Imitation of Boiling Curve depending on the Different Control Modes using a Water Electrolysis

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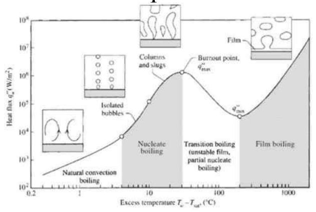
1. Introduction

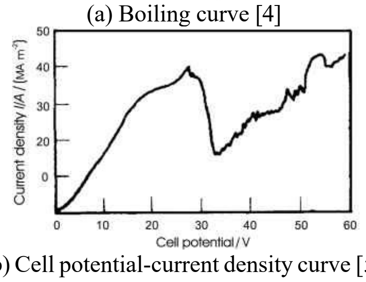
In the boiling curve, the fluid temperature changes depending on the different control modes. Since the fluid never encounters the transition boiling regime in the power controlled system such as the nuclear power plant, the critical heat flux (CHF) becomes an important parameter for the reactor safety due to the rapid temperature increase. Some studies [1, 2, 3] have reported similar relationships between the boiling and hydrogen systems. Based on the fact that systems have a specific upper operation limit called CHF and critical current density (CCD), this work performed experiments to identify the similarity between the boiling curve and the cell potential-current density curve depending on the different control modes. The power control mode was substituted by the current control mode, and the temperature control mode was substituted by the cell potential control mode. The experiments were performed using a water electrolysis, which generates hydrogen bubble at the cathode. The behavior of hydrogen bubbles was captured the high speed camera.

2. Background

It has been reported that the hydrogen evolving and boiling systems represent similar relationships in several studies [2, 3]. Both the CHF and CCD share N-shaped curve as shown in Fig. 1, which can be obtained by temperature control or cell potential control mode.



(a) Boiling curve [4]



(b) Cell potential-current density curve [5]

Fig.1. Similar N-shaped curves.

3. Experimental setup

The experimental apparatus and electric circuit are described in Fig. 2. The copper cathode (horizontal cylinder) and the copper anode (block) were located inside a glass container filled with the aqueous solution of sulfuric acid (H_2SO_4) of 1.5 M at atmospheric pressure and the room temperature of 294 K. Power supply (Keysight N8952A) and data acquisition system were employed to record cell potential (NI9225) and current. The current was recorded by measuring potential drop (NI9238) across the shunt register with small resistance, 0.1 mΩ. The high-speed camera (Phantom Lab 111 6GMono, Vision Research) captured the hydrogen behavior during the experiments.

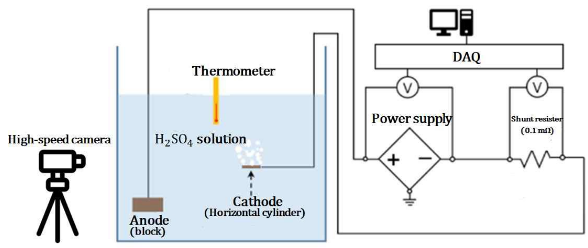
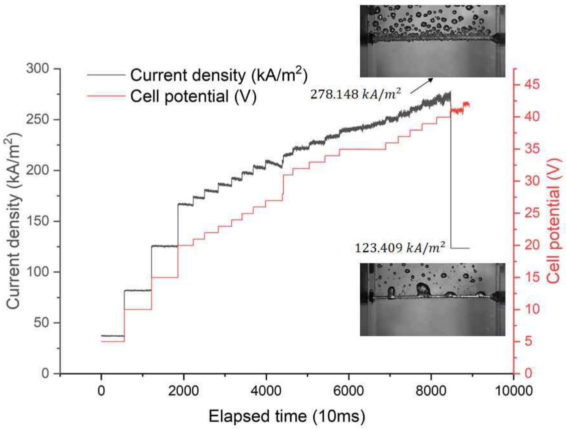


Fig. 2. Experimental apparatus and electric circuit.

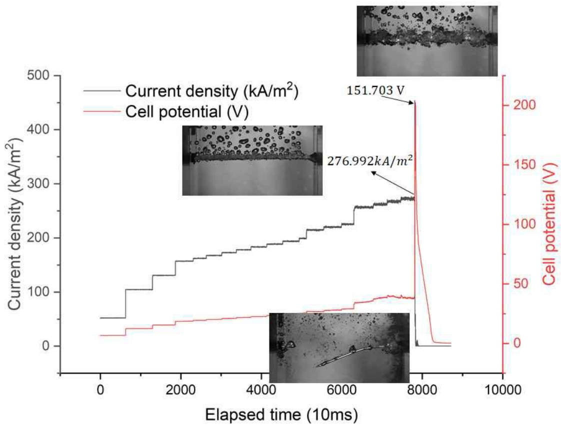
4. Results and discussion

Fig. 3(a) shows cell potential and current density according to the time, when voltage was controlled, which corresponds to the temperature control mode in the boiling system. Initially, as the voltage increased, the current density increased, just like the nucleate boiling regime. At a certain high cell potential was applied, the current density reached a maximum value, which is called the CCD and is similar to the CHF. After that, the current density decreased, which is similar to the transition boiling approaching to the Leidenfrost point. The sudden drop of current density was due to the hydrogen film covered the cathode surface as shown in the Fig. 3(a).

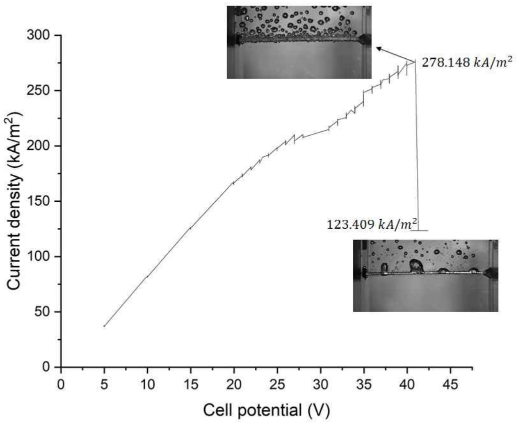
Fig. 3(b) reproduces Fig. 3(a) to show similar trend to the boiling curve. Although the experiment was terminated before stable film regime, a ridge-shape curve was obtained.



(a) Controlling the cell potential time dependent behavior of cell potential and current density

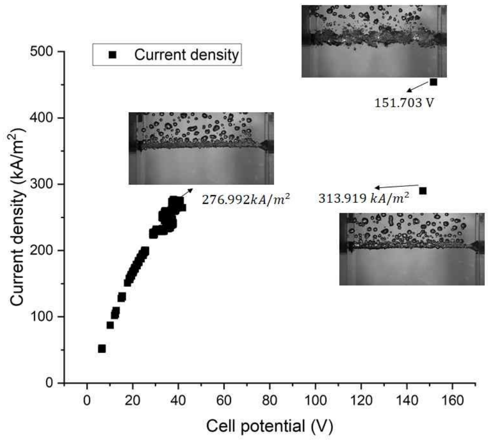


(a) Controlling the current time dependent behavior of cell potential and current density



(b) Cell potential and current density at controlling the cell potential

Fig. 3. Controlling the cell potential



(b) Cell potential and current density at controlling the current

Fig. 4. Controlling the current

Fig. 4(a) shows cell potential and current density according to the time when current was controlled, which corresponds to the power control mode in the boiling system. Initially, as when the voltage was controlled, the voltage increased as the current increased. It can be seen that when the current density was applied higher than the CCD, rapid increase in cell potential was measured, which is similar to rapid increase in the in the boiling system. The increased overpotential subsequently increased the temperature of the cathode resulting in the failure of the cathode.

Fig. 4(b) reproduces Fig. 4(a) to show similar tendency to the power controlled boiling curve. The system did not encounter transition boiling regime, similar to the boiling system.

5. Conclusion

The work obtained the cell potential-current density curves according to the cell potential and current control modes, which included similar characteristics to the boiling system.

Based on the result, future works to reveal analogy between the heat and mass transfer will be performed in two perspectives; 1) extension of two-phase flow analogy, and 2) augmentation of hydrogen production rate by utilizing conventional boiling studies, which have been extensively performed.

Acknowledgement

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REFERENCES

[1] H.K. Park and B.J. Chung, Comparative analysis of bubble behavior between boiling and hydrogen evolving system

at horizontal cylinders, Heat and Mass Transfer, Vol. 58, pp. 779–789, 2022.

[2] B. Mazza, P. Pedeferri, G. Re, Hydrodynamic instabilities in electrolytic gas evolution, Electrochim Acta, Vol. 23, pp. 87–93, 1978.

[3] H. Vogt, Heat transfer in boiling and mass transfer in gas evolution at electrodes – The analogy and its limits, Int J Heat Mass Transf, Vol. 59, pp. 191-197, 2013.

[4] A. Bejan, Convection Heat Transfer, 4th edn Wiley, New York, 2013.

[5] C.W.M.P. Sillen, E. Barendrecht, L.J.J. Janssen, S.J.D. Van Stralen, Gas bubble behaviour during water electrolysis, Int J Hydrog Energy, Vol. 7, pp. 577–587, 1982.