

# Comparison of bubble departure diameter between high-pressure boiling and hydrogen evolution reaction in water electrolysis under atmospheric pressure

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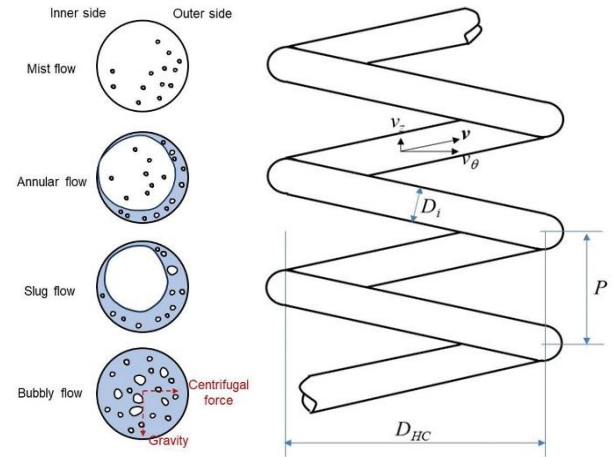
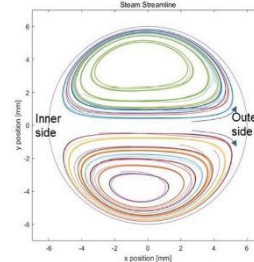
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2026. 5. 7

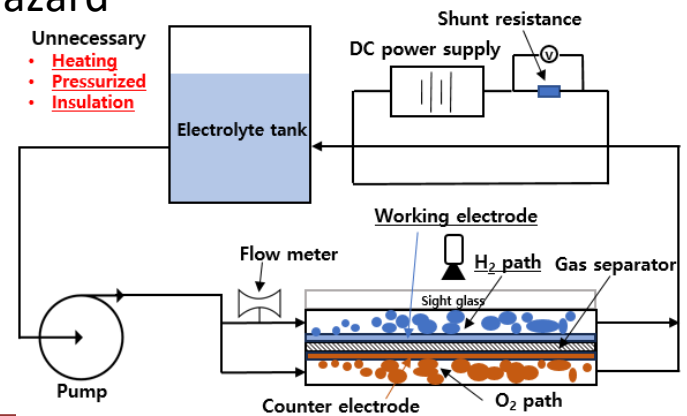
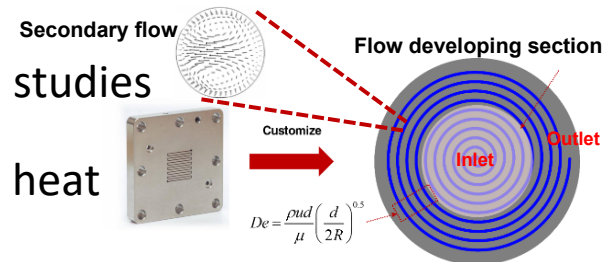
# Introduction

## i-SMR adopts Helical coil steam generator (HCSG)

- High-pressure two phase flow exists inside HCSG
- Two-phase flow is affected by centrifugal force



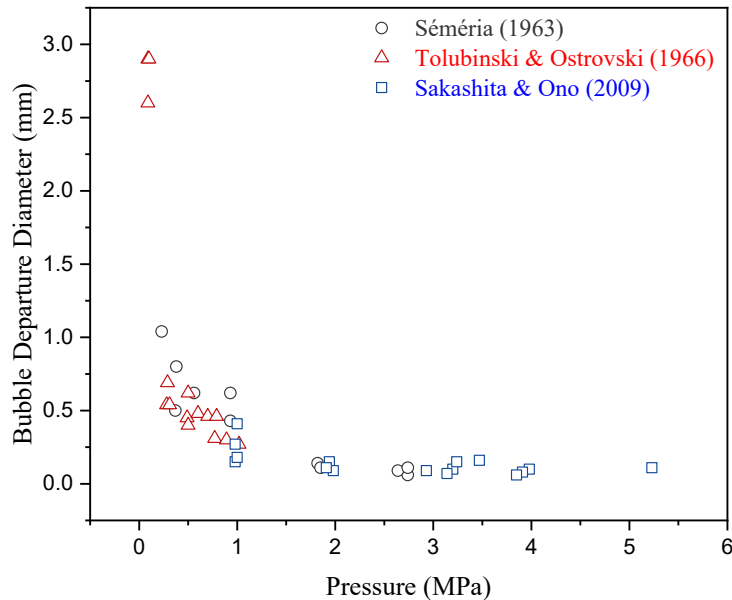
- Experimental data are limited due to the lack of visualization studies
  - High temperature and pressure conditions are limited in heat transfer experiments, because of high cost and hazard
- Direct visualization of HCSGs two-phase flow needed
- A **novel experimental method** is required
  - We suggest alkaline water electrolysis



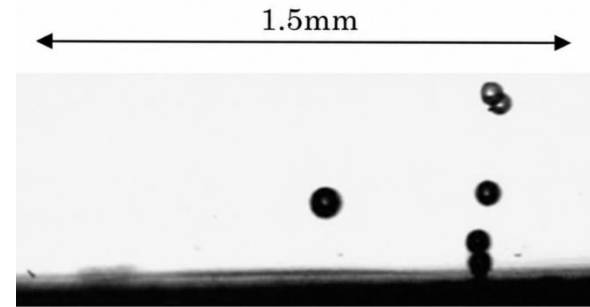
# Background

## A key parameter: small bubble departure diameter ( $D_d$ )

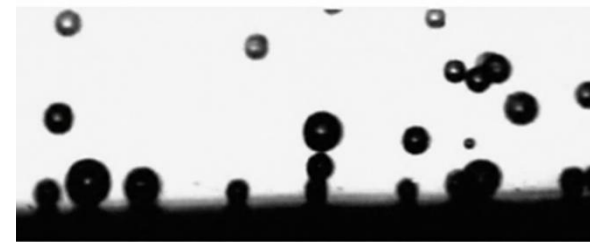
- The  $D_d$  decreases as the pressure increases
- At 5 Mpa (i-SMR), the  $D_d$  is **~0.11 mm**
  - Lack of experimental data



High-pressure  $D_d$  data (Kossolapov, 2024)



(a)  $q=0.0212\text{MW/m}^2$



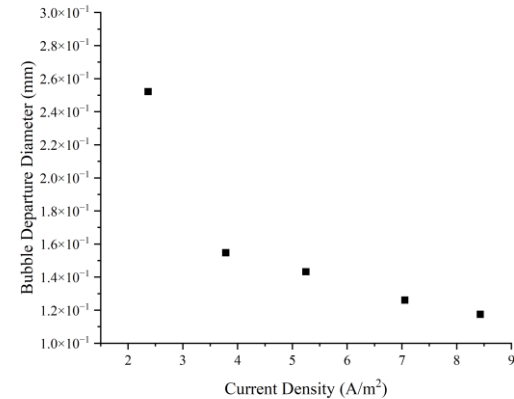
(b)  $q=0.0377\text{MW/m}^2$

Vapor bubbles on a horizontal plate (Sakashita, 2008)

# Experimental methodology

## Physical properties of water electrolysis

- $D_d$  of hydrogen value is  $\sim 0.1\text{mm}$
- But, **different physical properties** between water electrolysis and vapor bubbles
- Dimensionless number affecting two-phase flow will be matched vary parameters



Water electrolysis  $D_d$  data (Park, 2021)

## Comparison of physical properties

	Water (vapor)			Water electrolysis (H <sub>2</sub> /O <sub>2</sub> )
<b>P (MPa)</b>	1	3	5	0.101 (1 atm)
$\rho_l$ (kg/m <sup>3</sup> )	887.13	821.90	777.37	1076.6
$\rho_g$ (kg/m <sup>3</sup> )	5.15	15.00	25.35	0.084/1.33
$\sigma$ (mN/m)	42.22	29.84	22.76	74.5
$\mu_l$ (μPa-s)	150.49	114.17	100.12	$\sim 1700$

Key differences: density, viscosity, surface tension

$$Fr = \left( \frac{\rho_g j_g^2}{g(\rho_l - \rho_g)D_h} \right)^{0.5}$$

$$De = \frac{\rho u d}{\mu} \left( \frac{d}{2R} \right)^{0.5}$$

$$Bo = \frac{g(\rho_l - \rho_g)D_h^2}{\sigma}$$

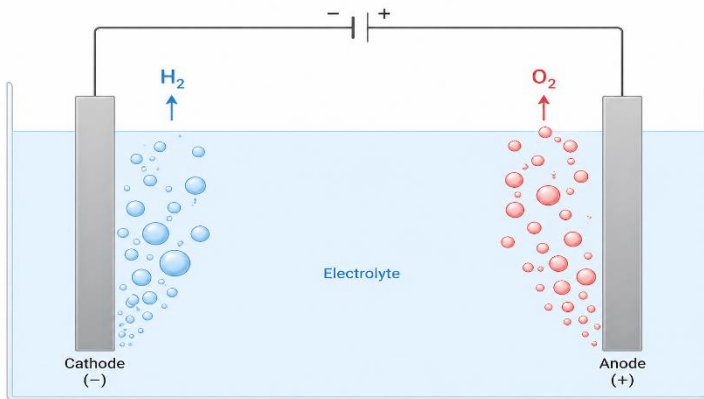
# Experimental methodology

## Similar bubble generation mechanism

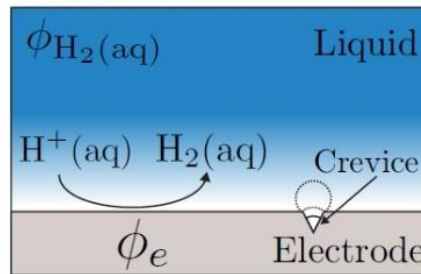
- Bubble growth takes place at surface cavity where tiny gas is entrapped in
  - Heterogeneous nucleation

## Similar Bubble parameter between boiling and water electrolysis

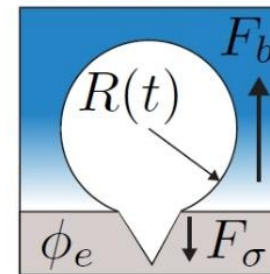
- Nucleation Site Density ( $N_a$ )
- Bubble Departure Diameter ( $D_d$ )  $\longrightarrow$  we focus on  $D_d$
- Bubble Frequency ( $f$ )



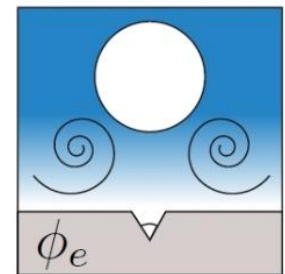
A) Nucleation



B) Growth



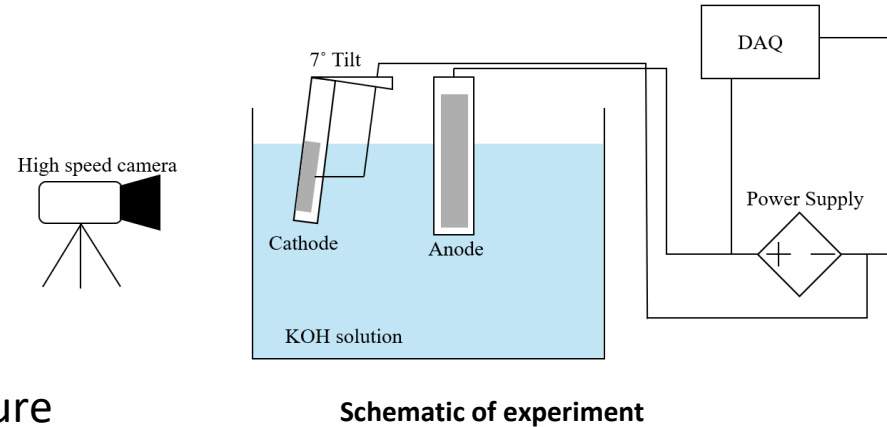
C) Detachment



# Experimental setup

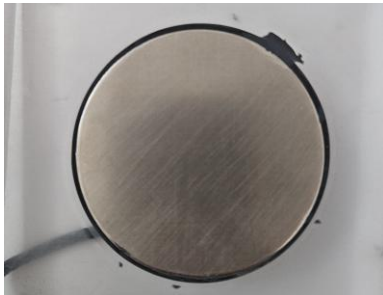
## Two-electrode water electrolysis system for hydrogen evolution

- Working electrode: cathode (Ni)
- Counter electrode: Anode (Ni)
- Electrolyte: 10 wt% of KOH solution
- Using surfactant (Triton X-100)
- Using high-speed camera for hydrogen capture



Test matrix

Case (#)	Concentration (ppm)	Current Density (A/m <sup>2</sup> )
1	0	0.98, 3.55, 6.03, 8.34, 10.60
2	37.50	
3	112.00	



56 mm diameter of Ni



Experiment setup

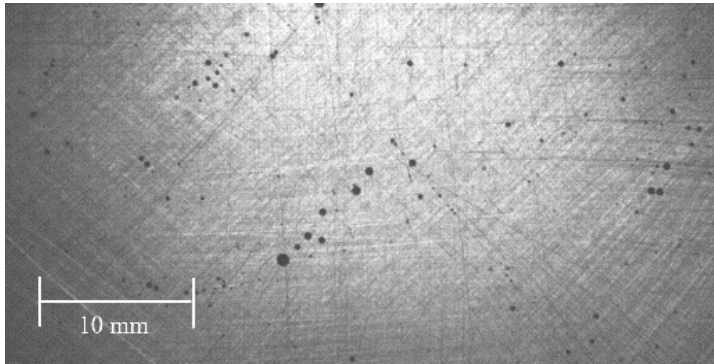
# Results

## Change current density and surfactant concentration

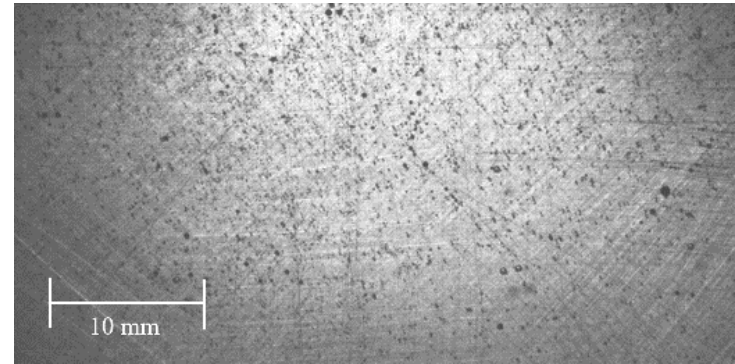
- Current density increase
- Surfactant concentration increase



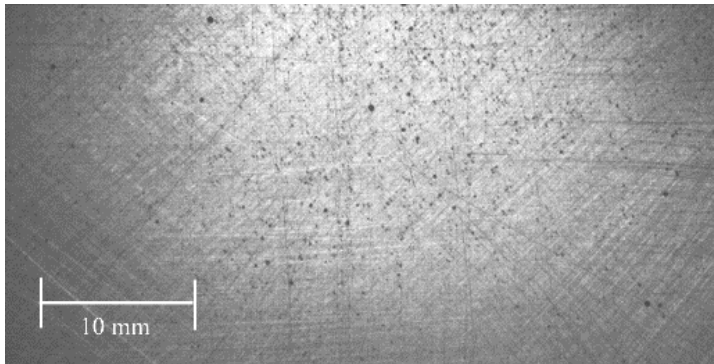
In conclusion,  $D_d$  decreases.



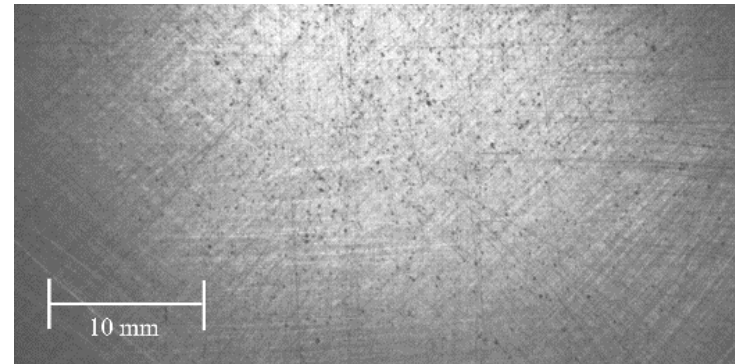
0 ppm, 0.97 A/m<sup>2</sup> (0.38 mm)



0 ppm, 10.52 A/m<sup>2</sup> (0.30 mm)



37.5 ppm 10.55 A/m<sup>2</sup> (0.22 mm)

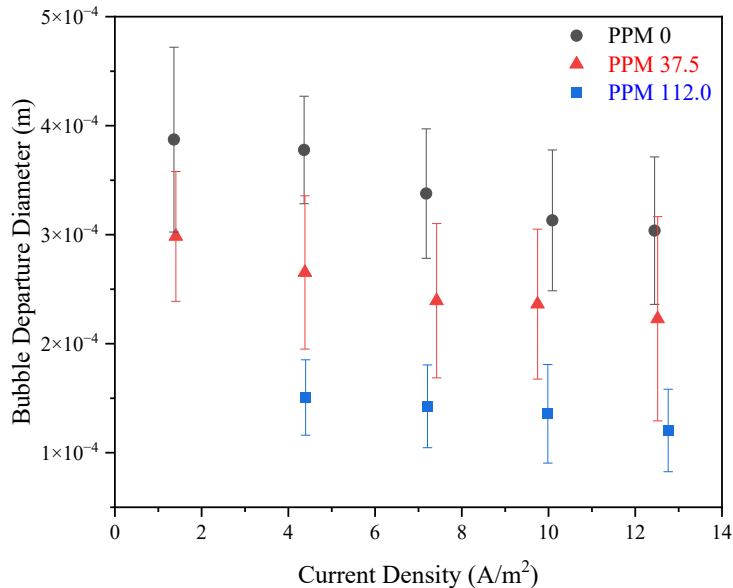


112 ppm 10.74 A/m<sup>2</sup> (0.12 mm)

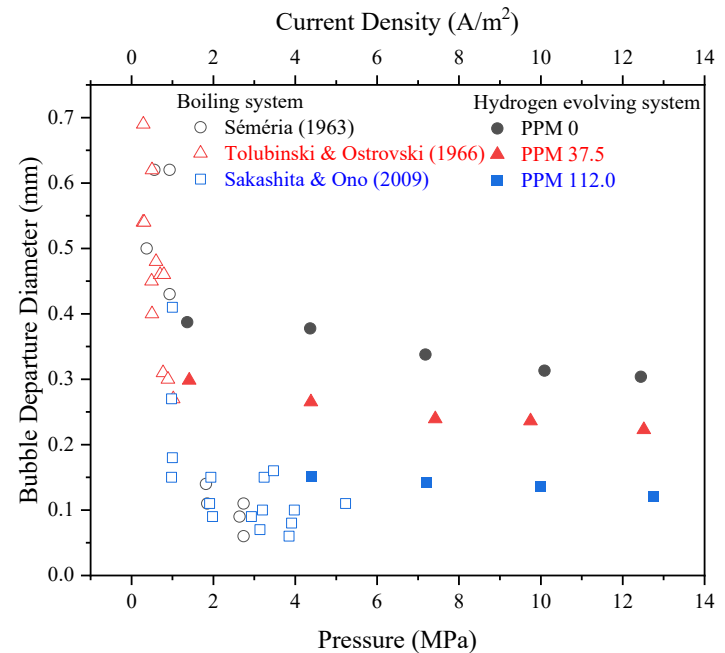
# Results

## Change the $D_d$ in water electrolysis using surfactant

- The lowest  $D_d$  (hydrogen)  $\rightarrow$  **0.12 mm**
  - Similar  $D_d$  vapor bubble
- The value is i-SMR operating conditions ( **$\sim 5\text{MPa}$** )



Comparison of  $D_d$  according to concentration of surfactant



Comparison of  $D_d$  boiling bubble and hydrogen bubble

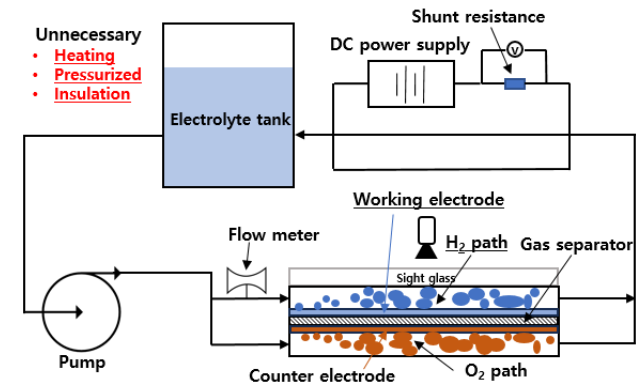
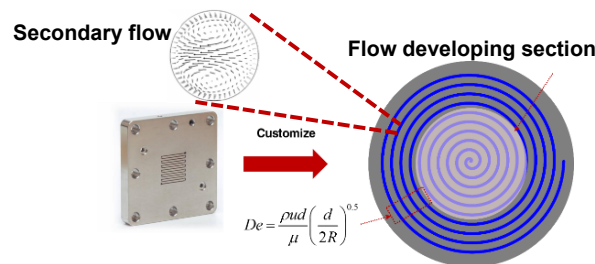
# Conclusion

## $D_d$ at high pressure vapor bubble is imitated using water electrolysis

- A preliminary study to investigate two-phase flow in HCSG introducing Water electrolysis
- Can be simulated under room temperature and standard pressure
- $D_d$  at 5MPa (i-SMR)
  - We manipulate  $D_d$  of hydrogen to match  $D_d$  of vapor in 5MPa (i-SMR)
  - Current density & surfactant were used

## Future work

- Dimensional analysis research on physical properties is needed
- Measurement  $D_d$  under flow conditions → Measured  $D_d$  considering centrifugal force and forced convection the HCSG structure



# Thank you!

# References

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- [1] Operation and Performance Analysis of Steam Generators in Nuclear Power Plants
- [2] S. H. Kwon, S. J. Lee, S. I. Kim, H. K. Park, Preliminary Experiment on Individual Hydrogen Bubble Behaviors in Alkaline Water Electrolysis, Transactions of the Korean Nuclear Society Spring Meeting, 25S-493, 2025.
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