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Numerical Study on Heat Transfer in a Microchannel with Micro-fins

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Abstract: We report an extended surface technique that utilises micro-fin arrays to enhance the heat transfer performance in the microchannels at Reynolds number ranging from 400 to 1000. Three different types of microfins namely Case A (cylindrical micro-fin), Case B (offset cylindrical micro-fin) and Case C (diverge cylindrical micro-fin) are designed. A comparative study between the three cases and bare rectangular microchannel was conducted. The technique enhances the thermal dissipation rate while keeping the pressure drop at a satisfactory level through proper design configurations. Numerical study has been performed in order to elucidate the single phase heat transfer phenomena in the present study.

Keywords: Extended surface; Heat transfer enhancement; Microchannel heat sink; Micro-fins; Single phase flow.

1. INTRODUCTION

Along with the rapid growth in electronic industry, applications of miniaturisation are immense in past decades. The miniaturization, however, inevitably generates excessive amount of heat on the highly limited surface area [1-2]. It is indeed crucial to develop an efficient cooling method, particularly when the conventional heat sink is inadequate to meet the high heat flux requirements [3-5]. Microchannel heat sink is the rapidly developing device to resolve the issue with the microscaled platforms or microchannels. This compact device has drawn considerable attention, attributed to its high convective heat transfer coefficient, large surface area-to-volume ratio and relatively less demand of coolant inventory.

Tuckerman and Pease [6] fabricated the microchannel heat sink in silicon device with 50 µm width and 320 µm height. The proposed device has the capability to remove the heat flux up to 700 W/cm^2. This pioneering work had opened the door for many researchers to further investigate the use of microchannels. Since then, uncountable of effort had been dedicated to the design and development of microchannel heat sink. For instance, Yadav et al. [7] had employed numerical methods to analyse the performance of the microchannel heat sink. Whereas, Rezania et al. [8] studied the use of microchannel heat sink in the thermoelectric application. It was observed that, experimentally and numerically, heat transfer performance can be improved with an optimal configuration of this device. Xu et al. [9] suggested the silicon heat sink with several transverse micro-chambers. They studied the heat dissipation with laminar flow in the proposed heat sink and found that the heat transfer can be augmented by reducing the effective flow length. Chai et al. [10] proposed a new design of interrupted microchannel heat sink with rectangular ribs in transverse chambers. They examined the optimal position of the rectangular ribs based on performance evaluation criteria. As a continuation of their work, they further investigated the different rib configurations and concluded that the ellipsoidal ribs showed the best heat transfer performance [11]. It was further highlighted, by Cheng [12], that stacked microchannel with uneven surfaces has better heat transfer performance than the smooth microchannels.

Heat transfer performances in the microchannels as the boundary layers become thicker were examined. It was reported that applying passive techniques such as filling the microchannels with porous material leads to significant enhancement in heat dissipation. Xia et al. [13] and Zhai et al. [14] investigated the microchannels with fan-shaped reentrant and internal ribs. It was observed that the proposed device with fan-shaped reentrant and internal ribs have relative higher performance than smooth surface. They then proposed empirical correlations of apparent friction factor and average Nusselt numbers as a function of Reynolds number and relative rib height. Mohammed et al. [15] numerically studied the heat transfer in wavy microchannel heat sink and presented that the wavy design exhibited better performance. In addition, Krishnamurthy and Peles [16] investigated the effect of inline pin finned entrenched on microchannel. They reported that the heat transfer coefficient was enhanced during the subcooled boiling for microchannel with pin fins compared to plain microchannel.

Recently, Hong and Cheng [17] and Liu et al. [18] examined the heat sink with offset strip fins and longitudinal vortex generators. They found that the proposed method could enhance the heat transfer performance, but it also resulted in a large pressure drop. Vafai and Zhu [19] presented a layout of counter flow double-layered microchannel heat sink to address the pressure drop issue. It was found to significantly reduce the pressure drop, but meanwhile, relatively increase the temperature as compared to the single-layered heat sink. Xie et al. [20] observed the double-layer wavy microchannel heat sink had lower pressure drop and better heat transfer performance compared to the single layer. In another work, they numerically compared the performances of those heat sinks with counter and parallel-flow. For better heat dissipation, they suggested that for low flow application, the parallel-flow arrangement was desirable; however, for the high flow application, counter flow arrangement was recommended [21]. It was evidenced that the constructal design in microchannel successfully augmented the heat transfer performance, however it also accompanied with considerable pressure drop penalty. As such, it is always in demand for an efficient microchannel heat sink design to enhance the heat transfer performance without jeopardising the pressure level. We therefore suggest an extended surface technique to enhance the heat transfer performance while keeping the pressure drop at a satisfactory level through proper design configurations. Numerical study has been performed in order to elucidate the single phase heat transfer phenomena in the present study.

2. MODELLING

In this study, extended surface heat transfer enhancement technique was adopted. Three different configurations of microchannel heat sink with micro-fins; namely Case A (cylindrical micro-fin), Case B (offset cylindrical micro-fin) and Case C (diverge cylindrical micro-fin) were proposed and compared with the bare rectangular microchannel. Each of the configurations was designed based on increase the surface area of fluid contact to wall. Figure 1 shows the schematic diagrams of the microchannel heat sink, whereas the corresponding geometry parameters are subsequently depicted in Figure 2.

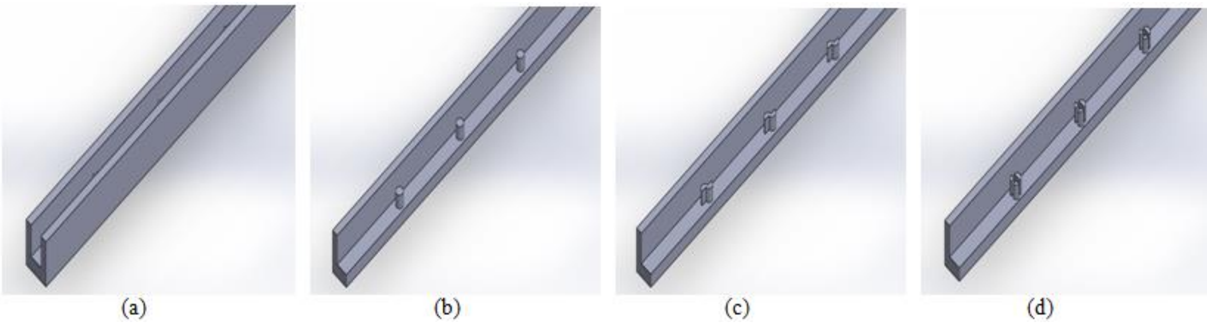

Figure 1. Different configurations of microchannel: (a) Bare rectangular microchannel (b) Case A (c) Case B and (d) Case C

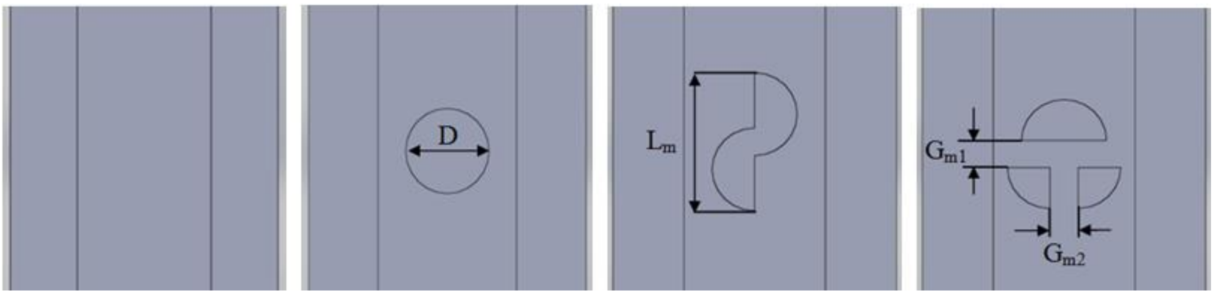

Figure 2. Top views of the microchannel: (a) Bare, (b) Case A, (c) Case B and (d) Case C

Table 1. The geometry dimension of the microchannel

Parameter	Dimension (mm)
D	0.3
L_m	0.5
G_{m1}	0.05
G_{m2}	0.05

The overall dimensions of the microchannel are $36 \times 0.5 \times 0.7$ mm^3 and the fin-to-fin distance (pitch of fins) is set as 3 mm. Table 1 tabulates the parameter dimension of the microchannel. In this numerical study, the dominant flow is in laminar flow and plain water was selected as working fluid. The inlet velocity was ranging from 0.689 to 1.607 m/s, which equivalent to $400 \leq Re \leq 1000$. Due to the symmetry geometry of microchannel, a single slice of microchannel was used for simulation instead of entire heat sink. The commercial software of Ansys Fluent 17.2 was employed and the third order MUSCL

(Monotonic Upstream Centered Scheme for conservation Laws) scheme was used for discretising the convective term in the momentum and energy conservation equations. Findings with the numerical model in this study were compared with the outcomes of [7] for validation.

3. RESULTS AND DISCUSSION

Figure 3(a) compares the numerical findings of temperature with [7] at different Reynolds number (*Re*). Likewise, the comparison of pressure drop at the heat flux of 100 W/cm^2 is presented in Figure 3(b). Good agreement of results can be seen. The velocity streamlines for all cases are shown in Figure 4 to give an insight of the heat transfer phenomena.

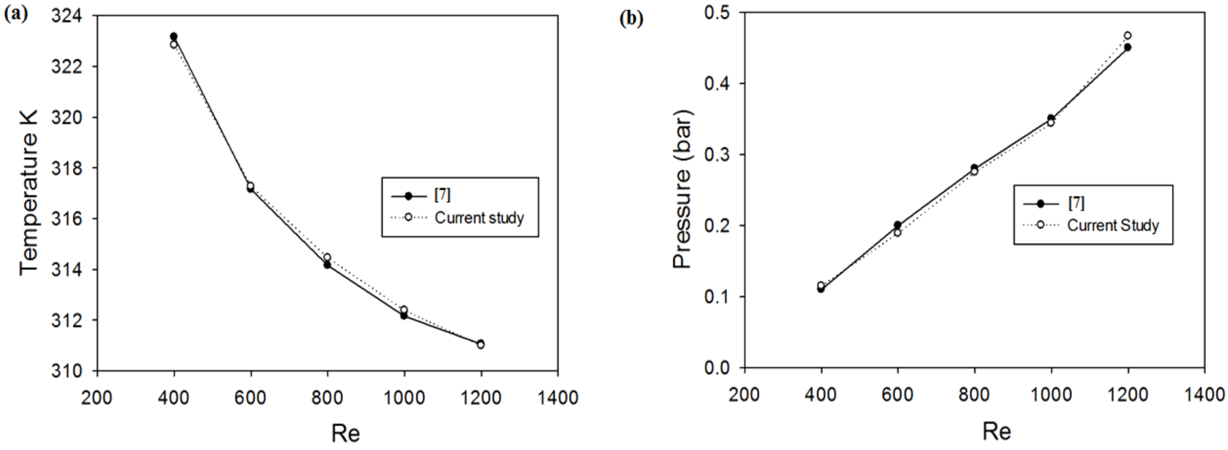

Figure 3. Comparison of (a) temperature with Re and (b) pressure drop with *Re* for plain microchannel

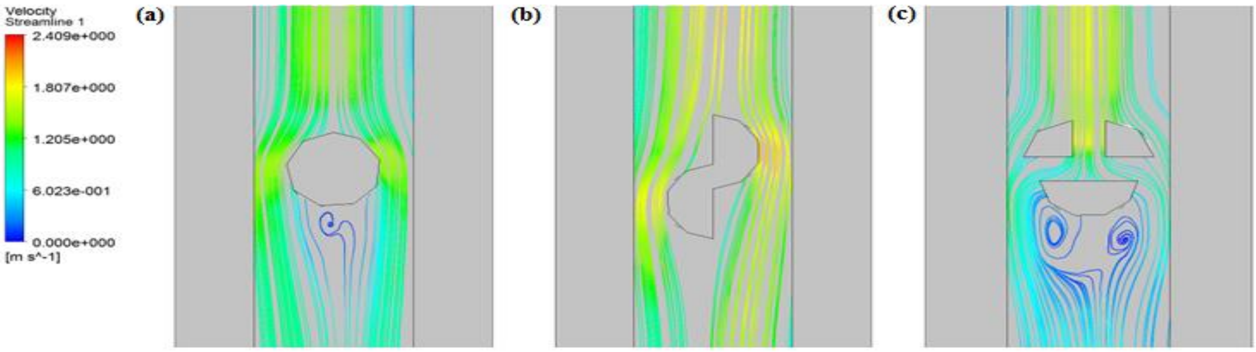

Figure 4. Velocity streamline at *Re* = 600 (a) Case A (b) Case B (c) Case C

Figure 5 shows the relationship between the temperatures with the Reynolds number. It is apparent that extended surface by micro-fin arrays (Cases A, B and C) significantly reduced the average interface temperature compared to the plain rectangular microchannel. An interesting phenomenon can be seen here is when the Reynolds number increases, the average interface temperature decreases. The maximum average temperature of case C reduced to 318K when Reynolds number equals to 1000. This can accredited to the increase of fluid velocity. When the Reynolds number increase, the fluid velocity increase as well, this mean there will be more fluid passing through the microchannel, thus, the better the heat transfer performance. Figure 6 depicts the variation of pressure drop with Reynolds number. It is worth noting that the pressure drop increases in all three cases as expected when compared to plain microchannel. Among all three cases, Case C owns the highest pressure drop. This is due to the large area of stagnation zone formed at the end of micro-fin. As the micro-fins located at the middle of the microchannel, the sudden contraction of flow area forces the core flow to squeeze to the side wall and a transverse flow produce simultaneously. The velocity of fluid drastically decreases at the micro-fins wake, hence, the laminar stagnation zone formed. However, the magnitude is still at an acceptable level. Considering the trade-off between heat dissipation performance and pressure drop, Case B design could be selected as an efficient design for better thermal management.

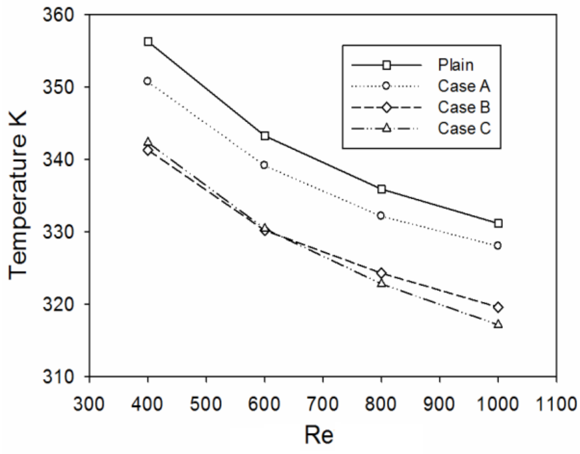

Figure 5. Temperature versus Reynolds number at heat flux 100W/cm^2

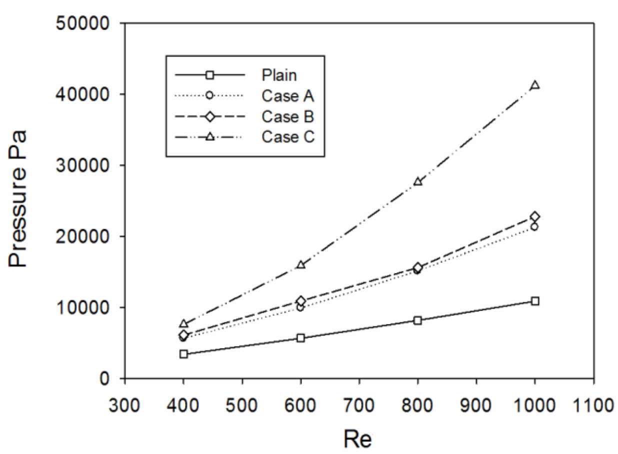

Figure 6. Variation of pressure with Reynolds number at heat flux of 100 W/m^2

4. CONCLUSION

It was found that the heat transfer performance in the microchannel could be enhanced with the cylindrical micro-fin, diverge cylindrical micro-fin and offset cylindrical micro-fin designs. Besides, the offset cylindrical micro-fin design resulted in a relative low pressure drop compared to the diverge cylindrical micro-fin, suggesting its feasibility to be employed for better thermal management.

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