

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

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1. Introduction

The i-SMR, a small modular reactor (SMR) being developed by Korea Hydro & Nuclear Power, adopts helical coil steam generators (HCSGs). In order to achieve a safer and more efficient operation of the HCSGs, the existing heat transfer and pressure drop models need to be improved. It is needless to say that understanding the two-phase phenomenon inside the HCSGs tube would play a crucial role in improving the existing models.

However, the two-phase flow in the HCSGs are difficult to visualize and analyze due to the high-temperature and high-pressure conditions. Furthermore, the presence of secondary flow due to centrifugal force makes prediction difficult using existing flow regime maps. We propose a novel experimental methodology to visualize two-phase flow patterns under high-pressure conditions.

In previous work [1], we linked boiling system and hydrogen evolving system to confirm the similarity between heat transfer and mass transfer. The behavior of hydrogen bubbles in water electrolysis and the vapor on the heated surface has been found to have similar behaviors.

Based on this finding, the experimental methodology aims to mimic the two-phase flow in a high-pressure boiling system via alkaline water electrolysis at standard pressure and room temperature.

In order to establish the proposed methodology a preliminary experiment was performed in this work to measure bubble departure diameter (D_d), varying surface tension (σ), which are the key factors affecting the two-phase flow pattern. A 10 wt% KOH aqueous solution was used as electrolyte, and nickel was used as an electrode.

2. Background

Previous study compared the bubble parameters such as nucleation site density (N_s), bubble frequency (f), and D_d in boiling and electrolysis systems [2]. The D_d measured in the copper electrode water electrolysis system using H_2SO_4 was approximately 0.1 mm under standard pressure.

Fig. 1 shows the D_d under pool conditions according to pressure [3]. The i-SMR HCSGs operate at

approximately 5 MPa, at which the D_d is on the order of 0.1 mm, as shown in Fig. 1.

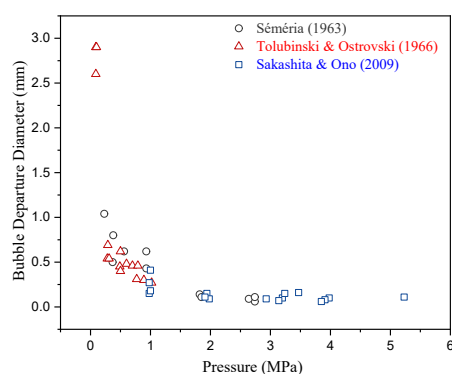


Fig. 1. Summary of high-pressure D_d data; reproduced form [3].

3. Experimental setup

3.1 Experimental apparatus and electric circuit

Fig. 2 shows the experimental setup and electrical circuit used in this study. A nickel cathode of 56 mm in diameter and a nickel anode 100×200 mm were fabricated for the experiment. The cathode was polished using 10,000 grit sandpaper to create a smooth surface. Fig. 3 shows a photograph of the cathode used in this study.

A 10 wt% aqueous KOH solution was employed as working fluid and commercial surfactant (Triton X-100) was used to reduce σ of the electrode. The experiment was conducted at standard pressure and room temperature (20 °C). The cathode was tilted as $\sim 7^\circ$ to allow to hydrogen bubbles to escape. Voltage and current were controlled using a power supply (Keysight E36232) and measured using a data acquisition system (NI9238, NI9227). Hydrogen behavior was captured using a high-speed camera (Phantom Lab 110).

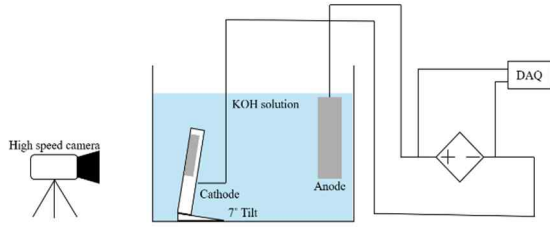


Fig. 2. Experimental apparatus and electrical circuit for bubble behavior analysis.



Fig. 3. Shape of Nickel cathode.

3.2 Test matrix and Experimental procedure

Table I shows test matrix. The concentration of surfactant was divided into three levels and D_d was measured by applying five different currents for each concentration case [4].

Table I: Test matrix

Case (#)	Concentration (ppm)	Current Density (A/m^2)
1	0	1.36, 4.36, 7.18, 10.09, 12.45
2	37.50	1.41, 4.38, 7.42, 9.75, 12.52
3	112.00	1.45, 4.40, 7.21, 9.98, 12.76

After applying current according to Table I, time duration was needed for a steady-state conditions. Once the steady-state-condition was established, hydrogen bubbles were captured using the high-speed camera, and then the voltage was increased to increased current density.

4. Results and discussion

Fig. 4 compares the D_d according to current density and surfactant concentration. Error bars represent the standard deviation. As the current density increases, the D_d decreases. The decreasing trend of D_d according to the current density would be affected by a rapid increase in active nucleation site density, which is an inherent feature of electrolysis in nature. Thus, typical trends of D_d show a contrast behavior between boiling and water electrolysis.

It is clearly observed that the surfactant concentration increases, the D_d decreases due to the

reduced σ . As shown in Fig. 4, the reduced D_d is affected predominantly by the surfactant rather than the current density.

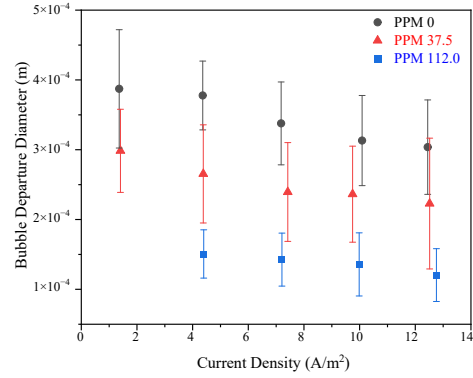
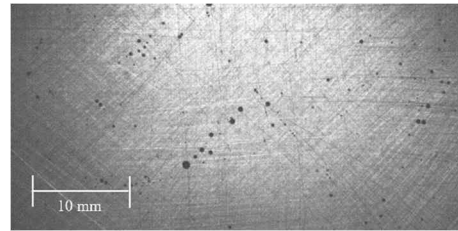
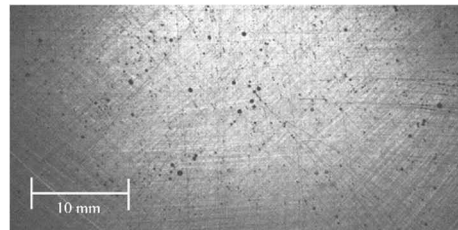


Fig. 4. Comparison of D_d according to concentration of surfactant.

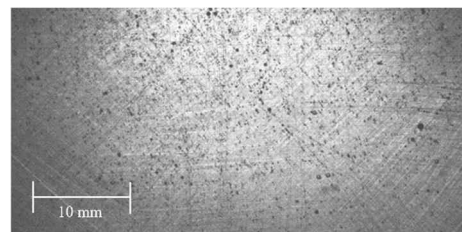
Fig. 5 and 6 are photographs of captured hydrogen bubbles, which support the measurement data in Fig. 4.



(a) 1.36 A/m^2

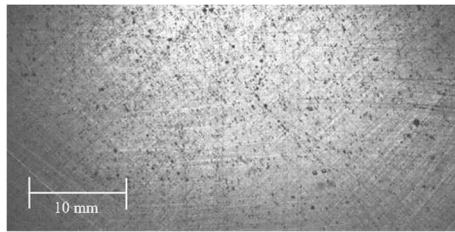


(b) 7.18 A/m^2

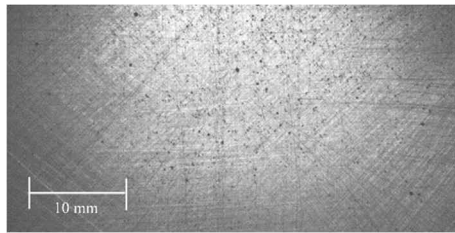


(c) 12.45 A/m^2

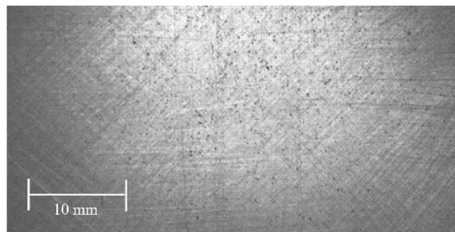
Fig. 5. Photographs of the D_d according to the current density.



(a) Case 1, 12.45 A/m²



(b) Case 2, 12.52 A/m²



(c) Case 3, 12.76 A/m²

Fig. 6. Photographs of the D_d according to the concentration of surfactant.

Fig. 7 compares the D_d values shown in Fig. 1 with the D_d values from this work. The minimum D_d of hydrogen in Fig. 4 was 0.12 mm, which corresponds to the D_d of boiling system at 5.23 MPa. This reduction in D_d was achieved by decreasing the surface tension through the use of a surfactant, thereby enabling the mimicry of high-pressure conditions up to 5.23 MPa. The results imply that the D_d measured under room temperature and standard pressure in the hydrogen evolving system can mimic a high-pressure boiling system.

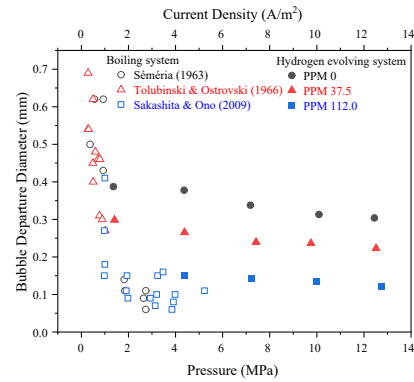


Fig. 7. Comparison of D_d boiling bubble and hydrogen bubble.

5. Conclusion

We measured the D_d under pool condition using hydrogen evolving system in 10 wt% KOH solution. The results compared with D_d under high-pressure conditions in the boiling system. In the hydrogen evolving system, the D_d decreased with increasing current density.

The D_d values could mimic the D_d values up to ~5 MPa, which fell into the operating range of i-SMR. Future work will be performed to measure D_d under flow condition. In addition, the experimental system will be further developed to mimic the internal condition of HCSGs by considering centrifugal effects and forced convection. and this study will be used to as basic data for two-phase flow simulation experiments.

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