

Measurements of critical current density in alkaline electrolysis varying inclination and vertical length of cathode

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Background

i-SMR adopt HCSG (Helical Coil Steam Generator)

- Phase change occurs along helical tube
 - Centrifugal force induces secondary flow
 - Flow instability by DWO, Structural integrity by FIV

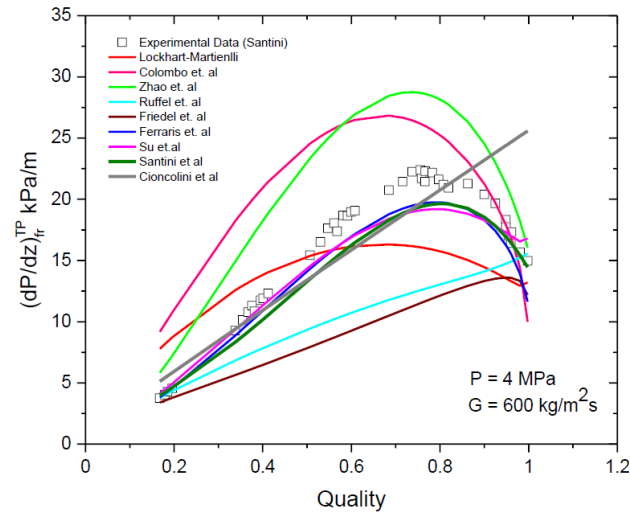


Fig. 1. Limitations of existing model on predicting pressure drop in a HCT (Two-phase flow) [1]

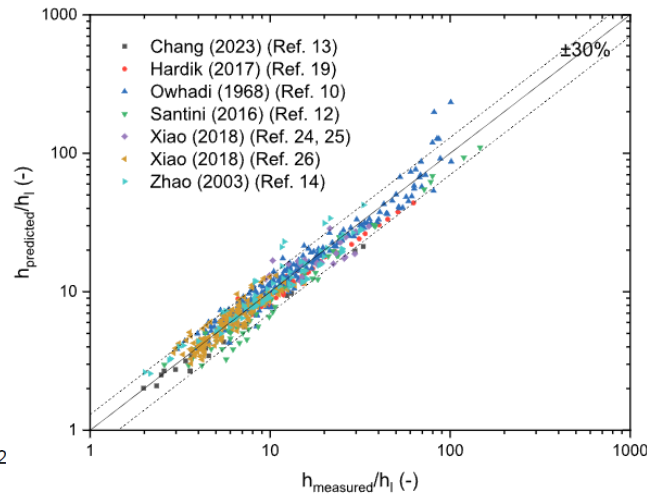
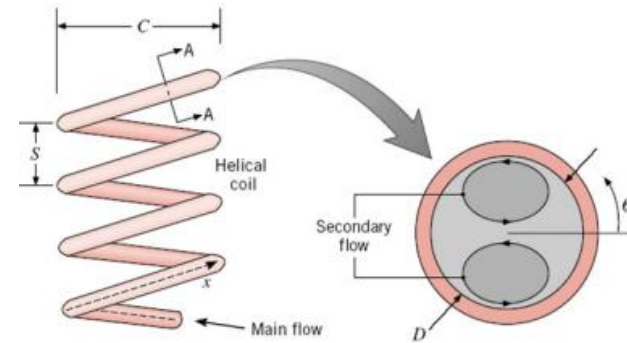


Fig. 2. Predicted versus measured heat transfer coefficient ratios [2]



Two phase flow regime map applicable to HCSG should be identified

Objective

Problem Summary

- Pressure drop, Heat transfer correlation
 - Based on fitting, inherent uncertainty
- Two phase flow pattern
 - Based on adiabatic condition or R 134a which has low boiling point, lack of validity

Ultimate goal

- **Construct two phase flow regime map applicable to HCSG**

Proposed experimental methodology - Alkaline water electrolysis

$$\text{Thermal power (J/s)} = \dot{m} \text{ (kg/s)} \times h_{fg} \text{ (J/kg)}$$

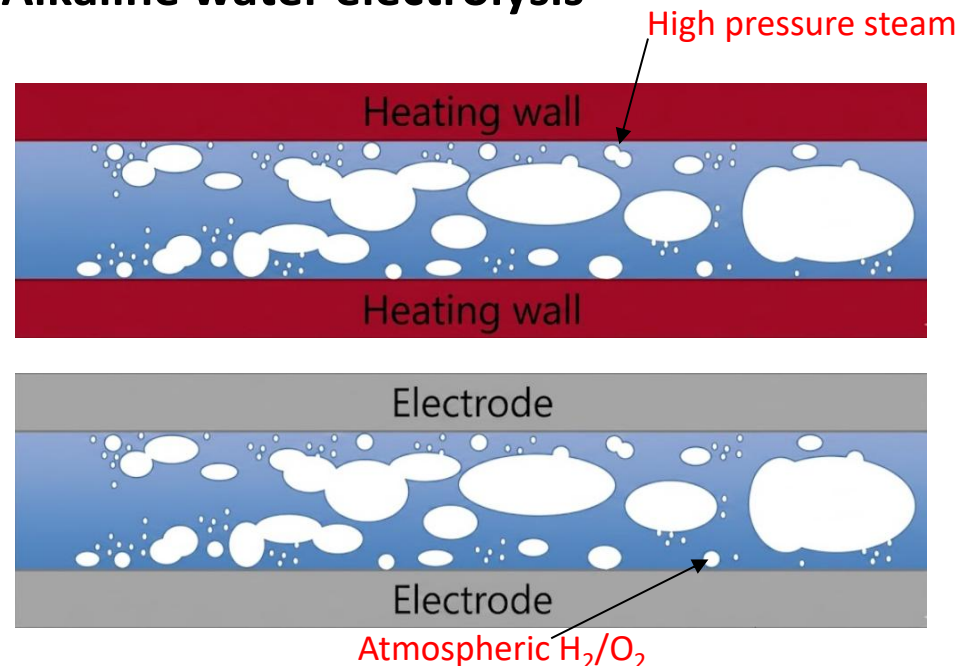
Steam generation rate Latent heat (Enthalpy)

Heat flux Applied
→ Steam bubble generation

$$\text{Current (C/s)} = \dot{m} \text{ (kg/s)} \times zF \text{ (C/mol)/M (kg/mol)}$$

Hydrogen/Oxygen generation rate Faraday constant/Molar mass

Current density Applied
→ Hydrogen/Oxygen bubble generation



Background

2D based test section + AWE to mimic flow boiling in HCSG

- HCSG curvature in 2D type
- Embed an electrode inside channel to act as heating-wall
- Drive flow alkaline water electrolysis
→ H_2/O_2 bubbles role of vapor; visualize bubble behavior with high-speed camera

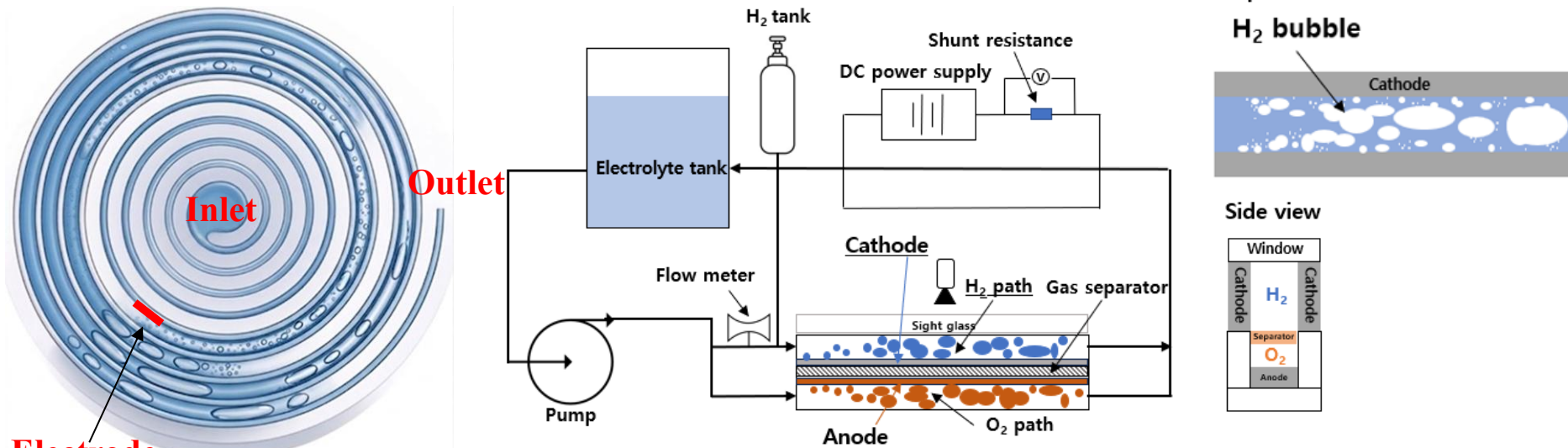


Fig. 3. Schematic of the AWE flow loop for two-phase flow visualization

Background

Water electrolysis



Boiling

Cell potential

Analogous

Wall superheat

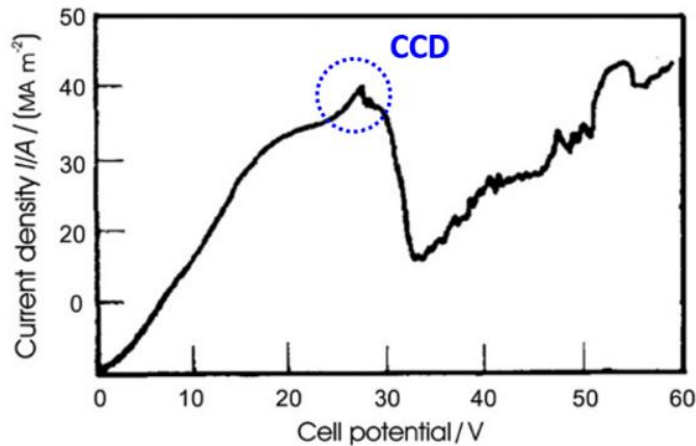
Current density

Heat flux

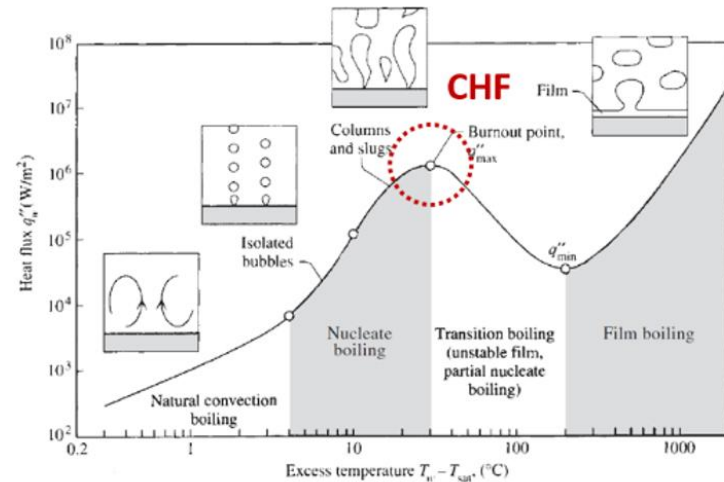
Hydrogen film, **CCD**

Operation limit

Vapor film, **CHF**



Cell potential-current density curve
(Sillen et al., 1982)



Boiling curve (Bejan, 2013)

Objective

Summary

- Cathode acts as **“Heating-wall”** analog to heating surface at boiling
- Electrolysis has an **“Operation limit”**, Critical current density (analog to CHF)
 - **Appropriate “Electrode Sizing” is needed**
- CCD is sensitive to cathode **geometry** (Area, Shape, Inclination angle)
- In HCSG, Continuous range of inclinations and vertical lengths

Objective of present work

- Preliminary study for channel designing to confirm limitation on operating limit
→ **CCD**

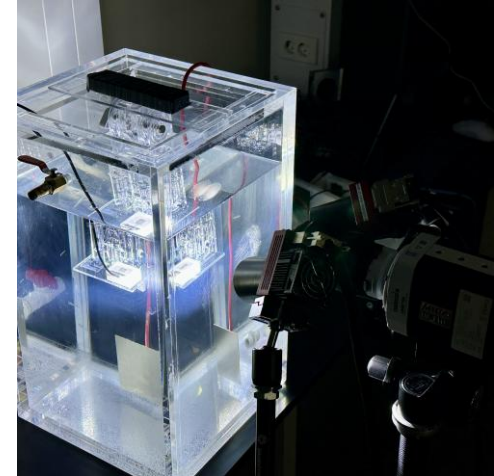
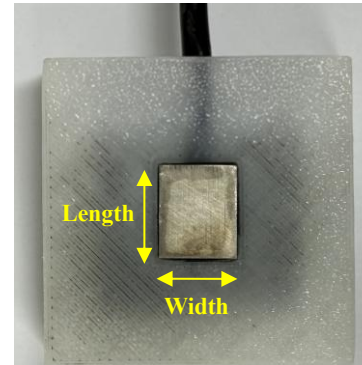
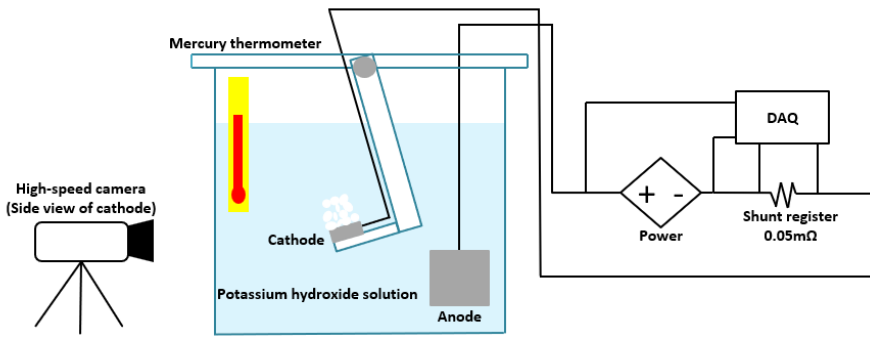
Scope of present work

- **Experimental investigation of the separate effects on cathode inclination and vertical length focusing on CCD, hydrogen bubble behavior**

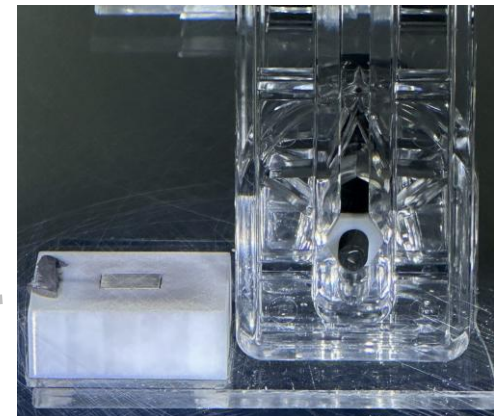
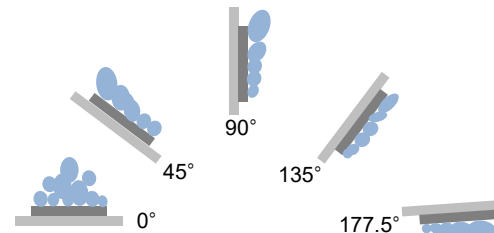
Experimental setup

Two-electrode water electrolysis system for hydrogen evolution

- Electrolyte: 1.94 M KOH aqueous solution
- Power supply: voltage applied (Keysight N8739A)
- Data measurement: DAQ system (NI 9225, NI 9238), shunt resistor
- Capturing Bubble Behavior: High-Speed Camera (Phantom Lab 1116GMono)



Parameters	Cases (#)				
	1	2	3	4	5
Cathode width, W (mm)	10				
Cathode length, L (mm)	4	8	12	16	20
Inclination angle, θ ($^\circ$)	0, 45, 90, 120, 135, 150, 160, 170, 175, 177.5				



Results

Detection of the CCD

- Voltage increases → Current density increases → Drops sharply after reaching CCD
 - N-shaped curve
- Determination of CCD
 - Maximum average current density immediately before a spike in standard deviation

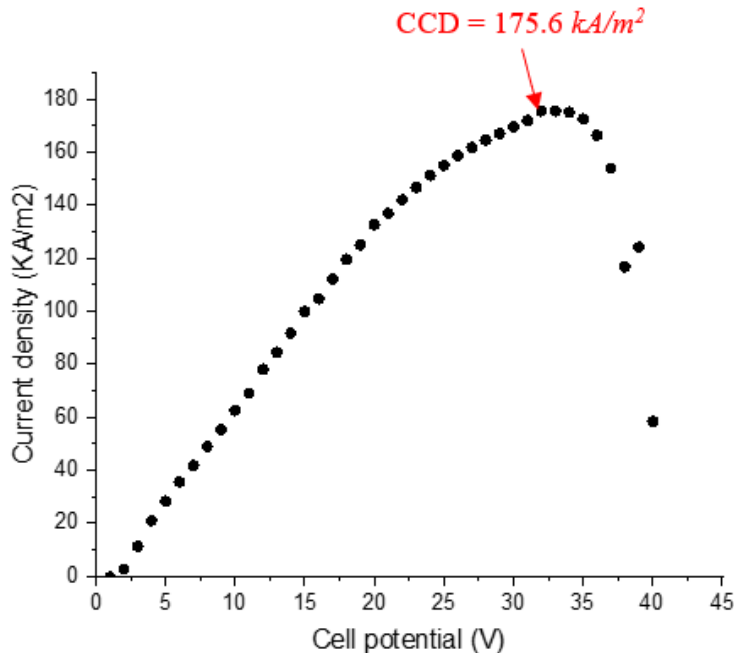


Fig. 4. V-I curves (Case 1, 0°)

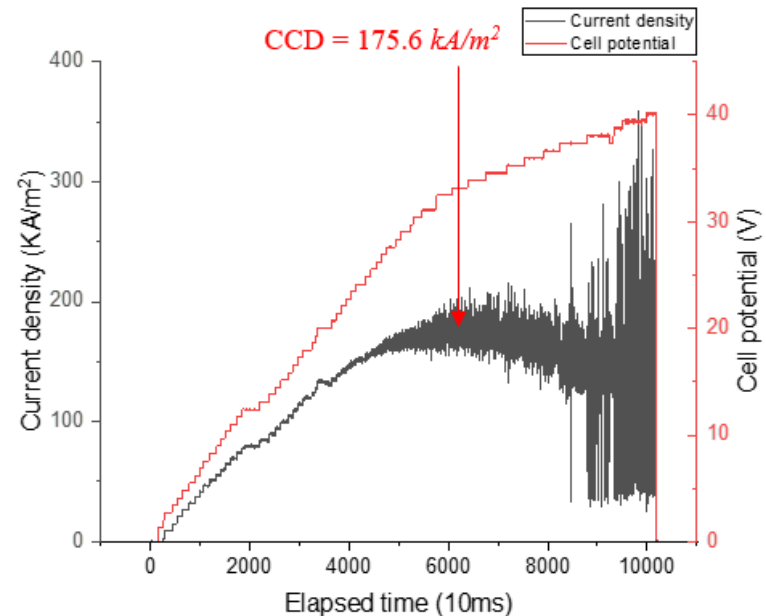
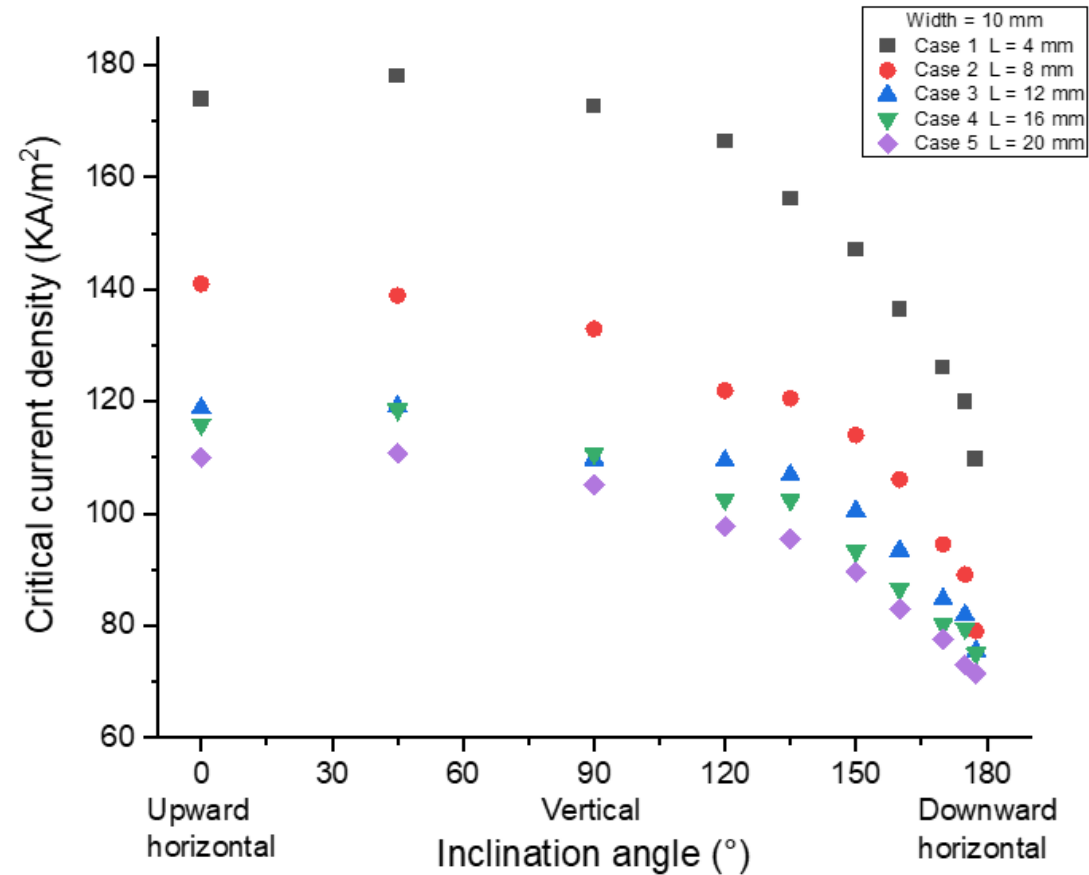


Fig. 5. Changes in voltage, current density over time when controlling voltage (Case 1, 0°)

Results

CCD trends with inclination angle and cathode length



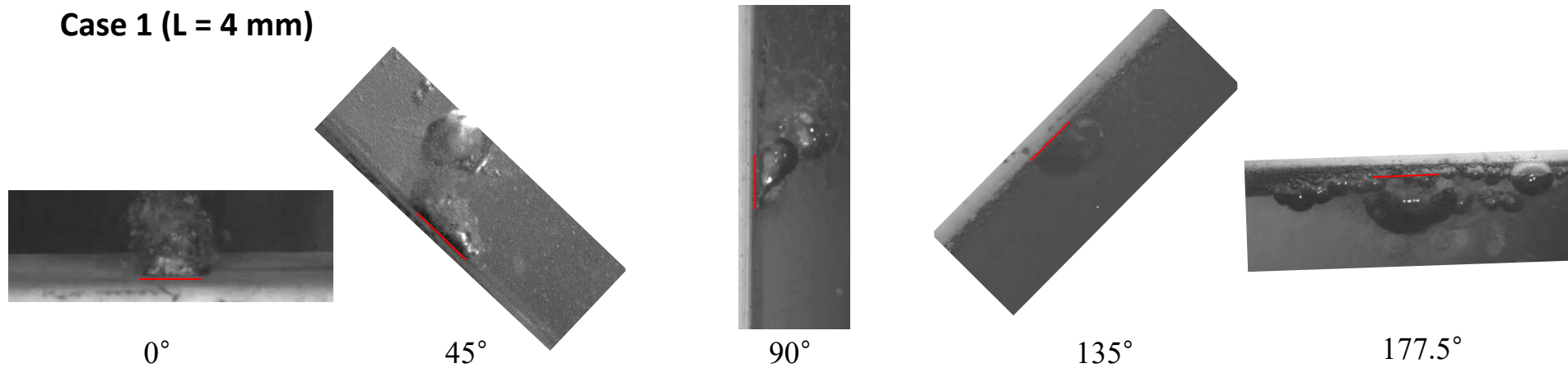
- CCD decreases monotonically with increasing inclination
 - Sharp drop upon entering the downward-facing region
- CCD decreases with increasing cathode length
 - Extended bubble escaping length causes bubble accumulation

Fig. 6. CCD trends with inclination angle and cathode length

Results

Hydrogen Bubble Behavior Analysis at the CCD

Case 1 (L = 4 mm)



Case 5 (L = 20 mm)

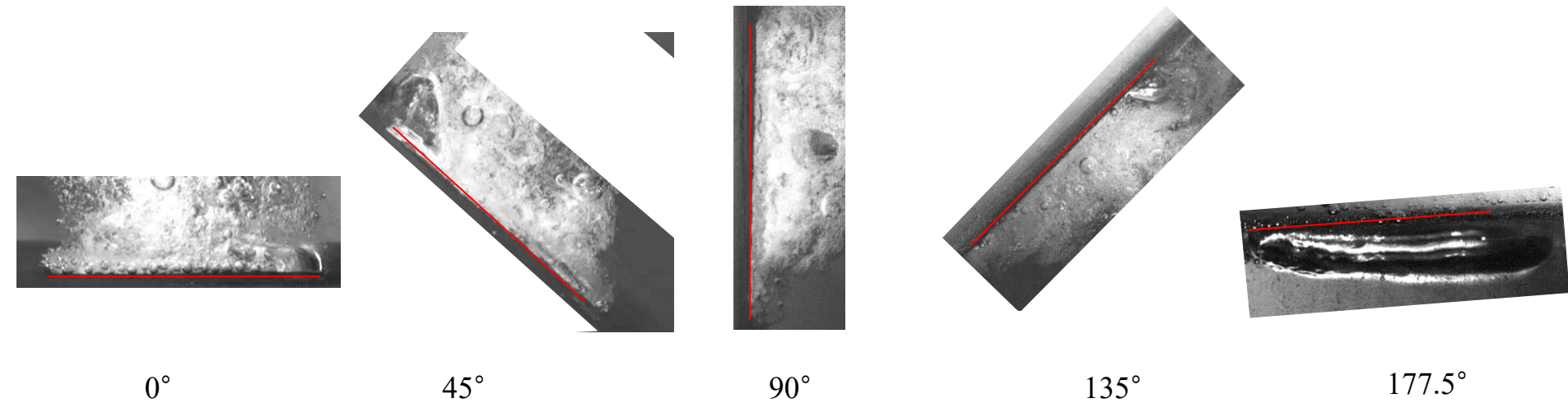


Fig. 7. Post – CCD partial film behavior by inclination

Conclusions

Summary of work

- Established a CCD baseline dataset over 50 test cases
 - Covering **geometric conditions** expected within the future curved 2D channel
 - Provide basis for **electrode sizing and channel design**

Findings

- Design basis for 2D channel
 - **Max CCD: 105 kA/m^2 (Case 5, 90°)**
 - **Operating limit $\leq 80 \text{ kA/m}^2$ (DNBR = 1.3 applied)**
- Increasing inclination angle and vertical length of cathode reduce CCD similar to CHF data

Future work

- Design and fabricate a **2D curved channel test section based on CCD baseline**
- **Construct two-phase flow regime map applicable to HCSG**

Thank you!

References

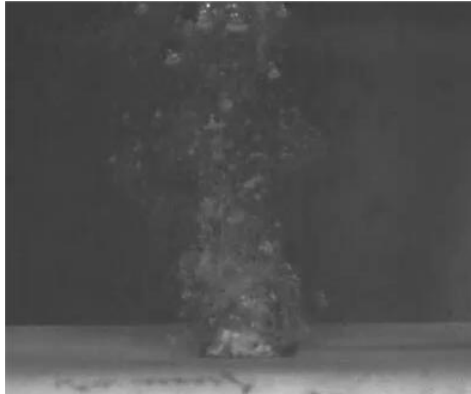
- [1] Kim, M.G., Yun, B., Jeong, J.J., 2025. Development of a New Correlation for Saturated Flow Boiling Heat Transfer in a Helically Coiled Tube. Nuclear Technology 211, 93–110. <https://doi.org/10.1080/00295450.2024.2319926>
- [2] Zaidi, O., Yun, B.J., Jeong, J.J., 2026. Development of frictional pressure drop models for single- and two-phase flows in a helically coiled tube. Nuclear Engineering and Technology 58, 104134. <https://doi.org/10.1016/j.net.2026.104134>

Appendix

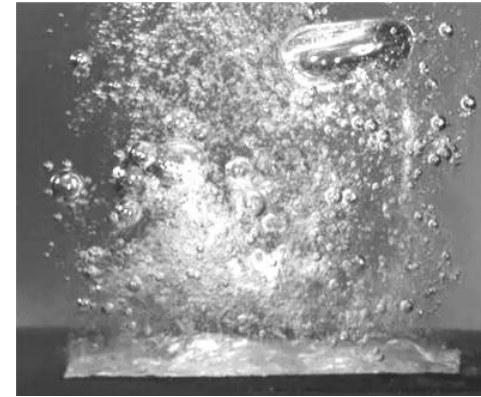
Prior Research

Author	Measurement	Variables & Findings
Ohk (2019)	CHF (Converted from CCD), Pool	<ul style="list-style-type: none">Inclination $90^\circ \rightarrow 177.5^\circ$ (downward-facing): sinusoidal decrease, drastic drop beyond 170°Channel gap size 1 ~ 10 mm: CHF \downarrow as gap narrows (impeded rewetting)
Han (2022)	CCD, Forced	<ul style="list-style-type: none">Inclination $90^\circ \rightarrow 172.5^\circ$ (downward-facing): CCD \downarrow as surface approaches horizontalMass flux 250 ~ 1500 kg/m²s: CCD \uparrow with mass flux increased (bubble sweep effect)
Park D.H. (2023)	CCD & V_b , Pool	<ul style="list-style-type: none">Cathode area \uparrow: CCD \downarrow (decrease rate depends on shape), $V_b \uparrow$Shape (disk vs rectangle): disk shows drastic CCD drop with area due to thick bubble layer growth; rectangle shows mild decrease with negligible bubble layer change. P/A (wetted perimeter/area) proposed as a unified parameter

Appendix



Case 1 (L = 4 mm), 0°



Case 5 (L = 20 mm), 0°

