Development of Slug Boiling Liquid Film Thickness Technique Measurement using Infrared Thermometry

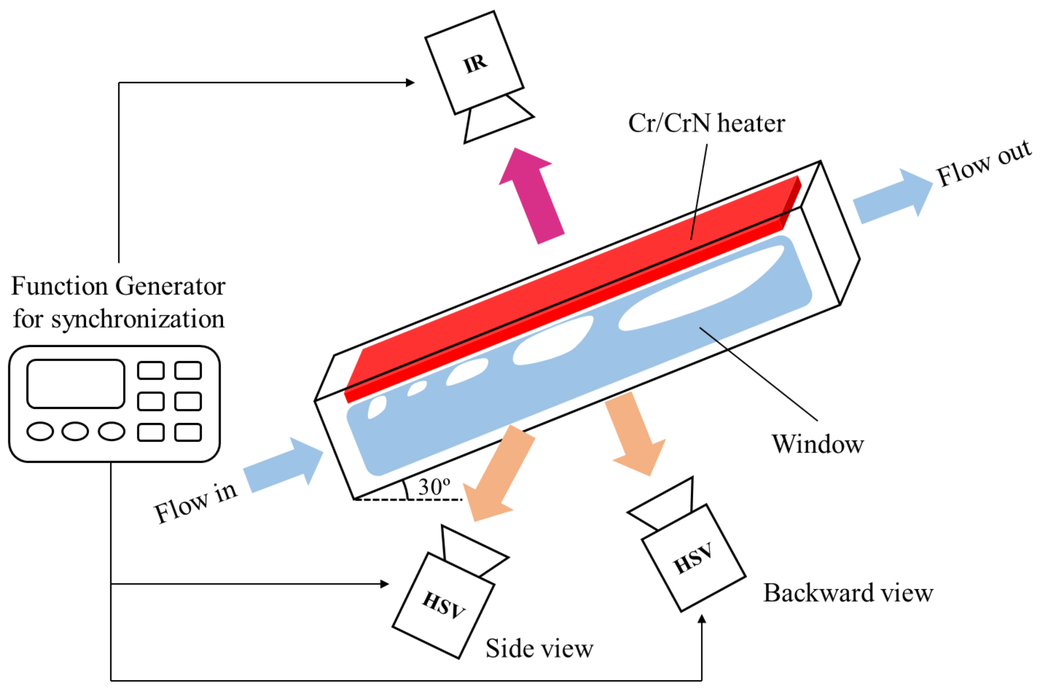
Junha Kang [a], Sangmin Park [a], Soonil Kwon [a], and Hyungdae Kim [a*]
[a] *Department of Nuclear Engineering, Kyung Hee University, 1732 Deogyeong-daero, Giheung-gu, yongin-si, Gyeonggi-do, 17104, Korea*
[*] *Corresponding author: hdkims@khu.ac.kr*

Introduction

- **Downward-facing flow boiling** is significant thermal-hydraulic phenomenon in relation to in-vessel retention and external reactor vessel cooling (IVR-ERVC) as a passive severe accident mitigation system.
- During the boiling phenomena, discrete bubbles nucleated on the heated surface merge before departing from the wall and form **large slug bubbles with liquid film** beneath them.
- Conduction heat transfer across the liquid film play a significant role during slug boiling hence the **thickness of the liquid film** is an important parameter for developing slug boiling heat transfer.

- **Objective**
  Experimentally measure liquid film thickness under slug bubbles using wall temperature and heat flux from infrared thermometry at various heat fluxes.

Experimental Setup



- Integrated infrared thermometry and high-speed measurement techniques are adopted.
- Subcooled flow boiling occurs on Cr/CrN heater deposited on a sapphire plate
- Experimental conditions.

Parameter	Range/Value
Mass flux [kg/m^{2}s]	300
Heat flux [kW/m^2]	500 - 1100
Inclination angle [°]	30

Liquid Film Measurement Method

Wall temperature and heat flux calculation

- **IR calibration experiment**
  - ✓ IR count → Wall temperature.
  - ✓ Achieve heat transfer coefficient.

$$h = \frac{q''_{apply}}{T_w - T_{sat}}$$

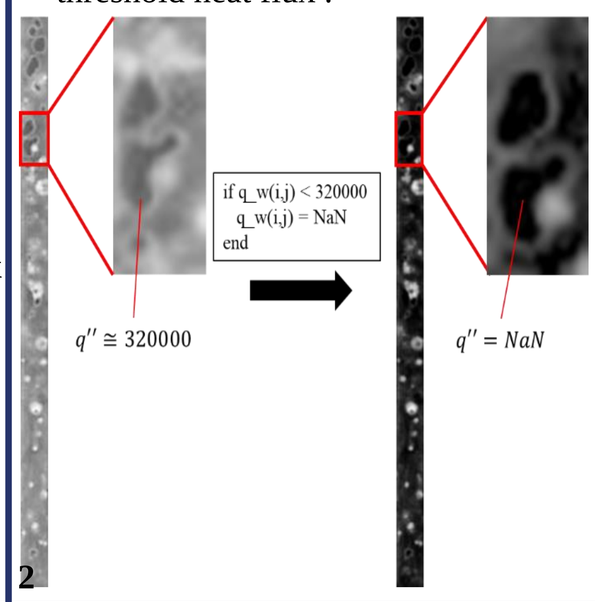
- **Wall temperature and heat flux distribution with 3-D Fluent analysis**
  - ✓ Heat loss calculation.

$$q''_w = h(T_w - T_{sat})$$

1

Dryout area removal

- Liquid film does not exist at dry out area.
- Remove dryout area by setting threshold heat flux .



2

3

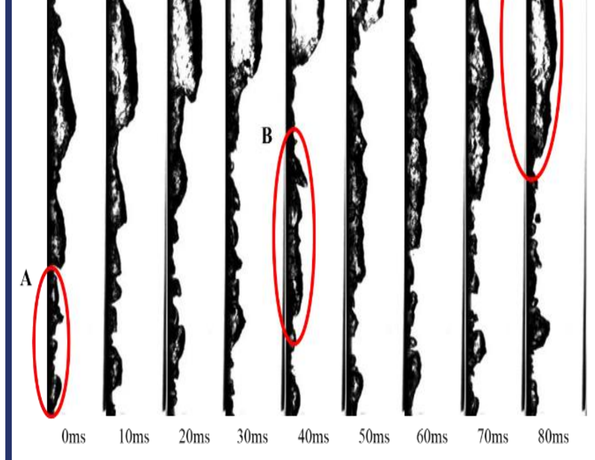
Liquid film thickness calculation

- 1-D conduction is dominant heat transfer between heated wall and liquid film.
- Calculate liquid film thickness with wall temperature and heat flux data from Step 1 through 1-D conduction equation.

$$\delta_m = k_l \frac{T_w - T_{sat}}{q''_w}$$

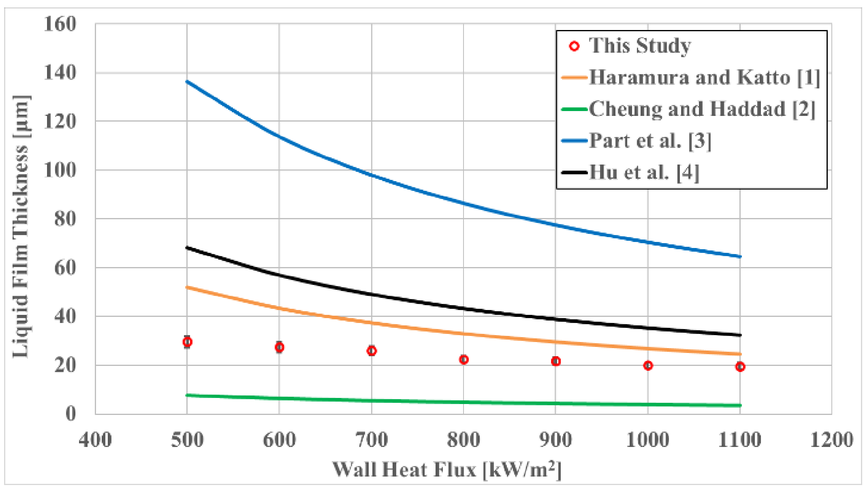
4

Determination of slug bubble region with HSV data



A: Discrete bubble B: Bubble coalescence
C: Slug bubble

Result and Discussion



- Liquid film thickness decreases as because the increases in heat flux will affect evaporation of the liquid film under slug bubble.
- The experimental result is compared with previous models of Haramura and Katto, Cheung and Haddad, Park et al., and Hu et al. that the result tends to decrease with increasing heat flux as other models.
- Liquid film thickness correlation

$$\delta_m = C_m \sigma \rho_g \left(1 + \frac{\rho_g}{\rho_f}\right)\left(\frac{\rho_g}{\rho_f}\right)^{0.4}\left(\frac{h_{fg}}{q''_w}\right)^2$$

Model	C_m value
Haramura and Katto [1]	0.00535
Cheung and Haddad [2],	0.00079
Park et al. [3]	0.014
Hu et al. [4]	0.00999 / (0.004365G + 1.296)

Conclusion

- This study presents the **indirect measurement method** of liquid film thickness under slug bubble using infrared thermometry technique.
- Thickness is calculated using **1-D conduction equation** since the corresponding heat transfer is dominant between the heated wall and the liquid film.
- This method will **improve slug boiling phenomena prediction** particularly related with IVR-ERVC.

- **Future works**
  Accuracy and reliability improvement of the experiment by directly measuring liquid film thickness.
  Extension of experimental conditions into various surface orientations and heat fluxes.