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Flow-pattern-based experimental analysis of convective boiling heat transfer in a rectangular channel filled with open-cell metallic random porous media

Dae Yeon Kim, Omid Nematollahi, Kyung Chun Kim *

School of Mechanical Engineering, Pusan National University, Busan 609-735, Republic of Korea

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ABSTRACT

This paper reports a visualization study on the flow boiling of R245fa in a rectangular channel filled with an open-cell random porous structure made of copper. The boiling heat transfer of the two-phase vertical upward flow inside the channel was measured while the refrigerant was asymmetrically heated by a hot-water-source channel. An experiment was conducted with a constant saturation pressure of 5.9 bar, inlet vapor quality of 0.05–0.99, channel heights of 3 and 5 mm, and mass flux of 133–300 kg/m^2 s. The results are compared with those of a plain channel in the same operating conditions. The two-phase flow characteristics are discussed along with the trend of the boiling heat transfer coefficient and mean vapor quality according to the flow patterns obtained with and without the metallic porous media. A non-dimensional analysis was also conducted for comparison.

1. Introduction

High-porosity open-cell metallic foam is a representative porous structure that has an extremely high heat-transfer area and many randomly connected paths inside the body of the medium. Open-cell metal foam can improve the thermal performance of compact heat exchangers, and many research groups have studied them for heat exchanger applications due to their high surface-area-to-volume ratios (790–2740 m^2/m^3) and porosity (>90%) [1–6]. They have also been investigated as a promising compact heat transfer medium, particularly for convective heat transfer of a single-phase liquid or air flow using electrical heating, in which the thermal performance is enhanced [7–19].

A more interesting aspect of the heat transfer mechanism is the phase changes that occur inside metal-foam-filled channels. The foam structures provide more nucleation sites, hold down bubble growth, and even break up bubbles when the flow is interrupted by the randomly oriented ligaments of the structure. This results in the flow field becoming more uniform and promotes the heat transfer. Some interesting and distinctive boiling phenomena are expected, which could lead to different boiling heat transfer characteristics from those of plain channel flows [20].

Topin et al. [21] presented the convective boiling heat transfer of n-pentane flowing through a rectangular channel (10 × 50 × 100 mm) that contained a copper foam with 40 pores per inch (PPI). Zhao and Tassou [22] investigated the flow boiling heat transfer of R134a refrigerant flowing through a horizontal tube (D_h = 26 mm) with 20-PPI and 40-PPI copper foam. This experimental study used mass fluxes of 26–106 kg/m^2 s at saturation pressures of 3.5 and 6 bar with electrical heating. Li and Leong [23] investigated the flow boiling characteristics of water and FC-72 flowing inside aluminum foam. They experimentally and numerically studied the heat transfer processes prior to nucleate boiling, the onset of nucleate boiling, and the hysteresis effect.

Zhao and Wirtz [24] conduct experiments on flow boiling with isopentane flowing through porous-structured fin with various operating pressures, flow rates, and mesh numbers. Madani et al. [25] studied the vertical upward flow boiling heat transfer inside a rectangular channel (10 × 50 × 100 mm) that contained 36-PPI copper foam that was soldered inside and n-pentane as the working fluid. They showed that the metallic foam insert enhances the heat transfer coefficient (HTC) by 2–4 times for low quality in comparison with the published correlation for a plain tube. Hu et al. [26] investigated the influence of the tube diameter on the boiling heat transfer characteristics of R410A. An experiment was conducted with 5 and 10-PPI copper-foam-filled tubes with inner diameters of 7.9 and 13.8 mm and compared them with bigger-diameter tubes from the literature. They found that lower specific

* Corresponding author.
E-mail address: kckim@pusan.ac.kr (K.C. Kim).

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