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Macro-to-microchannel transition in two-phase flow: Part 2 – Flow boiling heat transfer and critical heat flux

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This part of the paper presents the current experimental flow boiling heat transfer and CHF data acquired for R134a, R236fa and R245fa in single, horizontal channels of 1.03, 2.20 and 3.04 mm diameters over a range of experimental conditions. The aim of this study is to investigate the effects of channel confinement, heat flux, flow pattern, saturation temperature, subcooling and working fluid properties on the two-phase heat transfer and CHF. Experimentally, it was observed that the flow boiling heat transfer coefficients are a significant function of the type of two-phase flow pattern. Furthermore, the monotonically increasing heat transfer coefficients at higher vapor qualities, corresponding to annular flow, signifies convective boiling as the dominant heat transfer mechanism in these small scale channels. The decreasing heat transfer trend at low vapor qualities in the slug flow (coalescing bubble dominated regime) was indicative of thin film evaporation with intermittent dry patch formation and rewetting at these conditions. The coalescing bubble flow heat transfer data were well predicted by the three-zone model when setting the dryout thickness to the measured surface roughness, indicating for the first time a roughness effect on the flow boiling heat transfer coefficient in this regime. The CHF data acquired during the experimental campaign indicated the influence of saturation temperature, mass velocity, channel confinement and fluid properties on CHF but no influence of inlet subcooling for the conditions tested. When globally comparing the CHF values for R134a in the 0.51–3.04 mm diameter channels, a peak in CHF peak was observed lying in between the 0.79 ($Co \approx 0.99$) and 1.03 ($Co \approx 0.78$) mm channels. A new CHF correlation has been proposed involving the confinement number, *Co* that is able to predict CHF for R134a, R236fa and R245fa in single-circular channels, rectangular multichannels and split flow rectangular multichannels. In summary, the present flow boiling and CHF trends point to a macro-to-microscale transition as indicated by the results presented in Ong and Thome (2011) [1].

1. Introduction

Flow boiling research studies in the 1950s and 1960s have recognized that the heat transfer coefficient in macroscale flow boiling is an interaction of nucleate and convective boiling. In-tube flow boiling of refrigerants in macroscale or *conventional* channels can thus be classified according to nucleate boiling (relating to the formation of vapor bubbles at the tube wall surface) and convective boiling (relating to conduction and convection through a thin liquid film with evaporation at the liquid–vapor interface). While for simplicity, one may assume that these boiling mechanisms function independently of one another, in fact the flow mechanisms can coexist as the thermodynamic vapor quality increases, where convective boiling gradually supplants nucleate boiling. Thus, nucleate and convective boiling contributions can be superimposed by a very complex mechanism.

Steiner and Taborek [2] studied the fundamental characteristics of flow boiling in macroscale sized vertical tubes and suggested that convective boiling is the only mechanism for heat fluxes below the onset of boiling where the heat transfer coefficient is independent of heat flux over a wide range of vapor quality. For fully developed nucleate boiling at high heat fluxes, the heat transfer coefficient is virtually independent on mass flux and vapor quality. However, major differences in the transport phenomena have been reported in the microscale in comparison to the macroscale. Hence, this brings up the question of a possible channel size effect and and the proper definition of macroscale and microscale in two-phase processes and the need to address flow boiling processes in the transition from macro-to-microscale. Most macroscale heat transfer prediction methods have been found to be inadequate to describe the flow boiling process in the microscale. On a general basis, although by chance they sometimes work for a particular data set, the failure of these methods to accurately predict the heat transfer coefficient in microscale channels allows only part of the macroscale knowledge to be transferred to microscale studies. This

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