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Simulation of Evaporation Heat Transfer in a Rectangular Microchannel

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Abstract

Due to high heat transfer coefficient and compactness of the system, microchannel based cooling and heating techniques have immense prospect in dissipating high heat flux from electronic device. In respect of cooling performance, two-phase evaporative flow or flow boiling in microchannel is more effective than the single phase flow due to involvement of latent heat in the process. In this paper a numerical model is proposed to simulate evaporation heat transfer of a multiphase flow in a channel using different boundary conditions at channel walls. Volume of fluids approach was used which governs the hydrodynamics of multiphase flow. The source terms accounting for the energy and mass transfer at the interface of the liquid and vapor were included in the governing equations for conservation of energy and volume fraction. A two dimensional microchannel of length 1000 µm and hydraulic diameter of 100 µm was developed in ANSYS FLUENT 14.0. The fluid used was water and the liquid mass flux at inlet was given as 1 kg/m^{2}s. Results were analyzed in terms of the variation of volume fraction of vapor at different locations along the microchannel

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1. Introduction

Flow boiling in microchannel has attracted many researchers as a considerable amount of heat can be removed over small areas. Flow boiling in microchannels basically differs from that in larger channels because in former case, bubbles get confined at channel walls unlike in latter case. Therefore shape and size of the channel plays a vital role

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during the growth of bubbles. Wall heat transfer mechanisms as well as liquid flow are regulated by bubbles because of their ability to occupy whole cross-section of channel. High heat removal using low coolant flow rate and temperature uniformity in the channels are two favorable characteristics of two-phase cooling technique.

Ganapathy et al. [1] reported a numerical simulation in microchannels for the condensation heat transfer. He used volume of fluid interface tracking and reported the pressure drop and Nusselt number are within an average deviation of 8.1 % and 16.6 % with an empirical correlation. Kandlikar [2] experimentally studied the multichannel evaporators and observed flow boiling of water. Experimental setup had six parallel channels having a cross-section of 1×1 mm^2. In some channels, localized flow reversal was observed due to great fluctuations in pressure drop. Kandlikar [3] studied flow boiling in microchannels and proposed two dimensionless groups K1 and K2 , where K1 is the ratio of evaporation momentum force to the inertia force and K2 is the ratio of the evaporation momentum force to the surface tension force. He reported that due to the periodic flow of vapor and liquid slugs during a nucleate boiling process, boiling due to convection process diminishes.

Nomenclature

C	Courant number (-)
D	characteristic dimension (m)
E	energy per unit mass (J/kg)
F	force (N)
f_0	adjustable parameter (s^{-1}K^{-1})
h_{lv}	latent heat (J/kg)
k	thermal conductivity (W/m-K)
P	pressure (Pa)
S_α	mass source term (kg/m^{3}s)
S_h	energy source term (kg/ms^3)
T	temperature (K)
V	velocity (m/s)
VOF	volume fraction (-)
x	location along the length of microchannel (m)

Greek symbols

ρ	density (kg/m^3)
α	volume/void fraction (-)
μ	dynamic viscosity (kg/ms)

Subscripts and superscripts

eff	effective
i	denotes the ith phase
l	liquid phase
s	saturation
v	vapor phase

Kuan and Kandlikar [4] exhaustively reviewed the works based on the instabilities of two-phase flow in microchannels. They reported that heat transfer can be enhanced by providing flow restrictions thereby suppressing the flow instabilities. Hoffman and Stephan [5] used thermochromic crystals to measure temperatures below an evaporating meniscus and observed a drop in temperature because of high evaporative heat flux in the vicinity of the microregion. Bogojevic et al. [6] performed experiments in microchannels with uniform cross section and investigated flow boiling instabilities. They reported that subcooling conditions of working fluid as well as the ratio of heat flux to the mass flux affect the flow instability. Mukherjee and Kandlikar [7] presented a numerical analysis of microchannels with an inlet constriction to suppress flow boiling instability. They observed that the bubble formed due to vapor generation had a tendency to move towards the unrestricted end.

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