Numerical Modeling of Flow Boiling in a Rectangular channel using OpenFOAM

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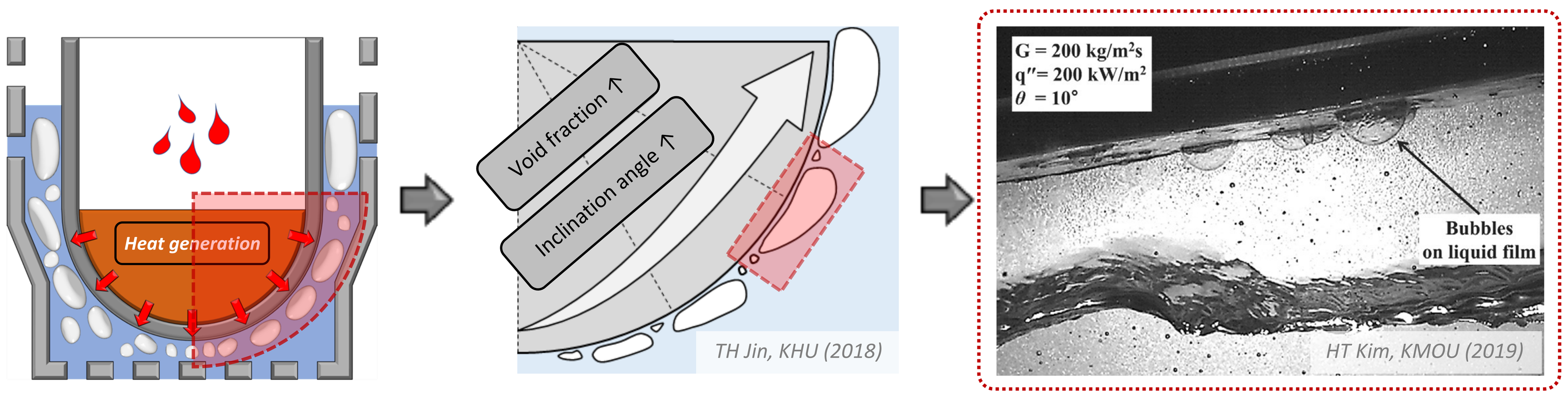
Motivation and Objective



- ERVC (External Reactor Vessel Cooling) is a crucial strategy for maintaining the integrity of the reactor vessel during severe accidents.
- When slug bubbles are generated, nucleate boiling occurs between them and the heated surface. This phenomenon indicates the presence of a thin liquid film, and the behavior of this film governs the heat transfer of slug bubbles.
- Therefore, accurately evaluating the cooling performance of ERVC requires considering the heat transfer mechanism of slug bubbles in a high void fraction flow regime.

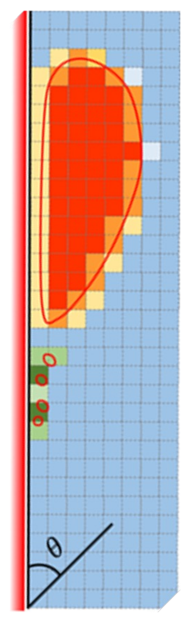
- Objective: A numerical modeling for flow boiling that can cover the high void fraction regime
  - Interface capturing method using multi-field solver
  - Population Balance Model to classify bubble groups
  - Hybrid Wall Heat Flux Partitioning model to reflect heat transfer mechanism of liquid film

Simulation methods

Interface capturing method

- To track the position of slug bubbles, the hybrid multiphase solver was used which can apply the interface capturing method selectively between discrete and slug bubbles.

$$\frac{\partial \alpha_k}{\partial t} + \vec{u}_k \cdot \nabla \alpha_k + \nabla \cdot \left(C_{\alpha,i} |\vec{u}| \frac{\nabla \alpha_k}{|\nabla \alpha_k|} (1-\alpha_k) \right) = \frac{\Gamma_{ki} - \Gamma_{ik}}{\rho_k}$$



Hybrid Wall Heat Flux Partitioning(WHFP) model

$$q''_w = [1 - H(\alpha_{cont.})] q''_{disp.} + H(\alpha_{cont.}) q''_{cont.}$$

- Blending function for WHFP model

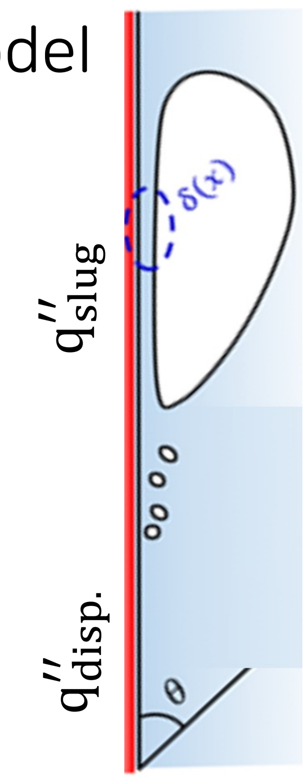
$$H(\alpha_{cont.}) = \max\left(0, min\left(1, \frac{\alpha_2^f - \alpha_{cont.}}{\alpha_2^f - \alpha_1^f}\right)\right)$$

- WHFP model for continuous phase bubbles

$$q''_{cont.} = \frac{k_l}{\delta_{film}} (T_w - T_{sat})$$

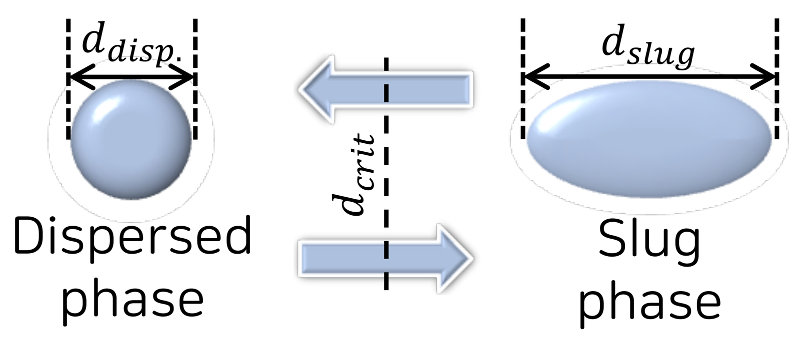
- WHFP model for dispersed phase bubbles

$$q''_{disp.} = q''_c + q''_q + q''_e$$



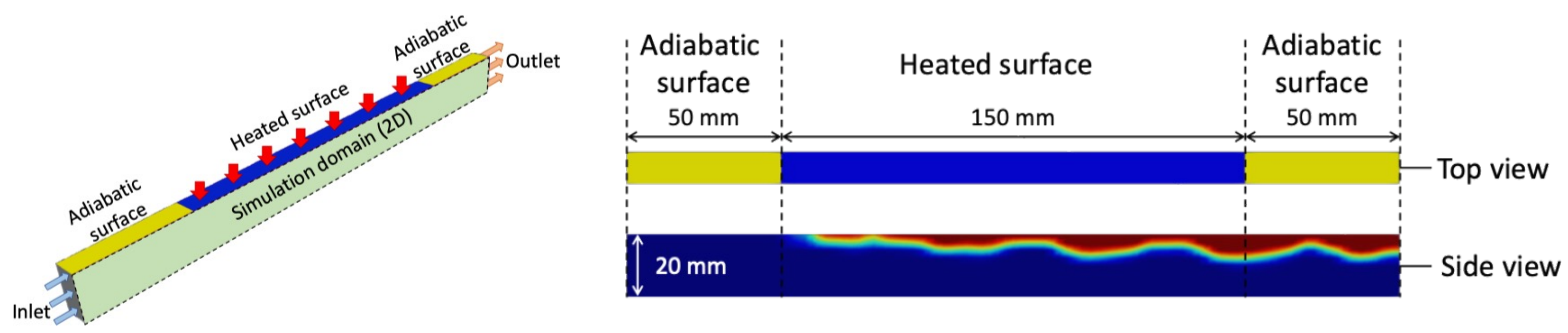
Population Balance model

- Bubble transition between bubble groups using critical diameter (d_{crit})
- d_{crit} : User input value



Simulation conditions & results

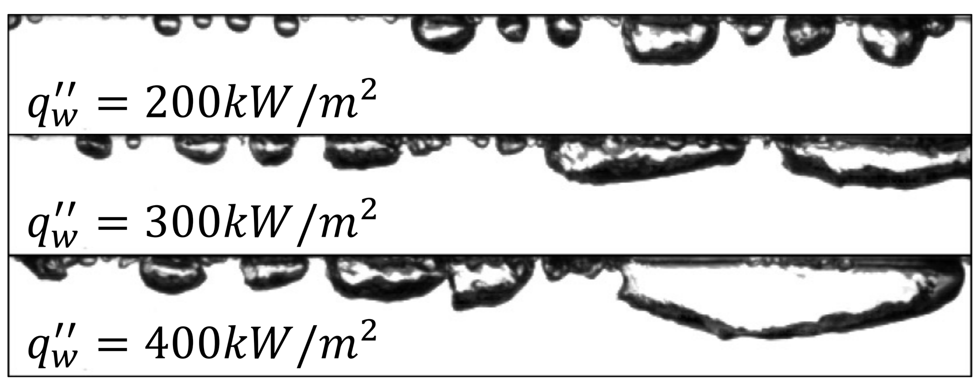
Computational domain



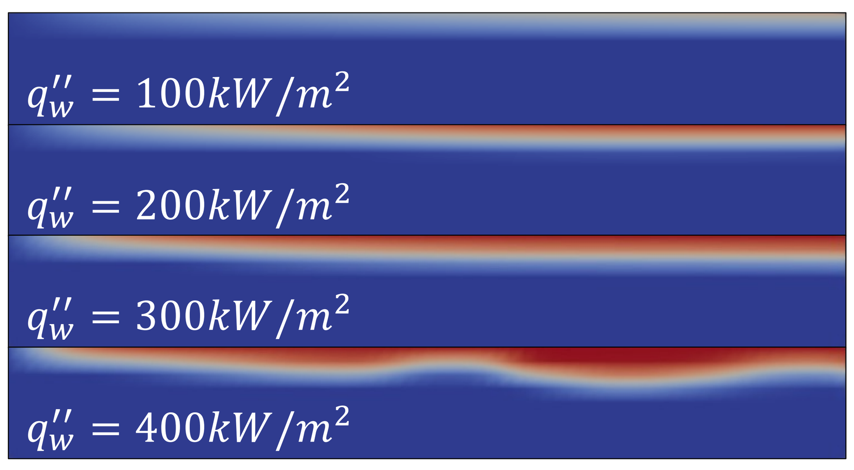
Major conditions of simulation

Variable	Value
System pressure	100 kPa
Inlet subcooling	5K
Mass flux	300 kg/m²s
Applied heat flux	100 ~ 400 kW/m²
Inclined angle	30°

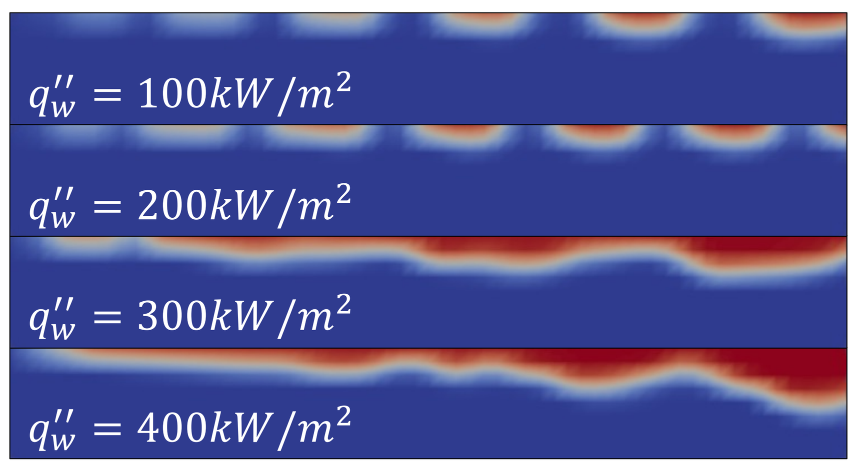
Simulation results



Experimental data set



Case set (1) Euler – Conventional WHFP model



Case set (2) VOF – Developed WHFP model

Conclusion & Future works

Conclusion

- A **numerical model was developed** to simulate the high void fraction regime in flow boiling.
- The **WHFP model** was designed to represent the **heat transfer mechanisms** of dispersed and continuous bubbles.
- A flow boiling simulation was carried out to compare the bubble behavior obtained from both the **conventional and developed modeling approaches, using experimental data**.
- The developed modeling exhibits a **more realistic behavior of bubbles** across a range of heat flux conditions.
- Conducting **sensitivity tests on critical diameter and mesh size** is necessary to achieve a more realistic representation of cap and slug bubble shapes.

Future works

- Conduct flow boiling simulations in the high void fraction regime to analyze the effect of conjugate heat transfer.