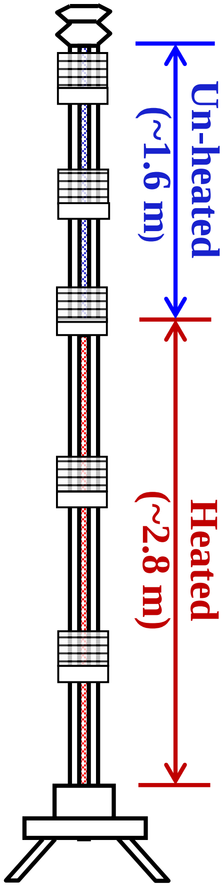
Challenges in 1-D codes

- Nuclear system codes ‘built’ for high pressure, high flow

  Fullmer et al., *PNE*, 2016





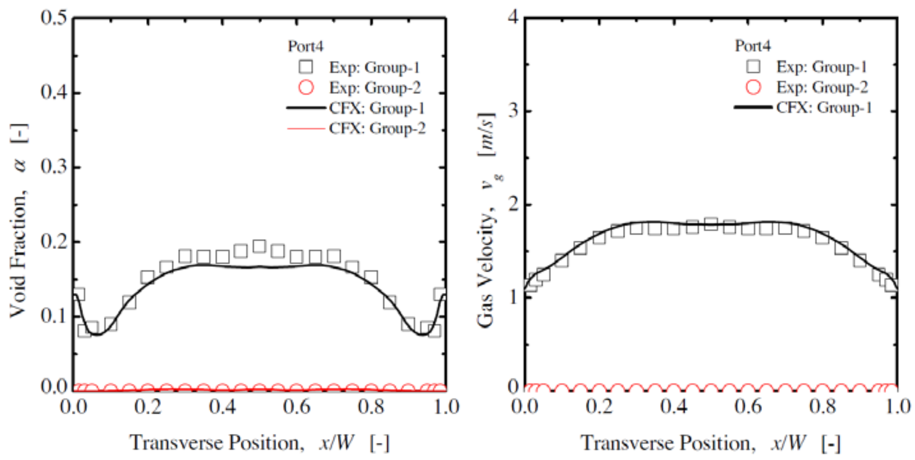


- Large error in void fraction under low pressure, low flow
- Passive safety systems
- Natural circulation

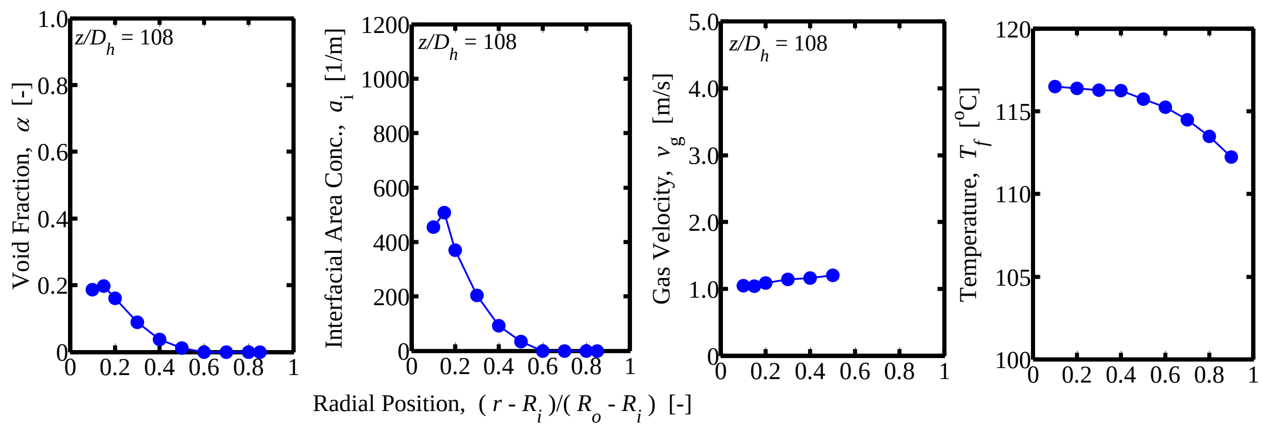
Challenges in multi-D codes

- Phase distribution – Interfacial forces

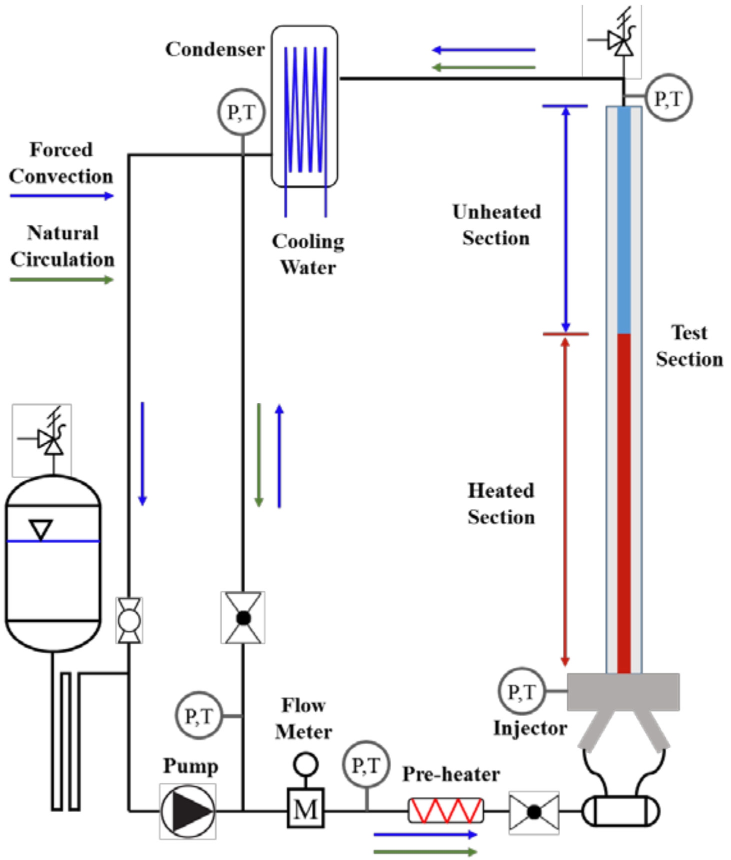
  Sharma et al., *NED*, 2017



- Phase-change
  - Wall nucleation
  - Condensation
  - Low quality CHF

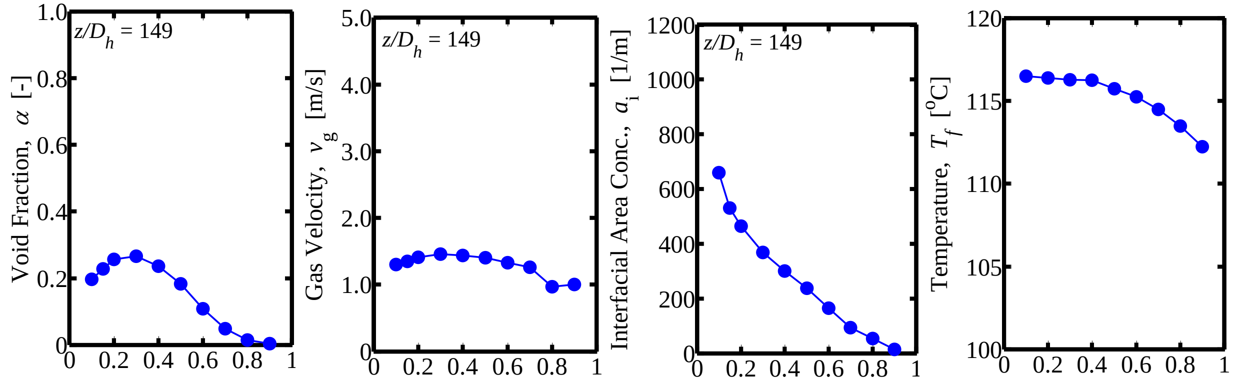


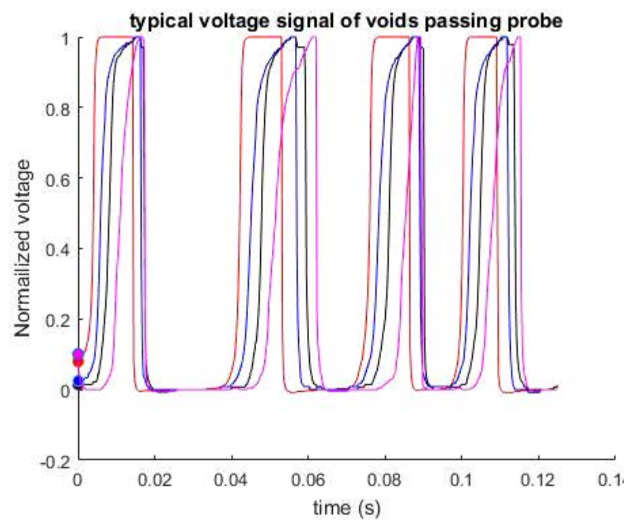
Experimental Capability: Heated annulus



Facility Specifications	
Geometry	Vertical internally-heated annulus
Channel Length	5.03 m
Heated length	3 m
Annular gap	3.81 cm (D_o), 1.91 cm (D_i)
Pressure (gauge)	0 ~ 1 MPa
Heat Flux	0 – 300 kW/m^2
Velocity	0 ~ 5 m/s

Experimental Capability: Heated annulus

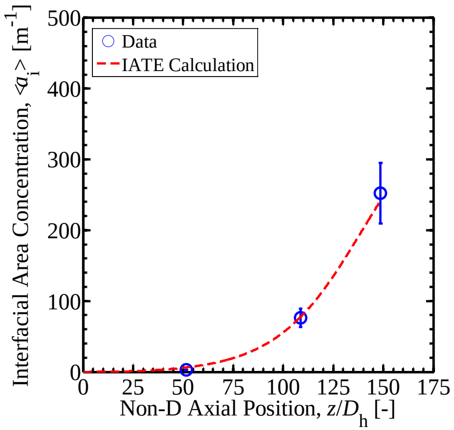


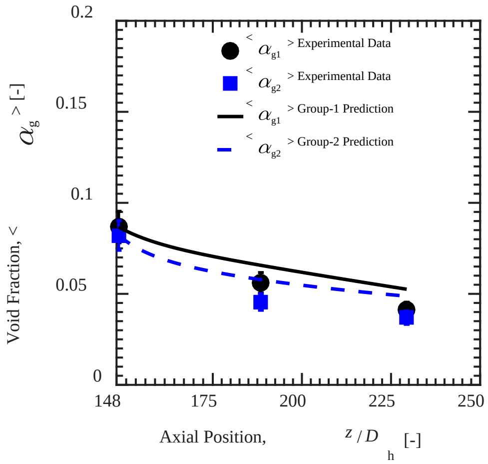


$$a_i \equiv \frac{1}{\Delta t}\sum_j \frac{1}{v_{ni,j}} = \sum_j a_{ij}$$

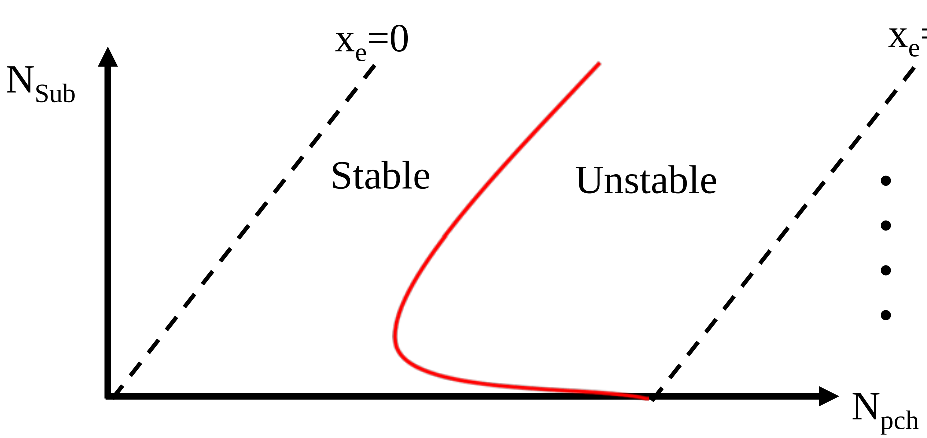
Experimental domain

- Model development and benchmark
  - Subcooled boiling
  - Condensation





- System code validation: DOE- NEUP: Natural circulation



- System pressure
- Inlet temperature
- Inlet k-loss
- Heat flux

Nuclear Energy University Program
U.S. Department of Energy

Validation approach- NEUP

Technical Reviewers

L. Zou (INL)
B.M. Golchert (WH)

Experimental
Lead: C.S. Brooks (UIUC)

Facility modification

Single-phase forced convection
- Component frictional losses
- Heat loss characterization

Natural circulation data acquisition

Computational
Lead: T. Kozlowski (UIUC)

Generate code input

Forced convection simulation

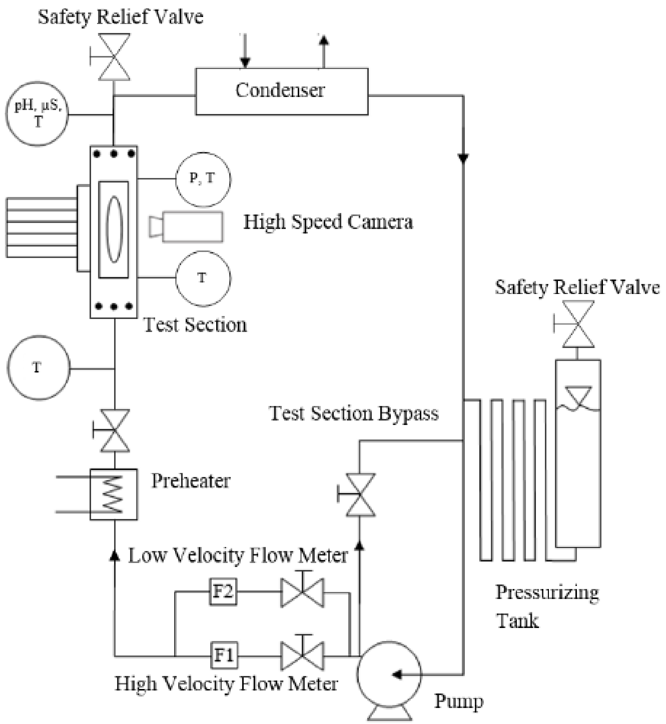
Natural circulation simulation

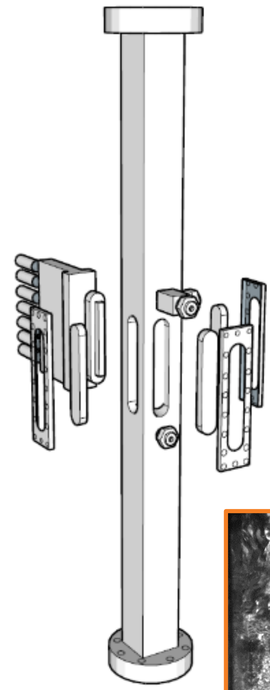
Inst. location
Inst. uncertainty
Post processing

Comparison

Uncertainty quantification
- Forward
- Inverse

Multiphase Thermo-fluid Dynamics Lab





Facility Specifications	
Geometry	*Vertical rectangular channel*
Channel Dimensions	*99.8 cm x 1.27 cm x 1.27 cm (variable)*
Heated Surface	*10.8 cm x 1.27 cm*
Pressure (gauge)	*-0.08 ~ 1 MPa*
Heat Flux	*0 ~ 2 MW/m²*

- Critical heat flux measurement
- Wall nucleation measurement
- Effect of gap thickness on boiling heat transfer
- Sub-atmospheric boiling
- High speed imaging, pressure, temperature.
- Boiling surface engineering (coatings, laser-texturing, wettability patterning, etc.)