An experimental study of pool boiling on micro-pillar surface under heaving condition

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1. Introduction

The domestic shipbuilding industry has been engaged in active research into floating offshore nuclear power plants, with a particular focus on the potential for growth in the nuclear power plant business. The thermo-hydraulic phenomenon of offshore nuclear power plants is subject to the influence of ocean motion, with heaving – defined as linear motion up and down – resulting in a change to the acceleration acting on the system. This alteration in acceleration exerts an impact on the thermo-hydraulic phenomenon, with a body of previous studies having been conducted in this area.

Previous studies [1,2] have reported that CHF decreases with increasing acceleration. Therefore, in this study, a pool boiling experiment was performed under heaving conditions by fabricating surfaces with different topographical characteristics to enhance CHF.

2. Methods and Results

2.1 Methods

The platform is designed to move up and down in a linear motion, following a continuous sinusoidal wave. The maximum acceleration of the platform is 0.45g, with an amplitude of 1000 mm and a period of 3 seconds. Under heaving conditions, the vertical oscillation of the platform is measured using a wire sensor. The measurement results validate that the platform exhibits a sine wave pattern and has an acceleration of 0.45. The pool boiling phenomena are compared under static (0g) and heaving (0.45g) conditions.

The heater fabrication method and pool boiling experimental apparatus are based on previous research [4]. A micro-pillar structure was fabricated on a silicon wafer using MEMS processing (Fig. 1). The micro-pillar structure has a diameter of 45 µm, a height of 20 µm, and a pitch of 90 µm. The bare 500 nm oxide film was deposited in a furnace on a silicon wafer. A platinum thin-film heater was fabricated on the back side of the wafer for heating and measurement. The effective heating area of the heater is 10 mm × 15 mm. The pool boiling experiment was conducted using the fabricated heater at atmospheric pressure with deionized (D.I.) water.

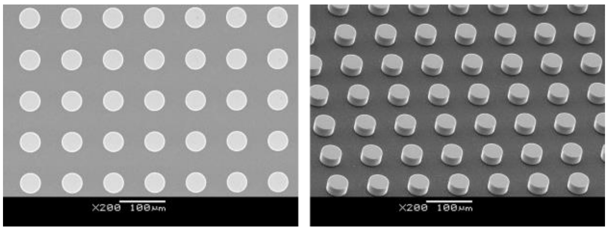

Fig. 1. SEM micrographs of micro-pillar surface

2.2 Results

A pool boiling experiment was conducted under static conditions to compare the differences between bare surfaces and micro-structured surfaces. These results are presented in the boiling curve shown in Fig. 2. The CHF values for the bare and micro-pillar surfaces were 1059 kW/m² and 1600 kW/m², respectively, showing approximately a 50% enhancement for the micro-pillar surface compared to the bare surface, consistent with previous studies [4]. This enhancement is attributed to the re-entry of liquid between the micro-pillar structures [3].

Under heaving conditions, the CHF values were 825 kW/m² for the bare surface and 1500 kW/m² for the micro-pillar surface. Compared to static conditions, the CHF decreased by 22% for the bare surface and by 6% for the micro-pillar surface under heaving. According to Otsuji and Kurosawa, CHF decreases by 14% under heaving conditions [1]. On the bare surface, CHF decreases within the margin of error reported in previous research. However, on the micro-pillar surface, CHF decreases by 6%, suggesting that the pillar structure delays CHF.

According to previous research, bubble behavior changes due to heaving motion. When the platform is positioned at the top, the net acceleration acting on the bubbles decreases, and the departure diameter and period of single bubbles increase. The increased bubble period allows for the evaporation of liquid in the microlayer beneath the bubbles, potentially leading to CHF. Therefore, the changes in bubble behavior induced by heaving result in a reduction in CHF.

On the micro-pillar surface, bubble behavior changes under heaving conditions, making it more difficult for bubbles to detach. However, the CHF on the micro-pillar surface decreased less than predicted. As shown in Fig. 3, the rewetting of the dry area beneath the bubbles may have occurred, effectively moistening the dry area and thus mitigating the reduction in CHF compared to the bare surface.

At heat fluxes exceeding 500 kW/m², mushroom-shaped bubbles are formed. At high heat fluxes, both surfaces exhibit a tendency for the heat transfer coefficient to decrease under heaving conditions compared to static conditions. Future work will involve visualizing the bubbles using a high-speed camera for further analysis.

3. Conclusions

In this study, the effects of micro-structured surfaces on CHF were investigated under both static and heaving conditions. Micro-pillar surfaces significantly enhanced CHF, showing a 50% increase compared to bare surfaces under static conditions. Under heaving conditions, the micro-pillar surface exhibited a smaller CHF reduction (6%) than the bare surface (22%), likely due to improved liquid re-entry into dry areas. These results suggest that micro-structured surfaces can effectively mitigate the adverse effects of dynamic conditions on boiling performance.

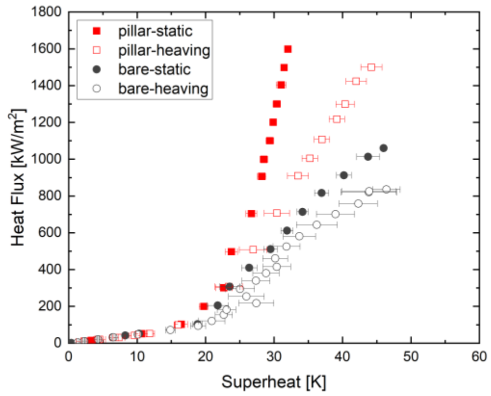

Fig. 2. Boiling curve under heaving conditions

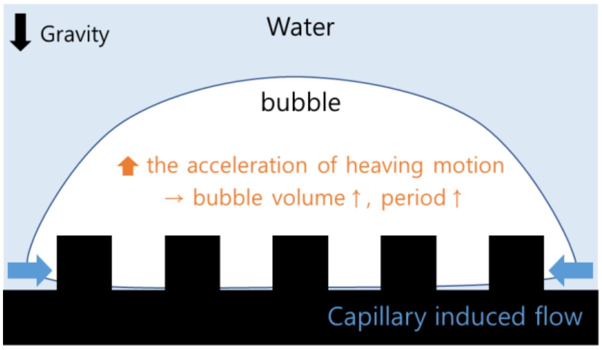

Fig. 3. Hypothesis on bubble dynamics under heaving motion: platform positioned at the top

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REFERENCES

[1] T. Otsuji, and A. Kurosawa, Critical heat flux of forced convection boiling in an oscillating acceleration field-I. General trends. Nuclear Engineering and Design, Vol. 71, No. 1, pp. 15-26, 1982.

[2] J.-S. Yoo, C.-W. Lee, H. Hong, H. Ko, J.-H. Ku, G.-W. Kim, et al., Experimental study on flow boiling CHF in annulus channel under heaving conditions using simulant fluid R134a targeting nuclear reactor applications, Applied Thermal Engineering, Vol. 236, 2024.

[3] D. I. Yu, H. J. Kwak, H. Noh, H. S. Park, K. Fezzaa, and M. H. Kim, Synchrotron x-ray imaging visualization study of capillary-induced flow and critical heat flux on surfaces with engineered micropillars, Science Advances, Vol. 4, 2018.

[4] H. R. Cho, S. C. Park, D. Kim, H.-M. Joo, and D. I. Yu, Experimental study on pool boiling on hydrophilic micro/nanotextured surfaces with hydrophobic patterns, Energies, Vol. 14, p. 14, 2021.