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Numerical Study of Condensation Heat Transfer in Curved Triangle Microchannels

Yuchuan Lei, Zhenqian Chen*

School of Energy and Environment, Southeast University, sipailou, Nanjing, 210096, China

Abstract

A number of simulations on condensation heat transfer of R134 in straight microchannels and curved triangle microchannels with various curvatures are proposed. The model is based on the volume of fluid (VOF) approach and user defined routines including interfacial mass transfer. The accuracy of the model has been accessed with available correlation in the literature. Both the increase of mass flux and the decrease of hydraulic diameter can bring better heat transfer performance. The wall heat flux has little effect on condensation heat transfer coefficient. For all of the heat fluxes, mass fluxes and hydraulic diameters specified in present cases, the curved triangle microchannel show an edge in heat transfer performance compared with straight channels, and the performance can be further improved when fin height are increased.

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Keywords: Condensation; Microchannel; Heat transfer; VOF; Curved triangle channel

1. Introduction

Film condensation heat transfer in microchannels has caught considerable amounts of attention in HVAC equipment with particular key point in enhancing heat transfer to increase system efficiency and reduce system footprint. High heat removal is required in industrial applications including heat pipes, air conditions and electronic devices, etc. Condensation in microchannels differs from that in traditional tubes due to different relative effects of

* Corresponding author. Tel.: +86-25-83790626; fax: +86-25-83790626.
E-mail address: zqchen@seu.edu.cn

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gravity and surface tension. It was considered that gravity force has little significance in the microchannel ($D_h \leqslant$ 1mm) by Garimella [1], while surface tension was expected to play a dominant role, especially in non-circular channels.

An extensive theoretical study by Wang and Rose [2,3] was presented to analysis film condensation heat transfer of R134a in horizontal square, rectangular and triangular microchannels ($0.5 \leqslant D_h \leqslant 5$ mm), taking surface tension, gravity and vapor shear stress into ac-count. Numerical research of film condensation in non-circular microchannels was conducted by El Mghari et al. [4]. They focused on the influence of the microchannel cross section shape on the film condensation heat and mass transfer, and found that surface tension, which drives the distribution of condensate along the cross-section circumference, was the key mechanism to improve the condensation heat transfer in microchannels with sharp corners. Wu et al. [5] proposed a steady numerical research by means of VOF to predict the film condensation in a rectangular microchannel. They found that condensation flow field could be divided into thin liquid film region and meniscus region. Zhao and Liao [6] have focused on a numerical research of condensation in equilateral microchannels, consideration curvature variation, interfacial shear stress, etc. The values of the average heat transfer coefficient in microchannels with triangular cross section were larger than those in circular ones with the same hydraulic diameters. This enhancement contributed to the fact that the liquid film was thinned along the sides of the channel. A numerical model was conducted by Nebuloni and Thome [7] by mean of VOF to predict condensation heat transfer characteristics in micro-channel (D_h = 1 mm) for R134a. They found that heat transfer coefficient in flower microchannels showed larger than circular ones due to geometrical shape and surface tension. Ohadi et al. [8] proposed that changes in microchannel shapes could yield significant enhancement in heat transfer performance.

There are still some gaps in the field, especially in terms of condensation heat and mass transfer improvement. The current paper investigates the condensation flow of R134a in curved triangle microchannel to enhance the heat transfer performance.

2. Numerical model

2.1. Method

The VOF model [9, 10] can solve momentum equations and track the liquid-vapor inter-facial volume fraction in the whole computational domain in order to simulate two immiscible fluids. The total of volume fraction α of two phases is unity. In a vapor-liquid system, the phases are represented by the subscripts L for liquid and G for vapor, and the volume fractions of all phases sum to unity in each control volume.

$$\nabla\left(\mathbf{u}\,\alpha_L\right)=\frac{S}{\rho_L} \tag{1}$$

$$\nabla\left(\mathbf{u}\,\alpha_G\right)=\frac{S}{\rho_G} \tag{2}$$

The properties in the transport equations are determined by each phase in control volume. Thermal conductivity λ, specific heat c_p and dynamic viscosity μ are computed in this manner. For example, the density in each cell is given by:

$$\nabla\left(\rho\vec{\mathbf{u}}\vec{\mathbf{u}}\right)=-\nabla P+\nabla\left[\left(\mu+\mu_{\mathrm{t}}\right)\left(\nabla\vec{\mathbf{u}}+\nabla\vec{\mathbf{u}}^{T}\right)\right]+\rho\vec{\mathbf{g}}+\overrightarrow{\mathbf{F}_{\sigma}} \tag{3}$$