Fifth International Conference on Computational Methods for Thermal Problems
ThermaComp2018, July 9-11, 2018, Indian Institute of Science, Bangalore, INDIA
N. Massarotti, P. Nithiarasu, Pradip Dutta and C. Ranganyakalu (Eds.)

NUMERICAL STUDY OF FLUID FLOW AND HEAT TRANSFER IN COMPOUND MICROCHANNEL

Sangram Kumar Samal, Manoj Kumar Moharana*
Department of Mechanical Engineering, National Institute of Technology Rourkela
Rourkela 769008 (Odisha) India
*mkmoharana@gmail.com

ABSTRACT

A three-dimensional numerical study has been carried out to investigate the fluid flow and heat transfer characteristics in a compound microchannel (CMC) under conjugate heat transfer condition. A compound microchannel is one in which the channel cross-section is a combination of two shapes. In this work, the thermo-hydrodynamic performance of the compound microchannel with different cross-sections are analyzed and compared with the simple microchannel (SMC). The average Nusselt number (Nu_{avg}), pressure drop (Δp), thermal resistance (R_{Th}), and performance factor (PF) for fifteen (15) different geometric cross-sections are evaluated for flow Reynolds number, Re = 100 and applied heat flux on bottom surface of the substrate, q'' = 10 W/cm^2. The results reveal that the compound microchannel having semicircular base (which is formed by combining square and semicircle) shows highest overall thermal performance with performance factor value of 1.34 among all the geometries considered in this study.

Key Words: *Compound Microchannel, Conjugate Heat Transfer, Average Nusselt Number, Performance Factor, Thermal Resistance.*

1. INTRODUCTION

Miniaturization of electronic components resulted in higher heat flux dissipation from the semiconductor devices. Unless these devices are maintained under some threshold temperature limits, the average life period are going to fall drastically. Therefore, thermal management of these devices is very important in controlling the operating temperature. Fluid flow through rectangular channels having hydraulic diameter less than 1 mm (referred as microchannel) is the simplest method which is commonly used for electronic cooling. Due to compact in nature, microchannel system easily fit in electronic devices in the form of heat sink or heat exchanger. Tuckerman and Pease [1] first proposed that high heat flux can be removed by using single-phase forced convection in microchannels. Since then many developments has been carried out on microchannel by considering different parameters such as shape and size of the microchannel, conjugate heat transfer, heat transfer enhancement through different means, two-phase flow etc.

It is an important aspect to study the effect of microchannel cross-sectional shape on the fluid flow and heat transfer characteristics. Peng and Peterson [2] found that the effect of geometry configuration and channel aspect ratio are very significant in the case of single-phase forced convection heat transfer through the microchannel. Moharana and Khandekar [3] numerically studied the effect of rectangular microchannel aspect ratio on its thermal performance and found that the local and the average Nusselt number over the total channel length is function of channel aspect ratio. It is found that the average Nusselt number is minimum corresponds to an aspect ratio of approximately two or slightly less than two, depending on the way the channel aspect ratio is varied. Salimpour et al. [4] found that microchannel with rectangular and elliptic cross-sections have better performance compared to microchannel with isosceles triangular cross-section. Recently Sahar et al. [5] numerically investigated the effect of hydraulic diameter and aspect ratio on the fluid flow and heat transfer in a microchannel and found that the aspect ratio does not affect the heat transfer coefficient while the Nusselt number increases with increasing hydraulic diameter.

From the literature review, it is observed that the effect of microchannel cross-sectional shape on fluid flow and heat transfer behavior is significant. So, in this work, the thermo-hydraulic performance of a microchannel whose cross-section is the combination of two shapes (referred as compound microchannel) is investigate and compared with that of simple cross section microchannel (SMC).

2. PROBLEM DESCRIPTION AND MATHEMATICAL MODELLING

Figure 1(a) presents the schematic diagram of the three-dimesional computational domain of a simple microchannel (SMC) with square cross-section. The length (L), width (W) and height (H) of the computational domain are 60 mm, 1.2 mm, and 0.8 mm respectively. Simple microchannel (SMC) shapes considered in this study are square, triangular, trapezoidal and semi circular. Compound microchannel (CMC) shapes considered in this study are formed by combining square and trapezoidal with square, triangular, trapezoidal and semi-circular shapes. Cross-sectional view of simple and compound microchannels considered in this study are shown in Figure 1(b), later on referred as case 1 to 15 (read from left to right and from top to bottom). Water is used as working fluid and silicon is used as substrate material. Constant wall heat flux q'' = 10 W/cm^2 is applied on the bottom face of the substrate while all other walls are considered as adiabatic.

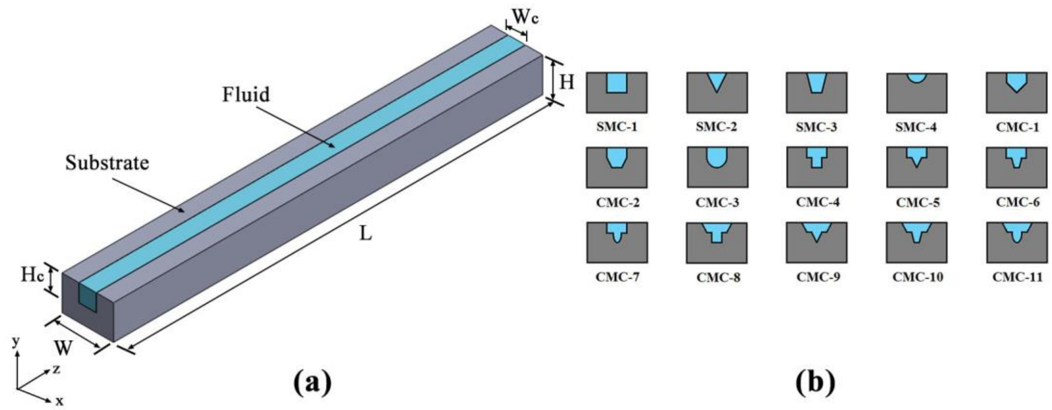

FIGURE 1. (a) Computational domain for simple microchannel (SMC) (b) Cross-sectional view of simple and compound microchannels considered in this study.

The governing equations for modelling of fluid flow and heat transfer in the microchannel are solver with the following assumptions: (i) steady laminar incompressible flow, (ii) constant thermo-physical properties for both solid and fluid, (iii) no internal heat generation in the domain, (iv) negligible heat losses due natural convection and radiation, and (v) gravitational force is negligible. The generalized governing equations for the fluid and solid domains are as follows:

Continuity equation:

$$\nabla \cdot \vec{v} = 0 \tag{1}$$

Momentum equation:

$$\rho\left(\vec{v} \cdot \nabla \vec{v}\right) = -\nabla p + \mu \nabla^2 \vec{v} \tag{2}$$

Energy equation for fluid:

$$\rho_f \left(\vec{v} \cdot \nabla T_f\right) = \frac{k_f}{C_{pf}} \nabla^2 T_f \tag{3}$$

Energy equation for solid:

$$k_s \nabla^2 T_s = 0 \quad (4)$$

Average Nusselt number (Nu_{avg}) over the channel length, thermal resistance (R_{Th}) and performance factor (PF) are evaluated using the follows expressions respectively:

$$Nu_{avg} = \frac{1}{L}\int_0^L Nu_z dz \quad (5)$$

$$R_{Th} = \frac{T_{max} - T_{min}}{Q} \quad (6)$$

$$PF = \left(\frac{Nu_{avg}}{Nu_{avg,0}}\right) \times \left(\frac{\Delta p_0}{\Delta p}\right)^{1/3} \quad (7)$$

where Nu_z is the local Nusselt number along the flow direction, Δp is the total pressure drop, T_{max} is the maximum temperature at the bottom surface and T_{min} is the minimum temperature which is inlet fluid temperature. $Nu_{avg,0}$ and Δp_0 are the average Nusselt number and total pressure drop for a simple microchannel with square cross-section.

3. RESULTS AND DISCUSSION

The parameters of interest are overall heat transfer and pressure drop due to flow of coolant. To obtain generalized outcome based on this study, the following parameters are evaluated for all the fifteen-geometrical cross-sectional shaped microchannels considered in this study and presented in Figure 2. The parameters are (i) Average Nusselt number over the channel length (Nu_{avg}) (ii) pressure drop (iii) thermal resistance (R_{th}), and (iv) performance factor (PF).

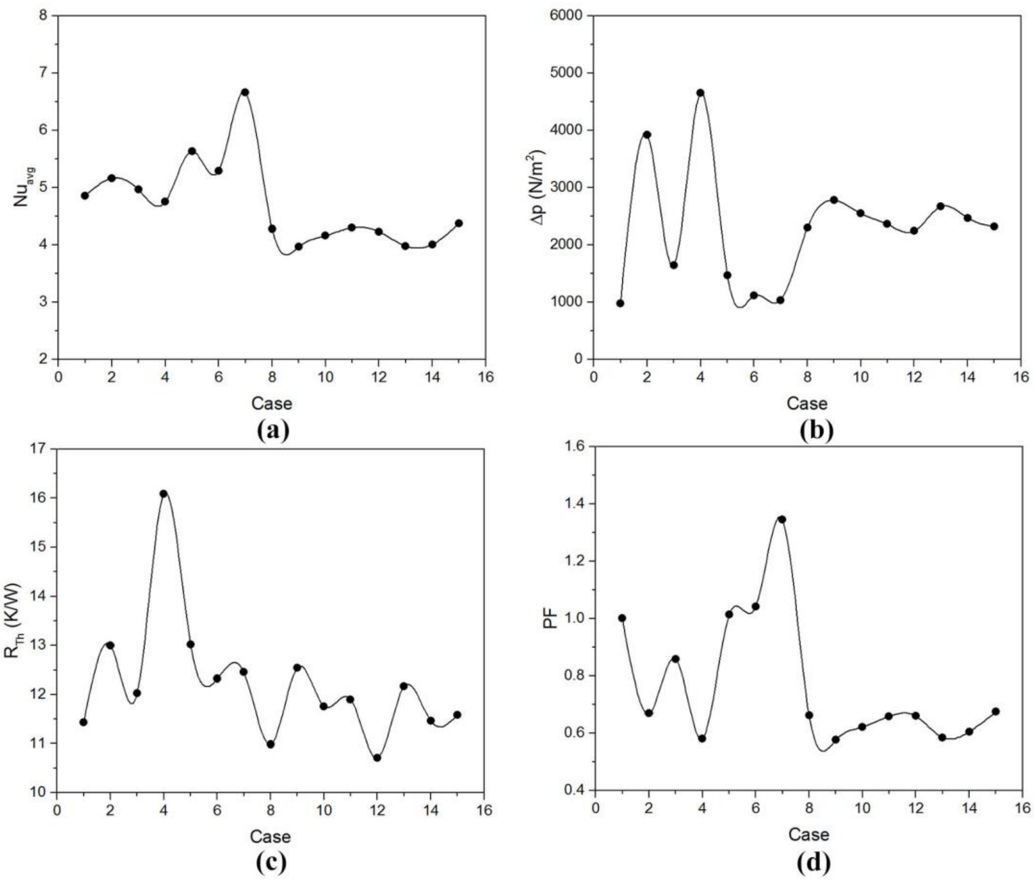

FIGURE 2. Plots of (a) average Nuseelt number (Nu_{avg}) (b) friction factor (f) (c) thermal reistance (R_{Th}) and (d) performance factor (PF) for different cases.

Figure 2(a) presents average Nusselt number (Nu_{avg}) for all the geometrical cases considered in this study. It can be observed in Fig. 2(a) that Nu_{avg} comes out to be maximum for case 7 i.e. for the compound microchannel formed in combination with square and semi-circular (CMC-3, see Figure 1(b)). The average Nusselt Number Nu_{avg} for simple microchannels i.e. case 1 to 4 is less than that of case 7. Also, the average Nusselt Number Nu_{avg} for case 5 and 6 is less than that of case 7 but more than that of case 1 to 4. This is because of proximity of the geometry in case 5 and 6 with that of case 7 but due to presence of corners. The average Nusselt number (Nu_{avg}) value for case 8 to 15 is almost equal and minimum among others. This is due to presence of corners and sharp bends. This also reflected in pressure drop value in Fig. 2(b) where pressure drop for cases 8-15 are higher compared to other cases except case 2 and 4. Pressure drop in Fig. 2 and 4 are higher because of higher perimeter per unit area of cross section. Next, thermal resistance is calculated using Eq. (6) which reflects direct relation with maximum temperature within the solid, which will occur at the bottom surface of the solid as the minimum temperature and heat input remain constant for all cases. Thermal resistance is maximum for case 4 as it carries less fluid i.e. less convective heat transfer from the solid substrate due to its smallest hydraulic diameter.

Finally, performance factor is calculated and presented in Figure 2(d), which presents the combined effect of heat transfer enhancement and pressure drop penalty if any. Performance factor value is found to be maximum for case 7 i.e. 1.34. This is due to higher hydraulic diameter (same as simple channel hydraulic diameter) and absence of two corners. Performance factor for cases other than 5 to 7 have value less than 1 while for case 5 and 6 it is slightly greater than 1.

4. CONCLUSIONS

A three-dimensional numerical study has been carried out to investigate the fluid flow and heat transfer characteristics in a compound microchannel (CMC) under conjugate heat transfer condition. Based on the numerical study for thermal performance of different design compound microchannels, it is found that microchannel having semi-circular base (case 7) perform better than other design compound microchannels considered in this study. This is due to maximum average Nusselt number and minimum pressure drop among other designs considered.

REFERENCES

[1] D.B. Tuckerman, and R.F.W. Pease, High-performance heat sinking for VLSI, *IEEE Electron Device Letters*, 2 (5), 126-129, 1981.

[2] X.F. Peng, and G.P. Peterson, Convective heat transfer and flow friction for water flow in microchannel structures, *International Journal of Heat and Mass Transfer*, 39(12), 2599-2608, 1996.

[3] M.K. Moharana, and S. Khandekar, Effect of aspect ratio of rectangular microchannels on the axial back conduction in its solid substrate, *International Journal of Microscale and Nanoscale Thermal and Fluid Transport Phenomena*, 4(3-4), 211-229, 2013.

[4] M.R. Salimpour, M. Sharifhasan, and E. Shirani, Constructal optimization of microchannel heat sinks with noncircular cross sections. *Heat Transfer Engineering*, 34(10), 863-874, 2013.

[5] A.M. Sahar, J. Wissink, M.M. Mahmoud, T.G. Karayiannis, and M.S.A. Ishak, Effect of hydraulic diameter and aspect ratio on single phase flow and heat transfer in a rectangular microchannel, *Applied Thermal Engineering*, 115, 793-814, 2017.