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Numerical Simulation of Heat Transfer Enhancement in Periodic Converging-Diverging Microchannel

Abhishek Kumar Chandra[a], Kaushal Kishor[a], P. K. Mishra[b], Md. Siraj Alam[a]*

[a]*Department of Chemical Engineering, Motilal Nehru National Institute of Technology, Allahabad-211 004, India*
[b]*Department of Mechanical Engineering, Motilal Nehru National Institute of Technology, Allahabad-211 004, India*

Abstract

Heat transfer performance and fluid flow in three-dimensional converging–diverging microchannel of circular cross-section are studied numerically. Three different types of microchannel, diameter 100 µm and length 6.125 mm each are used for simulation for the Reynolds number range of 50 to 1000. The effect of Reynolds Number, converging/diverging angle and converging-diverging cross-section length on pressure drop and heat transfer in proposed microchannels are investigated and discussed. The result indicated that the flow in the converging-diverging cross-section induces stronger recirculation and flow separation, which decreases with decreasing the converging and diverging angle and increases with increasing aspect ratio. However, the local and global heat transfer performances in the channels are improved by the converging-diverging cross-section at the expense of higher pressure drop compared to the straight channel with the same cross-section. Conversely, special attentions are given to analyze the thermal performance of microchannels through variation of thermal resistance with pumping power.

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Keywords: converging-diverging flow; heat transfer; non-uniform microchannel; thermal performance

1. Introduction

In the year 2009, International Technology Roadmap for Semiconductors (ITRS) has published a report, which makes clear that thermal management of new generation's high performance chip packages is most important since dimensions decreases continually. Additionally highlighted, the operating performance and long term reliability of

* Corresponding author. Tel.: +91-532-227-1584; fax: +91-532-244-5101.
E-mail address: msalam@mnnit.ac.in

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these devices are also affected. For example, a high speed digital circuits containing 10^5 gates would dissipate 100 W. Therefore, heat removal demand makes thermal management so important and requires more effective cooling options. The most attractive and efficient solution for this problem is microchannel based circuits with liquid cooling media. Microchannel based cooling systems are very promising due to material and process compatibility with electronic system. However, their performance is still far from being quite satisfactory and lot of research efforts have to be done to solve the existing problem and develop an advanced microchannel cooling system which accommodate the high heat dissipation rates and associated fluxes.

Although the need of enhancement in microchannel was first discussed by [1, 2] to meet high heat flux cooling needs. However, they recommended that enhancement techniques must be carefully evaluated with the increased pressure drop penalties in a given system. These techniques have acknowledged for enhancement of heat transfer in single phase flow in microchannels and minichannels [3]. The results implied that increase in heat transfer performance from these techniques placed a single-phase liquid system in competition with a two phase system. The cooling limits of single phase cooling media have been evaluated in plain channels [4] and investigated the use of variety of microstructures into the channels for heat transfer enhancement. Further, they investigated the pressure drop and heat transfer in an off-set strip fins enhanced microchannel for single phase fluid flow [5]. Experimental result shows that excellent improvement in heat transfer over plain or traditional microchannel with pressure drop penalty. On the other hand, polymeric microchannels with corrugated walls were analyzed for flow control and mixing [6]. The surface roughness effect on heat transfer was experimentally investigated in a rectangular microchannel [7]. The result shows that the local and average Nusselt numbers significantly departed from conventional theories for relative roughness 0.04 to 0.06. Some of the previous works are listed in Table 1.

Table 1. Previous works on varying-cross section channels.

Authors	**Heat Transfer Enhancement technique**	**Results**
Naphon (2007)	Flow disruption (40 Wavy channel)	Δp and *Nu* in the higher wavy angle channel are significant higher.
Colgan et al. (2007)	Flow disruption (staggered and continuous fins)	Able to cool chips with average power densities of 400 W/cm^2 or more.
Brackbill & Kandlikar (2007)	Surface roughness (triangular element)	The roughness elements cause an early transition to turbulent flow.
Meis et al. (2010)	Flow obstacle (triangular, rectangular, and circular/elliptical)	The triangle obstacle is consistently better than the other configurations Next one is the circle and then, rectangle.
Sui et al. (2010)	Flow disruption (wavy channel)	The relative waviness can be increased along the flow direction, which results in higher heat transfer performance.
Zhang et al. (2010)	Surface roughness (triangle, rectangle and semicircle)	Global heat transfer performance is improved by the roughness elements.
Liu et al. (2011)	Surface microstructures	The microstructure shield shape groove has the best heat exchange performance
Dharaiya & Kandilkar (2013)	Surface roughness (Sinusoidal element)	Nu number increases with increase in roughness height. And no effects of roughness pitch.
Kuppusamy et al. (2014)	Secondary flow	Thermal boundary layer re-development and flow mixing affect the overall performance of MCHS.

It is observed that sinusoidal wall shape was the most common shape, studied in past with range of Reynolds numbers that covers both laminar and turbulent flows. It is also observed from the literatures that by the two important means heat transfer can be enhances in microscale; 1) by interrupting the thermal boundary and 2) by inducing the mainstream separation. In the current study the boundary layer separation and thermal boundary layer redeveloping concept in microscale are used to propose a new design of microchannel with periodic converging-diverging cross-section and examine the local and average, flow and heat characteristics. In addition, numerical