Proceedings of the 11th World Congress on Mechanical, Chemical, and Material Engineering (MCM'25)
Paris, France – August 19-21, 2025
Paper No. HTFF 240
DOI: 10.11159/htff25.240

Boiling Heat Transfer Enhancement on Micropillar Surfaces through Size-Controlled Nanoparticle deposition

Hyunmuk Park[1], Yoomyeong Lee[1], Donghwi Lee[1,2*]
[1] Graduate school of Mechanical-Aerospace-Electric Convergence Engineering, Jeonbuk National University
567 Baekje-daero, Deokjin-gu, Jeonju 54896, Republic of Korea
qwq4943@jbnu.ac.kr, lkwon24@jbnu.ac.kr
[2] Department of Mechanical System Engineering, Jeonbuk National University
567 Baekje-daero, Deokjin-gu, Jeonju 54896, Republic of Korea
dlee462@jbnu.ac.kr
* Corresponding author

Extended Abstract

Boiling heat transfer is widely utilized across various industrial sectors due to its superior heat transfer efficiency. In boiling heat transfer, critical heat flux (CHF) is a key parameter that represents the maximum acceptable heat flux on a heating surface. At the CHF point, bubbles generated from the surface merge to form a vapor film that covers the surface. Since vapor has low thermal conductivity, the vapor film causes a rapid temperature rise at surface temperature, potentially leading to surface destruction. To enhance the CHF, fluid supply to the heated surface must be improved. Fabricating micro/nano-sized structures on the heating surface is a well-known method for enhancing fluid supply. The capillary forces generated between the microstructures significantly promote fluid supply, thereby effectively suppressing vapor film formation [1]. Moreover, researchers have also studied enhancing the CHF by increasing surface roughness through the deposition of nanoparticles. Numerous previous studies have focused on enhancing heat transfer performance by depositing nanoparticles onto micropillar structures [2]. However, there is a notable lack of research on the effects of nanoparticle size on boiling heat transfer performance on fabricated microstructures

This study aims to address this gap by examining the changes in boiling heat transfer performance when nanoparticles of various sizes are deposited onto pre-fabricated micropillar structures (MPS). For this study, silica (SiO_2) nanoparticles with 8,60, and 400 nm were selected. MPS with a diameter, gap, and height of 4, 10, and 15 μm, respectively, were fabricated using MEMS processes. These MPS samples were placed in a boiling chamber with dimensions of 25 X 25 X 20cm^3. The chamber was filled with a nanofluid prepared by dispersing the nanoparticles in deionized water at a concentration of 0.0005wt%. The experimental procedure was conducted by increasing the heat flux applied to the micropillar structures by 10W/cm^2 every 10 minutes. After each 10-minute deposition period, bubble behavior was recorded using a high-speed camera. Additionally, a wicking experiment was conducted to characterize the fluid supply properties of the surface.

Experimental results showed that only the 400nm NMPS exhibited improvements of 13% in CHF and 17% in heat transfer coefficient (HTC). Furthermore, boiling experiments confirmed that increasing the size of the deposited nanoparticles led to a greater enhancement in CHF. Although we attempted to correlate this CHF enhancement with the wicking experiment results, the wicking characteristics alone could not fully explain the observed improvement in CHF on the coated surfaces. Based on these findings, a new CHF correlation is proposed that incorporates both wicking ability and surface porosity [3]. This correlation accurately predicted the experimental results within a ± 5% margin of error. These results indicate that CHF and HTC can be effectively enhanced by improving both wicking and porosity through the deposition of 400 nm nanoparticles on microstructured surfaces.

Acknowledgements

This work was supported by the Nuclear Safety Research Program through the Regulatory Research Management Agency for SMRs (RMAS) and the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. RS-2025-02309978); by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant (RS-2022-KP002703, Sector Coupling Energy Industry Advancement Manpower Training Program) funded by the Ministry of Trade, Industry and Energy (MOTIE); by an internal project (development of critical heat flux measurement technique using optical fiber temperature sensor) grant funded by KEPCO Nuclear Fuel Co., LTD, Republic of Korea by funding from KEPCO Nuclear Fuel under the Korean government (MOTIE).

References

[1] H.T. Nam, H.H. Cho, S. Lee, D. Lee, "Temperature-dependent wicking dynamics and its effects on critical heat flux on micropillar structures in pool boiling heat transfer," *Int. Commun. Heat Mass Transf.,* vol. 146, 106887.

[2] Z Cao, B Liu, C preger, Z Wu, Y Zhang, X Wang, ME Messing, K Deppert, J Wei, B Sundén, "Pool boiling heat transfer of FC-72 on pin-fin silicon surfaces with nanoparticle deposition," *Int. J. Heat Mass Transf.,* vol. 126, pp. 1019-1033, 2018.

[3] S. G. Liter, and M. Kaviany, "Pool-boiling CHF enhancement by modulated porous-layer coating: theory and experiment," *Int. J. Heat Mass Transf.,* vol. 44, no. 22, pp. 4287-4311, 2001.