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水平円形伝熱面上での気泡微細化沸騰における蒸気泡挙動と沸騰音の相関

Correlation Between Vapor Bubble Behavior and Boiling Bound in Micro-bubble Emission Boiling (MEB) on Horizontal Circular Heating Surface

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Microbubble emission boiling (MEB) 1-4) has shown to have a highly efficient heat removal capability exceeding the critical heat flux (CHF) under high subcooling conditions. Generally, it is known that boiling under microgravity conditions tends to reduce the heat removal capability because the detachment of the vapor bubbles from the heating surface is suppressed.5) In contrast, MEB has a feature that tiny bubbles of $O(10^{-5}$ m) in size are radiated from the heating surface, which promotes spontaneous vapor-liquid exchange. It is thus expected that MEB can be applied to cooling technology even under microgravity conditions. Although a number of studies have been conducted focusing on its occurring condition and heat transfer characteristics, the mechanism of achieving high heat flux has not been cleared yet. In this study, a series of experiments were conducted on MEB on the horizontal circular heating surface to illustrate the correlation among heat transfer characteristics, spatio-temporal behavior of vapor bubbles, and boiling sound.

The experimental apparatus consists of a copper heating block and the stainless-steel vessel. The boiling takes place at the top end of the cylindrical rod carved from the copper block. Cartridge heaters are inserted in the bottom of the copper block to realize the designated heating of the cylindrical rod. Three K-type thermocouples are inserted in the copper block along the centerline of the cylindrical rod at 1 mm, 3 mm, and 5 mm from the heated surface. The temperature and the quasi-heat flux9) of the heated surface, T_w and q', respectively, are evaluated by assuming a one-dimensional temperature distribution in the rod. In the experiment, we set a designated heat input to the cartridge heaters, and wait until the temporal average of the surface temperature converges to realize 'steady state' under the given condition. We accumulate image data taken by a high-speed camera from the side of the heat transfer surface and the boiling sound data from a microphone placed in the vessel under the steady-state condition. Then we change the heating condition to the next designated one. The test fluid is distilled water under atmospheric pressure and the degree of subcooling, $\Delta T_{sub} := T_{sat} - T_\infty$, are varied in the range of 40-60 K, where T_{sat} and T_∞ are the saturation temperature and the ambient temperature of the test liquid, respectively.

A typical example of the quasi-boiling curve under $\Delta T_{sub} = 40$ K is shown in Fig. 1(a). Square marks indicate the data in the steady state regime under the designated condition. One finds that the quasi-heat flux sharply rises at about 60 K in the wall superheat, $\Delta T_{sat} := T_w - T_{sat}$, after the CHF. This is a typical characteristic for S-MEB.9) Top frames of the panel (b) are the snapshot of the images taken at the steady states (i)-(iii) as indicated in Fig. 1(a)). Each frame indicates the result in the boiling regime of (i) the nucleate boiling near the CHF, (ii) just after the MEB transition, and (iii) the fully developed MEB. Bottom frames of the panel (b) illustrate the spatio-temporal vapor bubble behaviors at 1 mm above the heat-transfer surface as the monitoring line. Those spatio-temporal behaviors are obtained by accumulating the line data at the monitoring line extracted from the successive high-speed image in time. Black region corresponds to the vapor bubble passing the monitoring line, and the periphery of those regions corresponds to the edge of the vapor bubbles. One obtains the information of the growth and condensation processes of vapor bubbles on the heating surface from these spatio-temporal diagrams. In (i) the nucleate boiling regime, the coalesced vapor bubbles pass the monitoring line at almost constant frequency. One finds the size and the growth/departing frequency are almost constant. While, (ii) after the MEB transition, the vapor bubbles pass over the monitoring line in a non-uniform manner in space. It is emphasized that the period of the vapor bubbles passing the monitoring line becomes much shorter than that in the nucleate boiling regime (see $t > 0.03$). This reflects a vigorous oscillating behavior of the vapor bubble.[9)] It is also emphasized that the vapor growth becomes non-uniform in the radial direction. In the case of (iii) the fully developed MEB with higher q′ than that in (ii), the period is almost equivalent to or slightly shorter than that in (ii) the early stage of the MEB. It is indicated that the vapor bubbles oscillate uniformly in the radial direction above the heating surface, and that such behavior is steadily realized in time. Based on these results, we illustrate the correlation between the vapor bubble oscillation and the corresponding boiling sound through the Fourier spectra. We will discuss the mechanism for achieving such a high heat flux for relatively low T_w.

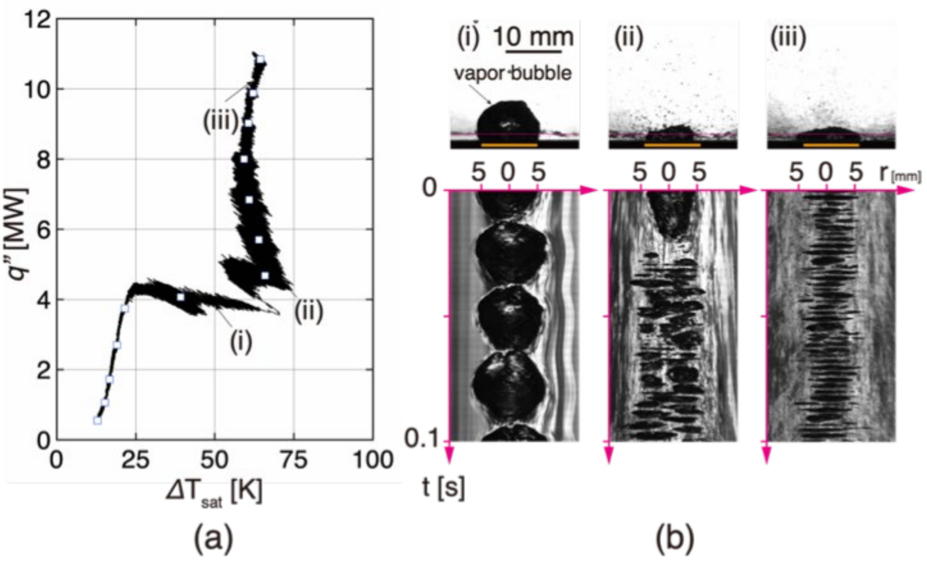

Fig. 1 (a) Pseudo-boiling curve (line) with steady state points under designated conditions (squares) for $\Delta T_{sub} = 40$ K. (b) (top) Snapshot of vapor bubble behavior observed from side, and (bottom) corresponding spatio-temporal behaviors of vapor bubbles over heated surface (1 mm above the heated surface as shown in top frame) under (i) nucleate boiling near CHF, (ii) early stage of MEB and (iii) fully developed MEB as illustrated in (a).

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