Experimental Investigation of Single-Phase and Flow Boiling, Submerged, and Confined Microjet Array Heat Transfer

by

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ABSTRACT

Confined and submerged microjet array impingement was experimentally investigated. Single-phase area-averaged heat transfer coefficients were measured with five microfabricated arrays with air and deionized water. Inline and staggered arrays were investigated with jet diameters of 54 and 112 μm over a 1-mm × 1-mm heater. The area ratio, defined as the fraction of the heater area covered by the total jet area, varied from 0.036 to 0.35. Reynolds numbers defined by the jet diameter were in the range of 180 to 5100 for air and 50 to 3500 for water. A heat flux of 1100 W/cm^2 was obtained at fluid inlet-to-surface temperature differences of less than 30°C resulting in a heat transfer coefficient of over 400,000 W/m^2-K. The results were compared with established correlations, and no evidence was found to suggest that the behavior of submerged and confined jets at the microscale is fundamentally different than at the macroscale. However, high area ratio arrays were not well predicted. Reynolds number, Prandtl number, and area ratio were found to significantly affect the heat transfer performance, and a curve fit which correlated 290 of the 295 data points within ±25% was developed.

Single-phase microjet array heat transfer with R134a was also investigated. Single-phase data were gathered over the range $3050 \leq Re_d \leq 10,600$ with $53.6 \leq \overline{Nu_d} \leq 128$. The incompressible flows of water and R134a were well correlated by $\overline{Nu_D} / Pr^{0.4}$.

An investigation of flow boiling with R134a was conducted with two arrays of microjets. Velocities of 4 and 7 m/s, subcoolings of 10, 20, and 30°C, and area ratios of 0.089 and 0.21 were employed. Lower subcoolings and lower velocities were found to enhance boiling and reduce the onset of nucleate boiling heat flux. The area ratio did not influence the onset of nucleate boiling but did increase the boiling enhancement of the heat transfer coefficient. An inconsistent temperature excursion behavior was observed but could not be conclusively explained. A study of the effect of nitrogen in the charge of R134a concluded that it was unrelated to the measured temperature excursion behavior. Surface roughness was also measure in an effort to find the controlling mechanism, but the surface was found to be unchanged after experiments and very smooth (surface roughness less than 30 nm). A correlation framework was also proposed with an initial data fit for the prediction of flow boiling with microjet arrays.