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Numerical Simulation of Heat Transfer in Rectangular Microchannel

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Abstract. Numerical simulation of heat transfer in a high aspect ratio rectangular microchannel with heat sinks has been conducted, similar to an experimental study. Three channel heights measuring 0.3 mm, 0.6 mm and 1 mm are considered and the Reynolds number varies from 300 to 2360, based on the hydraulic diameter. Simulation starts with the validation study on the Nusselt number and the Poiseuille number variations along the channel streamwise direction. It is found that the predicted Nusselt number has shown very good agreement with the theoretical estimation, but some discrepancies are noted in the Poiseuille number comparison. This observation however is in consistent with conclusions made by other researchers for the same flow problem. Simulation continues on the evaluation of heat transfer characteristics, namely the friction factor and the thermal resistance. It is found that noticeable scaling effect happens at small channel height of 0.3 mm and the predicted friction factor agrees fairly well with an experimental based correlation. Present simulation further reveals that the thermal resistance is low at small channel height, indicating that the heat transfer performance can be enhanced with the decrease of the channel height.

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1 Introduction

In an experimental study of microchannel flow about twenty years ago, Tuckeman

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and Pease [1] discovered, for the first time, that the heat transfer in a narrow flow channel can be enhanced by reducing the height or diameter down to microscale. This finding initiated numerous in-depth studies over the last decades that lead to the microchannelling technology. The technique has now been widely used in various fields, e.g., the development of high efficient cooling devices by applying enhanced heat transfer [2]. Recently, research activities have been primarily focused on the heat transfer performance in microchannel for growing number of microengineering and biomedical applications [3, 4]. While the experimental approach has been proved to be very successful in microchannel flow study [5], the methodology is often constrained by two key facts: first, the current ability for machining microstructures with the restriction of instrumentation and second, the limitation of measurements on heat transfer parameter along the channel wall due to its very small scale and three-dimensionality associated with other complex physical phenomena. Because of these two reasons, experimental measurements often exhibit significant discrepancy, and one typical example is the dependency of fraction factor on the channel spacing, for which the experimental measurements have shown significant scattering. Furthermore, some contradictive findings were often found in published results by various researchers. As an example, Pfahler et al. [6] performed a study of rectangular microchannel flow with small hydraulic diameters of 1.6∼3.4 μm and Reynolds number of 50∼300, and they revealed that the measured friction factor was consistently lower than theory. Peng and Peterson [7] also performed a similar study applying water flow through rectangular machined steel grooves with large hydraulic diameters of 133∼367 μm and found that the friction factor was not inversely proportional to the Reynolds number in the laminar region, in contrary to theory. On the other hand, studies by Rahman and Gui [8] and Qu and Mudawar [9] concluded that the measured friction factor and pressure drop agree well with theory in the laminar regime. Thus there are clear demands of further refinement studies to clarify these contradictive findings.

With the advancement of numerical simulation technique, one recent trend is to perform numerical study for microchannel flow problem, such that any difficulties associated with micro-manufacturing and instrumentation could be easily avoided. Among various methods, two methodologies are often adopted for microchannel flow simulations as (1) the lattice Boltzmann modelling [20, 21] with a kinetic approach, and (2) the Navier-Stokes modelling with a continuum approach. The present study adopts the latter approach, following some previous studies [10,11]. By referencing to the experiment of Gao et al. [5], Gamrat et al. [10] carried out a numerical simulation of flow configuration same as that in the experiment. While the simulation results agree well with the test data for channel heights greater than 0.3 mm, no scaling effect was found at a small channel height of 0.3 mm, which in fact has been observed by Gao et al. [5] and other researchers. To verify this, present authors re-visited the case by performing a numerical study [11] and not surprising, the scaling effect at small channel height was predicted, in agreement with the experimental observations. Our study was extended further to a smaller channel height of 0.1 mm where the scal-