International Journal of Thermal Sciences 50 (2011) 881–889

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Subcooled flow boiling heat transfer from microporous surfaces in a small channel

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A R T I C L E I N F O

Article history:
Received 14 June 2010
Received in revised form
16 January 2011
Accepted 18 January 2011
Available online 18 February 2011

Keywords:
Flow boiling
Small channel
Microporous
Heat transfer enhancement

A B S T R A C T

The continuously increasing requirement for high heat transfer rate in a compact space can be met by combining the small channel/microchannel and heat transfer enhancement methods during fluid subcooled flow boiling. In this paper, the sintered microporous coating, as an efficient means of enhancing nucleate boiling, was applied to a horizontal, rectangular small channel. Water flow boiling heat transfer characteristics from the small channel with/without the microporous coating were experimentally investigated. The small channel, even without the coating, presented flow boiling heat transfer enhancement at low vapor quality due to size effects of the channel. This enhancement was also verified by underpredictions from macroscale correlations. In addition to the enhancement from the channel size, all six microporous coatings with various structural parameters were found to further enhance nucleate boiling significantly. Effects of the coating structural parameters, fluid mass flux and inlet subcooling were also investigated to identify the optimum condition for heat transfer enhancement. Under the optimum condition, the microporous coating could produce the heat transfer coefficients 2.7 times the smooth surface value in subcooled flow boiling and 3 times in saturated flow boiling. The combination of the microporous coating and small channel led to excellent heat transfer performance, and therefore was deemed to have promising application prospects in many areas such as air conditioning, chip cooling, refrigeration systems, and many others involving compact heat exchangers.

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1. Introduction

Subcooled flow boiling is one regime of the forced convection boiling heat transfer when the liquid bulk temperature remains below the local liquid saturation temperature and the thermodynamic quality is below zero. It is associated with the combination of phase-change and convection heat transfer, and yields a high heat transfer rate with small wall superheats. Therefore, subcooled flow boiling process has been very widely utilized in the liquid cooling systems in modern industrial applications.

With the remarkable technological development in various industrial fields, new challenge has been brought about, demanding high heat flux dissipation from confined spaces or very small areas. In this context, many studies have been conducted to investigate heat transfer characteristics and mechanism of flow boiling in small channels. The small channel has been proved to be able to enhance the boiling heat transfer performance. Sumith et al. investigated water flow boiling in a vertical 1.45 mm-diameter tube [1]. They found that small diameter tube produced a remarkable heat transfer enhancement and existing flow boiling correlations largely underpredicted the heat transfer coefficient, especially for a low heat flux condition. Martin-Callizo et al. [2] found that smaller channel diameter led to better heat transfer of the refrigerant R-134a subcooled flow boiling in a vertical small tube (diameter 0.83–1.70 mm). Chen et al. [3] found that the subcooled heat transfer coefficients of R-407C in a 1 mm annular duct could be 40% higher than those in a 2 mm duct. Besides, small channels also provide smaller volume, lower total mass, lower inventory of the working fluid and acceptable pressure drop. Cooling devices consisting of small channels are therefore good choices for microelectronic chip cooling, compact heat exchangers in the air conditioning and refrigeration systems, nuclear reactor and aeronautic applications, in which subcooled flow boiling phenomenon takes place to transmit significant heat flux.

Methods of heat transfer enhancement can be introduced into the small channel to guarantee superior heat transfer performance in a confined space. In order to significantly intensify boiling heat transfer, micro-structured surfaces containing reentrant cavity geometries are often employed [4]. These surfaces manufactured industrially are of two categories, those made by finning and/or knurling the tube surface (such as Thermoexcel series of Hitachi, Turbo-B of Wolverine and Gewa series of Wieland-Werke) or by covering the surface with capillary-porous structures sintered or deposited on the surface (such as High Flux of UOP) [5]. In general, sintered or deposited microporous surfaces are more favorable in

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doi:10.1016/j.ijthermalsci.2011.01.019