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ENHANCING THE BOILING HEAT TRANSFER COEFFICIENT THROUGH CONFINEMENT

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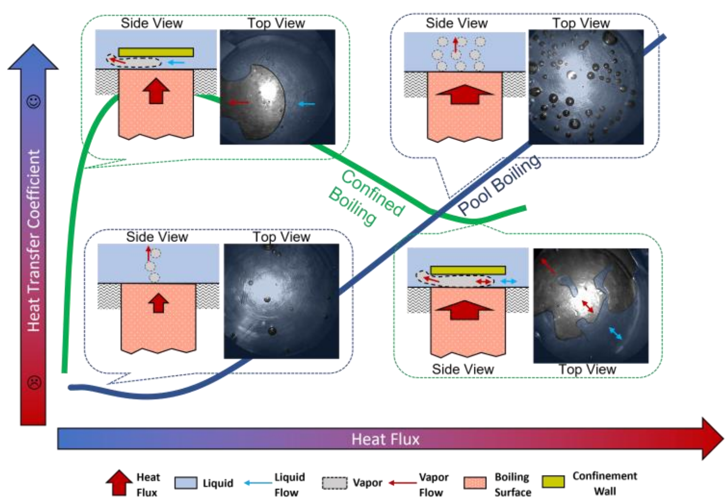
ABSTRACT

The high heat transfer coefficient associated with boiling is attractive for increasing the thermodynamic efficiency of power and refrigeration cycles. Notably, the boiling heat transfer coefficient depends on the applied heat flux. The maximum heat transfer coefficient occurs prior to the critical heat flux limit, concurrent with the highest active nucleation site density. Here, we propose a technique to enhance the heat transfer in conditions where conventional pool boiling results in low active nucleation site density. A confinement wall above the boiling surface allows only partial departure of the generated bubble. Residual vapor pockets, or stem bubbles, act as a seed for subsequent vapor bubble generation without requiring nucleation. This technique enhances the heat transfer coefficient up to five time higher than the unconfined pooling boiling.

KEYWORDS: Stem Bubbles, Liquid-vapor Interface, Two-phase Heat Transfer, Confined Boiling



INTRODUCTION

The extremely low thermal resistance typically associated with pool boiling enables a high transfer rate of thermal energy with a relatively low driving temperature difference. However, current measurements of the pool boiling thermal resistance are only a fraction of the theorical limit for the thermal resistance of vaporization from a flat liquid-vapor interface based on the kinetic theory of gases. In particular, the low surface superheat at the low range of boiling heat flux results in a low active nucleation site density, which reduces the effective vaporization interface area. Increasing the surface superheat enables the growth of a wider size range of vapor embryos which increases the density of the nucleation sites and the effective vaporization area [1]. As a result, the heat transfer coefficient for pool boiling is typically proportional to the boiling surface superheat and, subsequently, the heat flux [1].

Microscale surface modifications have been shown to enhance the heat transfer coefficient at the low rang of heat fluxes by increasing the nucleation site density [2]. However, microscale features are susceptible to fouling resulting in deterioration of the enhancement over time [3]. In this study, we illustrate an effective technique to enhance the heat transfer rate without the need for boiling surface modifications. The new technique uses a confinement wall above the boiling surface to facilitate only partial departure of generated vapor bubble. The residual regions of vapor, so called "vapor stem bubbles", provide seeds for subsequent boiling without requiring active nucleation sites to continue the cycle of vapor bubble generation. Here, we evaluate the effect of confinement through the measurement of the boiling curves and high-speed visualization.

RESULTS AND DISCUSSION

A confined boiling apparatus is used to measure the surface heat flux and surface superheat for boiling water, as described in our previous work [4, 5]. The apparatus is also equipped with high-speed visualization of the two-phase interface dynamics. The flow visualization confirms the existence of small residual pockets of vapor, "stem bubbles", that remain on the boiling surface through a pinch-off process. The relatively large radius of stem bubbles compared to vapor embryos on the boiling surface allows for vaporization at surface superheat lower than what is required for the growth of the vapor embryos on the boiling surface. As a results, the stem bubbles suppress nucleation and enhance heat transfer coefficient as shown in Figure 1. However, enhancement due to stem bubbles deteriorates at the higher heat fluxes due to partial dryout of the confined surface, where regions of boiling surface remain continually covered with vapor.

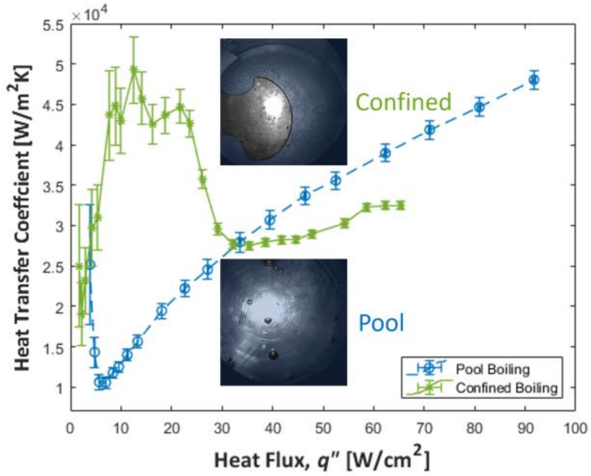


Figure 1: **Heat transfer coefficient (HTC).** For the pool boiling case, the HTC increases with the flux due to the increase in active nucleation site density reaching a maximum at dryout limit. On the other hand, for boiling within a gap of 764 µm, the maximum HTC is achieved at the low range of heat flux due to stem bubbles.

CONCLUSION

The thermal resistance associated with activating nucleation sites in pool boiling results is a heat transfer coefficient that depends on the applied heat flux. The maximum heat transfer coefficient is typically observed in unconfined pool boiling prior to dryout limit. Here, we propose a technique to enhance the heat transfer coefficient at the low range of heat fluxes up to five time higher than the unconfined pooling boiling through the introduction of a confinement wall above the boiling surface. The confinement wall produces stem bubbles that suppress nucleation in certain conditions and enhance heat transfer coefficient. This new enhancement technique can impact the design of compact two-phase thermal management solutions.

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