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Optimum design of triangular shaped micro mixer in micro channel heat sink

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ABSTRACT

The focus of the present study is on the effect of triangular shaped micro mixers placed between the main stream channels in micro channel heat sink (MCHS). These micro mixers are constructed based on three parameters (inner and outer angle and depth of the joining point) and positioned periodically at an assigned distance. A single unit wall with separated channels is selected from the simple MCHS and micro channel with a triangular shaped micro mixer (MTM) as the computational domain for the numerical simulation. The performance of both micro channels are compared at identical boundary conditions. The effect of volume flow rate of the fluid, flow direction, position of the micro mixer (parallel or alternating), and geometrical parameters of micro mixer on the flow and heat transfer performance of MTM is studied. It is found that the performance of MTM is greatly dependent on the variation of all geometrical parameters. It has to be also highlighted that overall enhancement factor of MTM improved up to 1.53 times compared to simple MCHS with slight reduction in friction factor. This binary benefit of MTM makes it highly possible to be implemented in the practical application.

1. Introduction

Micro channel heat sink (MCHS) appears to be one of the most promising and highly effective thermal management technologies that are prominently used in a variety of devices especially in electronic cooling. The electronic chips are widely used and mainly referred to central processing unit and graphic cards in computers. Many engineers have shown great interest in using micro level cooling for data centers to improve the overall cooling capability and energy efficiency. Researchers have given great deal of interest to investigate the fluid flow and heat transfer in micro channel heat sink after the pioneering work done by Tuckerman and Pease [1]. Steinke and Kandlikar [2] proposed that for single-phase liquid flow in micro channel, the classical theory Stokes and Poiseuille flow is still applicable from their review on existing literature of experimental data on the friction in microchannels. In another review of heat transfer in microchannels, Rosa et al. [3] suggested that standard theory and correlations to describe heat transfer in microchannels but scaling effects has to be considered critically.

However, the simple MCHS does not seem sufficient for cooling as a result of tremendous accession of power density and minuscule of electronic packages. According to Moore's Law, the microprocessor transistor count doubles up every two year and increase the cooling demand of the device to run in operating temperature. Thus, intensive researches have been actively conducted to improve the heat transfer and fluid flow characteristics in MCHS in an attempt to resolve the issue.

Xu et al. [4,5] provided three-dimensional numerical simulations of conjugate heat transfer in a newly proposed interrupted micro channel heat sink. The new silicon micro channel heat sink consists of parallel longitudinal micro channels and several transverse micro channels. Cheng [6] numerically studied the flow and heat transfer in a stacked two-layer micro channels with easy-processing passive microstructures and found that stacked micro channel has better thermal performance compared to simple one. Korichi and Oufer [7] studied the flow and thermal performance of a horizontal channel with obstacles mounted alternatingly on both upper and lower walls numerically. It was found that a travelling wave generated by the vortex shedding from the constriction and expansion contributes mainly to heat transfer enhancement.

Promvonge et al. [8] numerically studied the laminar flow and heat transfer characteristics in a three-dimensional isothermal wall square channel with 45° angled baffles. Sui et al. [9] examined

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Nomenclature

A	area (m^2)
$A1$	arrangement 1
$A2$	arrangement 2
c_p	heat capacity (J/kg K)
d	depth of micro mixer (μm)
$D1$	direction 1
$D2$	direction 2
D_h	hydraulic diameter (m)
k_s	thermal conductivity (W/K m)
G	mass flow rate (kg/s)
$\bar{h}$	heat transfer coefficient (W/K m^2)
k	thermal conductivity (W/K m)
L	length of micro channel (mm)
n	number of micro mixer
$\mathcal{N}$	improvement factor
Nu	Nusselt number
Δp	pressure drop (kPa)
q''	heat flux (W/m^2)
T	temperature (K)
u_{in}	inlet velocity (m/s)
u, v, w	velocity vector
x, y, z	Cartesian coordinate

Greek symbols

ρ	density (kg/m^3)
θ	inner angle (°)
τ	outer angle (°)
μ	viscosity (Pa s)

Subscripts

avg	average
f	fluid
FD	fully developed
in	inlet
m	mean
MTM	micro channel with triangular shaped micro mixer
r	ratio
s	solid

the performance rectangular wavy micro channels at laminar condition. An enormous thermal enhancement was obtained due to the secondary flow (Dean Vortices). Foong et al. [10] performed numerical simulation on the fluid flow and heat transfer characteristics of a square micro channel with four longitudinal internal fins and analyzed the effect of the pin height and flow condition on the performance of micro channels. It was found there is an optimum pin height to achieve the best performance. Dogan and Sivrioglu [11] performed experimental study on the mixed convection heat transfer from longitudinal fins in a horizontal channel with a uniform heat flux at the bottom surface and found optimum fin that dependent on the fin height and modified Rayleigh number for heat transfer enhancement. Danish et al. [12] investigated numerically the thermal-resistance and pumping-power characteristics of MCHS with a grooved structure optimized the shape using a multi-objective evolutionary algorithm. Decline in thermal resistance and increment in Nusselt number observed in a grooved microchannels compared to a smooth MCHS with a small increment of pumping power.

Liu et al. [13] used CFD (computational fluid dynamics) and LB (lattice Boltzmann) approaches to the numerical study of forced convection heat transfer occurring in microchannels. The results implied that the shield shaped groove microchannel possessed high heat exchange performance with the increment of Nusselt number at about 1.3 times of the plain surface structure. Chai et al. [14] studied the pressure drop and heat transfer characteristics of the interrupted microchannel heat sink with rectangular ribs in the transverse micro chambers and analyzed the effects of dimension and position parameters of rectangular rib on these characteristics.

Xia et al. and Chai et al. [15–17] analyzed the effect of geometric parameters of fan-shaped and triangular reentrant cavities on water flow and heat transfer characteristics in MCHS. Optimal geometric parameter was obtained based on thermal enhancement factor performance.

In numerical investigation of microchannel heat sink with grooved wall, Abouali and Baghernezhad [18] found that grooved microchannel with thicker wall and lower mass flow rate of cooling water has a higher heat dissipation and coefficient of performance compared to simple microchannel with small wall thickness. Kuppusamy et al. [19,20] performed numerical analysis on the thermal and flow performance of the MCHS with different shapes of grooves on the sidewall of the MCHS using nanofluid. It was found that thermal enhancement enhanced significantly compared to simple MCHS using water with negligible pressure loss.

Lee et al. [21] attempted to enhance the performance of copper MCHS by introducing periodic oblique cuts on the fins of MCHS in order to transform the fluid flow. This could induce redevelopment of the thermal boundary layer that would result in significant heat transfer enhancement with negligible pressure drop penalty. The average Nusselt number increased up to 103%, from 11.3 to 22.9 and the maximum temperature rise reduced by 12.6 °C. Kuppusamy et al. [22] introduced secondary passage in the separating wall of the MCHS and found that the slanted secondary passage significantly enhanced the Nusselt number of the MCHS as well the with reduction in pressure drop compared to the simple one. Therefore, significant overall enhancement is obtained compared to the simple MCHS. Beside various optimization techniques have been implemented to optimize thermal performance of MHCS.

Recently, there are numbers of articles published related to optimization of micro channel heat sink. Leng et al. performed an optimization study on double-layered micro channel heat sink [23,24]. Khan et al. [25] performed multi-objective optimization on inverse trapezoidal microchannel heat sink. Shi et al. studied the effect of staggered arrays of pin fin structure with tip clearance and optimized the entropy generation in microchannel.

From the literatures, it is clear that the substantial techniques to enhance micro scale heat transfer are vortices generation, thermal boundary layer interruption, and induce the mainstream separation and mixing. Considering this mechanism, the present work focuses on the introduction of micro sized mixers in MCHS that could result in all the effects mentioned above. The effect of the geometrical parameters of the micro mixers in MCHS on the thermal and flow performance is analyzed. The thermal and flow performance are presented in terms of friction factor and average Nusselt number respectively. Both of these results are compared in terms of overall enhancement coefficient. The heat transfer enhancement of micro channel heat sinks with periodic triangular shaped transverse micro mixer (MTM) is numerically investigated.