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CRITICAL HEAT FLUX DURING FLOW BOILING IN MINI AND MICROCHANNEL-A STATE OF THE ART REVIEW

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ABSTRACT

A state of the art review of critical heat flux during flow boiling through mini and microchannels has been provided based on the open literature. This review mainly examines three aspects, namely the experimental investigations, the available correlations and the state of prediction using those correlations and finally the proposed physical mechanisms as well as the theoretical models. Before discussing the specific literature on microchannels, a brief overview of critical heat flux for pool and flow boiling is provided. The review has been concluded with a summary of the available information on this topic and the need for future research.

Keywords: *Critical heat flux, minichannel and microchannel, sub cooled boiling, saturated boiling, mechanistic model*

1. INTRODUCTION

Microchannel cooling holds an enormous potential for the further development of many cutting edge technologies like space systems, microelectronics, MEMS, photonics etc. Efficient thermal management of such systems not only increases the reliability and functionality but will also help to achieve the next level of miniaturization. In fact, the development of terahertz computers will only be possible through some unique breakthrough (Chung et al., 2011) in the existing cooling technology. One can definitely hope to see a greater deployment of microchannel cooling in miniature refrigeration plants, medical appliances, automobile heat exchangers etc. It is not surprising that there is a tremendous upsurge of interest in the field of microchannel flow and microchannel cooling in recent years. This itself has culminated in the development of diverse techniques for the fabrication of microchannels, methodology for driving flow through such conduits and efforts for understanding and characterizing this unique domain of fluid dynamics. The research initiative in this field can be appreciated not only from the expanding volume of publications on this topic but also from the launching of new journals and organization of many topical conferences.

As the development of various technology demands the dissipation of ever increasing thermal energy from the smallest possible volume, the thrust in microcooling technique has experienced a shift from the gas cooling to single phase liquid cooling and then naturally to cooling with a change of phase like boiling or evaporation (Agostini et al., 2007).

For any system, where heat is dissipated by boiling, the operation is restricted to the nucleate boiling regime to exploit the associated high heat transfer rate. Microchannels are no exception. Critical heat flux signifies the highest limit of the nucleate boiling heat transfer in any system; micro or macro. Beyond critical heat flux, there is not only a deterioration of the capability of heat dissipation, but also a potential risk of damage due to burn-out. The present article aims at a comprehensive review of the critical heat flux during flow boiling through microchannels based on published literature.

2. DEFINITION OF MICROCHANNELS

Before proceeding with the review, it would be prudent to define its scope by defining microchannels. Though the word microchannel may give the usual connotation for a channel with dimensions (or at least one dimension) of its cross-section of the order of a few microns ($\simeq 10$ µm, say); it is used rather loosely in practice. It has been argued elsewhere (Thome, 2007), that the distinctive features of two-phase flow in microchannel do not appear suddenly at a particular channel dimension. There is a gradual change of flow characteristics from macrochannel to microchannel over a range of physical dimensions as one can expect a typical flow regime to transform into another gradually due to the change in operating parameters.

Over the years, it has been observed that as the dimensions of the channel cross-section reduce, two phase flow starts exhibiting features different from those observed in large sized channels. The flow patterns and their transition boundaries in microchannels are distinguishingly different from those observed in macrochannels. Bhushan et al. (2009) demonstrated that the rise velocity of a Taylor Bubble will be strongly influenced by the orientation of the channel cross section when one of the dimensions is of the order of mm. Almost three decades ago Barnea et. al. (1983) showed that gas-liquid two-phase flow through horizontal tubes with diameters ranging from 4 mm to 12 mm has criteria for flow regime transition different from large sized tubes.

In essence, in case of two-phase flow, the effects of miniaturization can be envisaged much before the dimensions of the channel cross-section is reduced to micron level. Keeping this fact in mind, many researchers have tried to define a criterion for the transition from macro to microchannel. As the importance of surface force for gas-liquid two-phase flow through small-sized channels increases, Kew and Cornwell (1997) defined the Confinement Number Co, where,

$$Co^{-2} = Bo \tag{1}$$

$$Bo = (\rho_l - \rho_v) g d^2 / \sigma \tag{2}$$

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