Preliminary Experiment on Individual Hydrogen Bubble Behaviors in Alkaline Water Electrolysis

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1. Introduction

Advanced reactors, small modular reactors (SMRs) including non-water reactors would offer not only electricity but also thermal energy. When the grid system requires the reactor to perform the load-following operation, a water electrolysis system directly connected to the reactor can store the energy by producing hydrogen gas [1]. Hence, improvement of hydrogen generation in the water electrolysis would be a promising technology in the near future. Hydrogen bubbles generated during the water electrolysis exhibit hydrodynamic similarities to bubbles generated during the boiling heat transfer [2, 3, 4]. The work has been performed based on the analogy between heat and mass transfer, by connecting two research fields, boiling heat transfer and electrochemistry. Although some comparative studies have been conducted [2, 3, 4], the existing research mainly focuses on the H_2SO_4 electrolyte-copper electrode system. The present study investigates the bubble behavior in a KOH electrolyte-nickel electrode system, which is commonly used in commercial water electrolysis to observe the hydrodynamic behaviors of hydrogen based on the knowledge well-developed in boiling heat transfer. The active nucleation site density (N_a), bubble departure diameter (D_d), and bubble frequency (f) were measured and visualized using a high-speed camera. These parameters were compared with the H_2SO_4-copper water electrolysis and boiling heat transfer systems to extend the analogous relationship.

2. Experimental setup

2.1 Experimental apparatus and electric circuit

Fig. 1 shows the experimental apparatus and electrical circuit used for the present work. A nickel cathode, diameter of 40 mm, and nickel anode, diameter of 56 mm were used, immersed in 1.94 M KOH electrolyte solution. The cell potential and current density were recorded using a data acquisition system (DAQ, NI9225), while bubble behavior was captured using a high-speed camera.

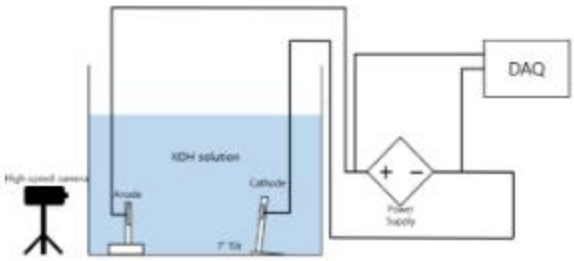

Fig. 1. Experimental apparatus and electrical circuit for single bubble behavior analysis

2.2 Experimental procedure and test matrix

This experiment was carried out under atmospheric pressure conditions. Both electrodes were connected to a DC power supply and installed vertically at the bottom of the tank. As listed in Table I, low currents (up to 13.6 mA) were applied to observe individual bubbles. After achieving steady-state conditions, the system was maintained for approximately 500 seconds, and the hydrogen bubble behavior was captured. In turn, the bubble parameters were quantitatively analyzed using image analysis software (PickPick) with a 0.265 px/mm resolution. The average surface roughness (R_a) values of the nickel cathode were measured by atomic force microscopy (AFM), and the average of R_a was 0.0038 μm (Table II).

Table I: Applied currents density for single bubble behavior analysis

Cases	Current density (A/m^2)
1	1.1937
2	3.8197
3	6.1275
4	8.5148
5	10.8225

Table II: Surface roughness of the nickel cathode

Trials	***R_a(μm)***
1	*0.0036*
2	*0.0037*
3	*0.0031*
4	*0.0031*
5	*0.0041*
6	*0.0046*
Average	*0.0038*

3. Results and discussion

3.1 Active nucleation site density

Fig. 2 compares the N_a between the KOH-nickel system and the H_2SO_4-copper system [2]. The N_a gradually increased with increasing current density in the KOH-nickel system, which is a similar tendency to the H_2SO_4-copper system. Despite the significantly lower surface roughness of the nickel electrode (0.0038 μm) compared to the copper electrode (0.148 μm), the N_a was higher than the copper electrode. This suggests that factors other than surface roughness may have influenced the N_a; electrolyte type, electrode material, solution conductivity, and overpotential. The measured N_a, the range of 10^6 to 10^7 is about 10^2 to 10^3 times higher than that of the boiling heat transfer cases.

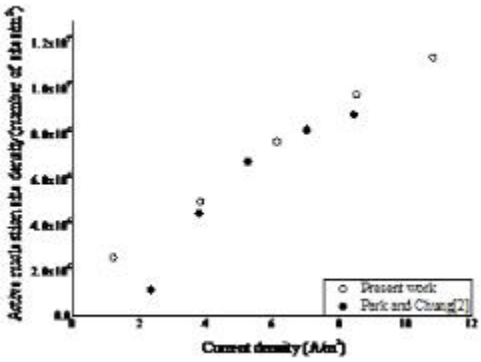

Fig. 2. Comparison of active nucleation site density.

3.2 Bubble departure diameter

Fig. 3 compares the D_d between the KOH-nickel system and the H_2SO_4-copper system [2]. In the KOH-nickel system, the D_d decreased as the current density increased, consistent with the H_2SO_4-copper system. This contrasts with typical boiling systems, where the D_d usually increases with heat flux. However, there is a opposite trend of D_d in the heat transfer system by Judd and Hwang [5]. They reported a decrease in D_d with increasing heat flux due to the rapid increase in the N_a using dichloromethane (methylene chloride) under 0.5 atm. Likewise, the decreasing trend of the D_d in the water electrolysis systems may also be influenced by the sharp increase of the N_a. And the D_d in the water electrolysis systems is approximately 10 times smaller than that observed during boiling. Since the surface tension of the KOH-nickel system is between 75 mN/m and 98 mN/m [6], which is comparable to water surface tension (72 mN/m), there would be additional parameters affecting decrease in bubble departure diameter.

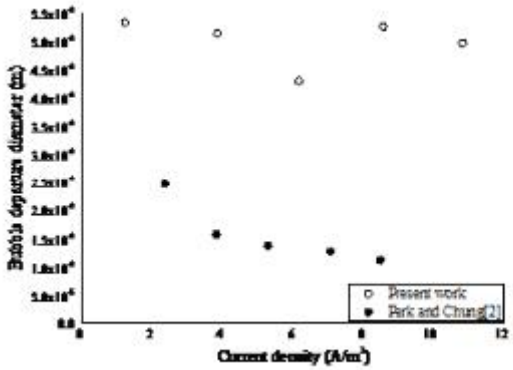

Fig. 3. Comparison of bubble departure diameter.

3.3 Bubble frequency

Fig. 4 compares the f between the KOH-nickel system and the H_2SO_4-copper system [2]. The f increased with the current density, consistent with previous studies. However, in both hydrogen-evolving systems, only bubble growth time (t_g) could be measured, while waiting time (t_w) could not be measured due to the incoherent formation of the N_a. Since the t_w could not be measured in the hydrogen evolving system, a direct comparison of the f between the hydrogen evolving system and boiling heat transfer system was not available.

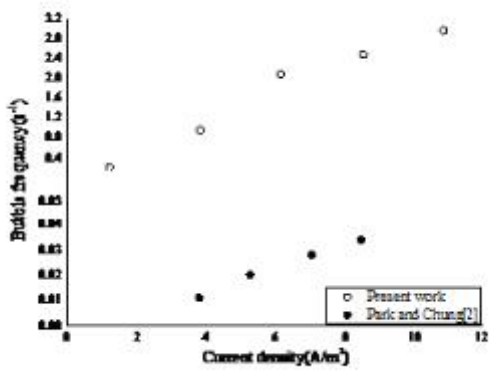

Fig. 4. Comparison of bubble frequency.

4. Conclusions

The present work measured the bubble characteristics of the hydrogen using 1.94 M KOH electrolyte-nickel electrodes. Bubble parameters such as N_a, D_d, and f were measured from the photographic data and compared to previous studies on the H_2SO_4-copper systems and existing heat transfer data.

The N_a increased gradually with the current density, exhibiting behavior consistent with the previous work and boiling system. In contrast, D_d exhibited a decreasing trend with increasing current density, consistent with the previous studies. This decreasing trend is rarely observed in boiling systems and contrasts with the typical trend observed in conventional boiling heat transfer. The f increased with the current density, similar to the previous work. Since boiling systems show significant dependence of the t_g and t_w on the heat transfer characteristics, future work on the f involving detailed video analysis and flow simulations is recommended.

It was confirmed there are hydrodynamic similarities and differences between the boiling heat transfer and hydrogen evolving systems. However, further investigations are necessary to clarify the contradictory trend of D_d, the inability to measure t_w, and to explore additional factors influencing N_a apart from surface roughness.

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