Design of an Experimental Apparatus for Visualization Studies of Bubble Dynamics in Subcooled Flow Boiling at High Pressure

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I. INTRODUCTION

Background

- **Boiling heat transfer (BHT)** is widely applied in nuclear reactor systems
- In APR1400, subcooled BHT occurs at **high pressure (15.5 MPa)** through reactor subchannels
- CFD is being developed to perform **accurate predictions in the BHT** for safety management
- BHT is predicted through **wall boiling models** developed by RPI and MIT

Wall Boiling Models in CFD

Wall heat flux partitioning model			
q''_{wall}	Single-phased convection		$q''_{1\phi} = h_{1\phi}(\Delta T_{sub} + \Delta T_{sup})$
	Evaporation	Inertia growth	$q''_{e,in} = \frac{4}{3}\pi\left(\frac{D_d}{4}\right)^3 \rho_v h_{fg} f N''$
		Microlayer evaporation	$q''_{e,ml} = \frac{2}{3}\pi\left(\frac{D_d}{4}\right)^3 \delta_m \rho_l h_{fg} f N''$
	Transient conduction		$q''_{sc} = \frac{2k_l(T_w - T_l)}{\sqrt{\pi\eta_l t^*}} a_{sl} t^* f N''$
	Quenching		$q''_q = \frac{2}{3}\pi\left(\frac{D_d}{4}\right)^3 \rho_h c_{ph} \Delta T_{sub} f N''$

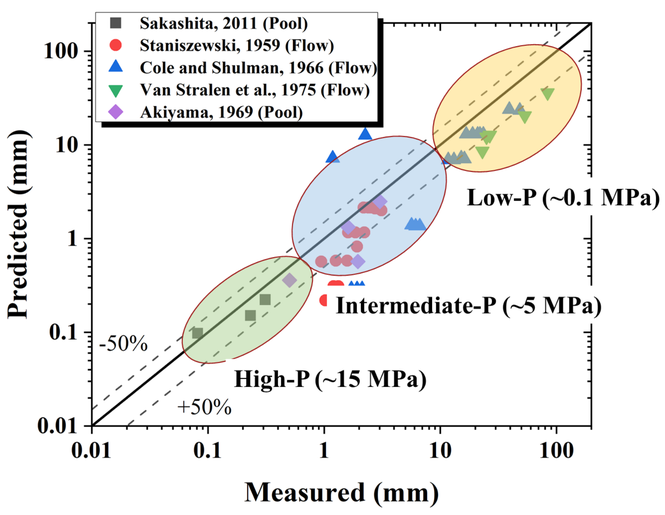
Objective

The heat transfer model is highly influenced by bubble dynamics parameters

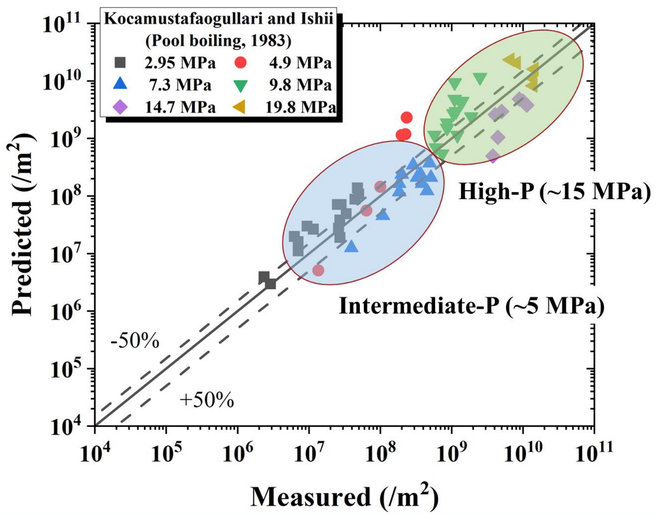
- **Analysis of existing experimental results** of bubble parameters applied in common CFD models
- **Design of an experimental apparatus** applicable at high pressure and temperature based on normal operation conditions of APR1400

II. EXPERIMENTAL RANGES OF EXISTING BUBBLE DYNAMICS MODELS

Bubble Departure Diameter



Nucleation Site Density



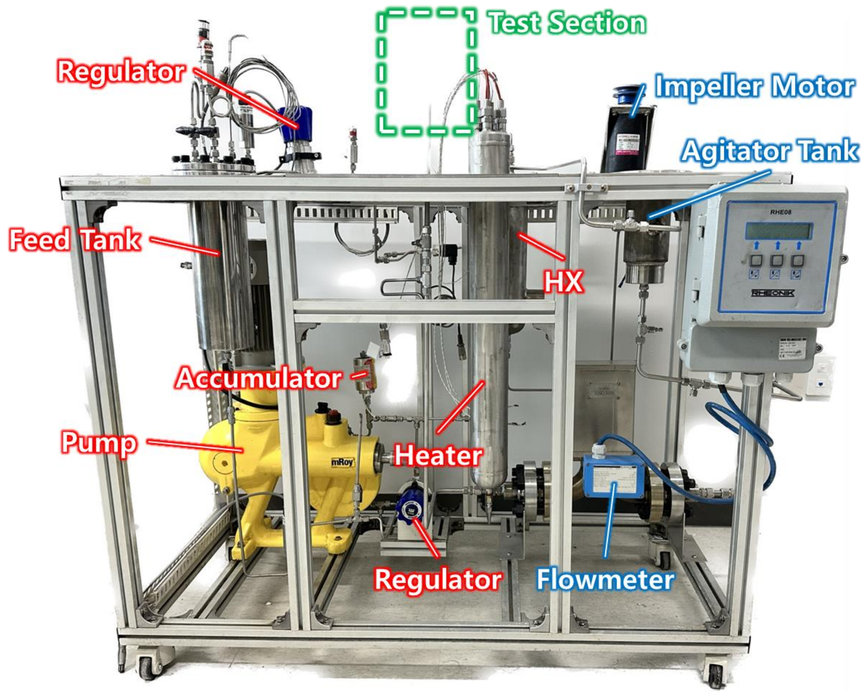
Limitations in Existing Models

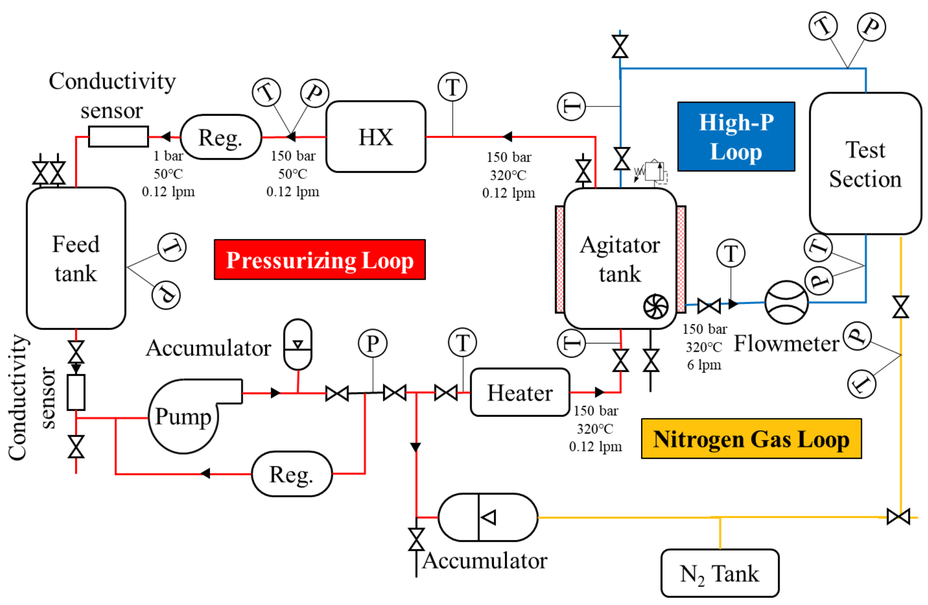
- Experimental data used to develop predicting models were obtained in conditions under,
  - ➢ **High pressures of pool boiling**
  - ➢ **Flow boiling under intermediate pressures**

★ **High-precision measurements of bubble dynamics parameters in HIGH-PRESSURE FLOW BOILING are necessary for the accurate prediction of BHT applicable to PWRs**

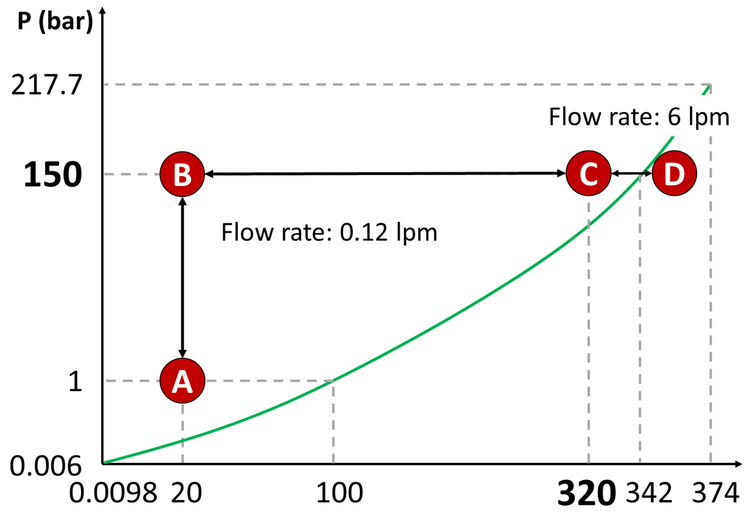
III. DESIGN OF HIGH-PRESSURE APPARATUS

Advanced High-pressure System for Nuclear energy AppLication - AHSNAL -



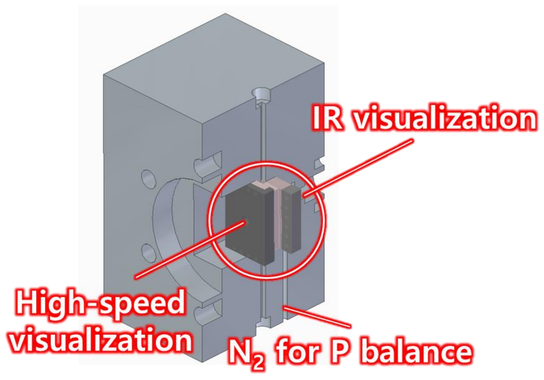


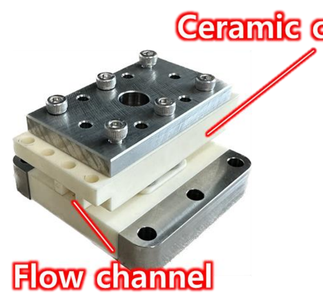
Operating Conditions

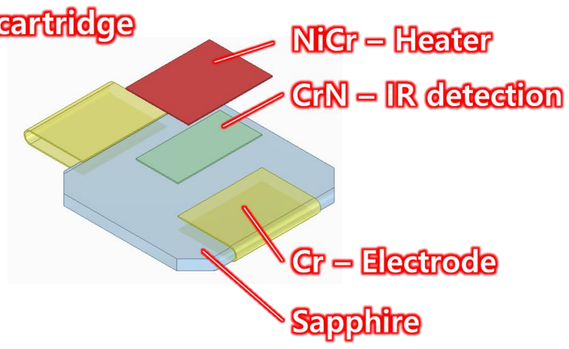


A → B	Pressurized by the **pump** and the **regulator**
B → C	Heated by the **heater** up to 320°C
C → D	Flow boiling at the **test section** Accelerated by the **agitator**
D → C	Condensed due to high subcooling
C → B	Cooled by the **heat exchanger**
B → A	Depressurized by the **regulator**

Test Section



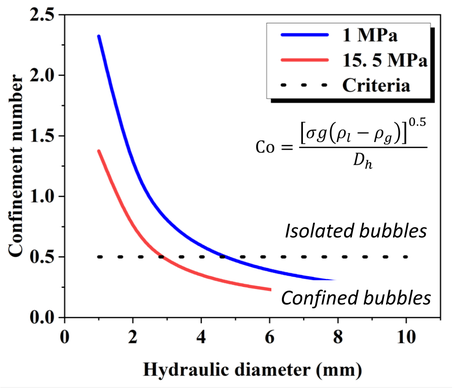


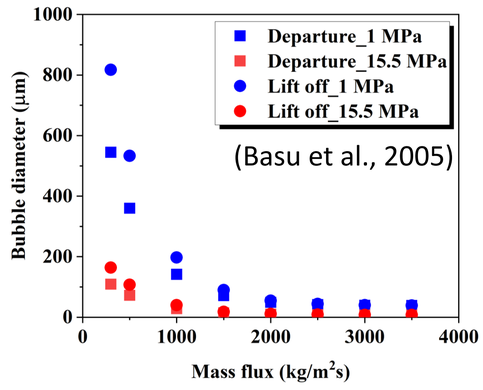


Nitrogen Gas Loop

- Sapphire sample has a thin thickness 1 mm
- Sapphire is far from being damaged as it lies between the working fluid and the N_2 gas, which have the same pressure

Design Criteria





Hydraulic Dia. → 5 mm **Heating Area → 4 x 8 mm²**

IV. CONCLUSION

Summary

- Bubble dynamics parameters in CFD are not validated in PWR conditions
- An experimental apparatus was designed under the same hydraulic conditions as APR1400

Future Works

- Experimentally obtain high-precision bubble parameters data with infrared and high-speed visualization techniques
- Improve bubble dynamics models used in common CFD