STUDY OF THE CRITICAL HEAT FLUX CONDITION IN MICROTUBES

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ABSTRACT

With the development of faster electronic chips, power densities have increased dramatically and adequate cooling to dissipate power is required so that the chips can be maintained at an acceptable temperature. The current cooling techniques are insufficient to handle such high heat fluxes, and the use of liquid-cooling in microchannels employing flow boiling heat transfer is a promising solution. Also, ultra-compact heat exchangers are being explored for use as evaporators/vapor generators in automotive, aerospace and cryogenic industries. The common feature in the thermal control (e.g. chip cooling) and thermal processing (e.g. vapor generators) applications is the boiling of liquid in very small channels.

The boiling heat transfer is constrained by a crucially important factor—the critical heat flux (CHF) condition—which sets the upper limit on the boiling heat transfer and is a transition from a very efficient heat transfer mechanism to a very inefficient one. The design of effective cooling approaches for electronic devices or the design of ultra-compact heat exchangers requires validated and reasonably accurate models to predict the critical heat flux condition. The current literature on CHF is not adequate to design such devices with confidence for safe operation. The objectives of this study are to gain a better quantitative and qualitative understanding of the CHF condition.

For this, extensive experimentation was performed in single microtubes to obtain the flow boiling critical heat flux. These data have been obtained in microtubes ranging from diameters as low as 0.286 mm to about 0.700 mm over a wide range of mass fluxes (320 kg/m^2s–1570 kg/m^2s), inlet subcoolings, and exit pressures for two different working fluids water and R-123. Flow instabilities were controlled during the experiments, and stable CHF data could be obtained.

The effect of different operating parameters — mass flux, inlet subcooling, exit quality, heated length and diameter — were assessed in detail and compared with such effects in conventional sized channels. The effect of inlet/subcooling and exit quality on CHF is complex. Flow patterns for the data were established using the existing flow pattern maps for microchannels. It is seen that flow pattern has a strong influence on the way operating parameters affect the CHF condition and flow in transitional regime (churn-annular or slug-annular) can cause the peculiar increase of CHF with exit quality. The conventional DNB type behavior is observed in the high subcooled region and the typical dryout type behavior in the high-quality saturated region when the flow is completely annular. Also, in microtubes,

the increased void fraction near the saturated region in subcooled boiling results in increased subcooled CHF values. Unlike conventional tubes, the heated length has a strong influence on the critical heat flux condition.

Existing correlations for predicting CHF in large-sized channels do not seem to be applicable to microchannels. This study has provided new subcooled CHF data for low mass fluxes and the earlier available subcooled boiling CHF correlation for microchannels (based on the data available for very high mass fluxes) is not suitable to predict such data. Based on the new subcooled CHF data, a correlation to predict CHF in low-flow subcooled boiling has been developed.

Thus, new CHF data have been acquired in single microtubes and analyzed for different parametric effects and provide essential information and insight into the governing processes associated with the critical heat flux condition in micron-sized channels. This investigation also opens additional research which combined with the present study could aid engineers to effectively design boiling heat transfer equipment utilizing micron-sized flow passages.