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An experimental study of flow friction and heat transfer in wavy microchannels with rectangular cross section

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ABSTRACT

Experimental investigation has been conducted on the flow friction and heat transfer in sinusoidal microchannels with rectangular cross sections. The microchannels considered consist of ten identical wavy units with average width of about 205 μm, depth of 404 μm, wavelength of 2.5 mm and wavy amplitude of 0–259 μm. Each test piece is made of copper and contains 60–62 wavy microchannels in parallel. Deionized water is employed as the working fluid and the Reynolds numbers considered range from about 300 to 800. The experimental results, mainly the overall Nusselt number and friction factor, for wavy microchannels are compared with those of straight baseline channels with the same cross section and footprint length. It is found that the heat transfer performance of the present wavy microchannels is much better than that of straight baseline microchannels; at the same time the pressure drop penalty of the present wavy microchannels can be much smaller than the heat transfer enhancement. Conjugate simulation based on the classical continuum approach is also carried out for similar experimental conditions, the numerical results agree reasonably well with experimental data.

1. Introduction

Since the classical work of Tuckerman and Pease [1], direct liquid cooling incorporating microchannels has drawn more and more attention [2–7]. Microchannel heat sinks have high heat removal ability; also they could be directly integrated into the heat-dissipating devices. However, there are still some challenges to overcome. With regard to single-phase cooling, due to the reduced feature size of microchannels, high flow rates will cause a sharp increase in pressure loss. The coolant flow through microchannels is always in laminar flow regime. A conventional microchannel heat sink generally employs straight channels, the fluid mixing is poor and the heat transfer is thus not efficient.

Various approaches have been proposed to enhance the heat transfer performance in microchannels, for example microchannel heat sinks based on fractal-like branching channels networks [8,9], tree-shape microchannels nets [10], coiled or even hybrid-geometry channels [11]. In fact, convective heat transfer in the laminar flow region strongly depends on fluid mixing. One promising flow mechanism for enhancing fluid mixing involves the use of Dean vortices. It is well known that when liquid flows through curved passages at sufficiently high Reynolds numbers, secondary flows (Dean vortices) may be generated due to centrifugal forces. The secondary flows promote rotation of fluid elements in the spanwise plane of the curved passage, which in turn causes stretching and folding of the fluid elements, thus improving the mixing as well as heat transfer. This mechanism has been employed by many researchers for mixers [12,13] and heat transfer enhancement [14–17]. Recently, Fletcher and coworkers [18–23] performed systematic numerical studies of fully developed flow and heat transfer in periodic serpentine channels with various foot-path and cross-section shapes. Manglik et al. [24] numerically investigated the forced convection in wavy-plate-fin channels under periodically developed air flow conditions. Their simulations focused mainly on the steady laminar flow regime. It was found that Dean vortices and more complex vertical flow patterns emerge when the liquid coolant flows through the bends. The heat transfer performance could be greatly enhanced over straight channels with the same cross section; at the same time the pressure drop penalty was much smaller than the heat transfer enhancement.

Motivated by previous studies [11–24], the present authors proposed to improve the performance of microchannel heat sinks by replacing the conventionally employed straight channels with sinusoidal channels [25]. Furthermore, it was proposed to vary the relative wavy amplitude of the microchannels along the flow direction for various practical purposes. Three-dimensional numerical simulation was conducted to investigate the liquid-water flow and heat transfer in such wavy microchannels with

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