Chapter 66
Thermohydraulic Characteristics of Microchannel Heat Sinks Used in Electronic Cooling Applications

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Abstract Microchannel heat sinks (MCHS) have been gaining demand in electronic industry because of size and performance. Electronic chips produce more temperatures and these temperatures have to be eliminated to avoid failure of electronic chips. MCHS shows higher heat transfer rates, however, with a penalty of pressure drop. In this work, the influence of variation in cross-sectional area on the thermohydraulic characteristics at a constant heat flux of 80 W/cm^2 for MCHS has been studied. Grid independence study has been studied. Five different cross-sectional areas ranging from 0.12 mm^2 to 0.20 mm^2 have been considered for computational investigation. Friction factor, pressure drop have been considered to evaluate hydraulic characteristics and cooling capacity, and temperature difference have considered to evaluate thermal characteristics.

Keywords Microchannel heat sinks · Pressure drop · Heat flux · Cooling capacity

Introduction

Electronic devices have become much faster, smaller, and very powerful because of enhancements in technology. Because of raise in temperatures, the performance is reducing in electronic devices. The large integration of electronic components and the raise in voltage–current managing have led to high accumulation of heat in such devices. The heat elimination or rejection has become a major factor, which constraints the electronic product's development. Hence, to increase the life span and performance of electronic chips, heat management has become crucial.

Most of the authors has did their work on thermal characteristics of fluid by using air as cooling fluid to remove heat from the electronic chips. However, when it comes to dealing with such parts, which contains a huge number of transistors, which are working at high frequency. The temperatures of chips will reach to a point where normal cooling process is not enough. MCHS showing better performance in terms

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of removing higher temperatures. Recently, [1] has studied on the microchannel heat sink with annular flow through it, [2] has proposed microchannel heat sink with an unique structure of rhombus fractal like structure, [3] has proposed transverse microchannels to the main channels, [4] has added cavities and fins to the MCHS, [5] has passed cryogenic fluid through microchannel heat exchangers, [6] has passed nanofluids through the MCHS, [7] has worked on different shapes of MCHS, and [8] has considered three different shapes and different aspect ratios. In this work, the variation in cross-sectional areas has been investigated at a constant heat flux of 80 W/cm^2 for different Reynolds numbers ranging from 200 to 1000 for a rectangular MCHS at an aspect ratio ($\alpha = H_{ch}/W_{ch}$) of 11.442. Five different cross-sectional areas are 0.12 mm^2, 0.14 mm^2, 0.16 mm^2, 0.18 mm^2, and 0.20 mm^2, with widths 0.102 mm, 0.110 mm, 0.118 mm, 0.125 mm, and 0.132 mm, respectively. Water has considered as flow fluid and copper has considered as substrate. The schematic diagram of MCHS has drawn in ANSYS 14.5 as shown in Fig. 66.1.

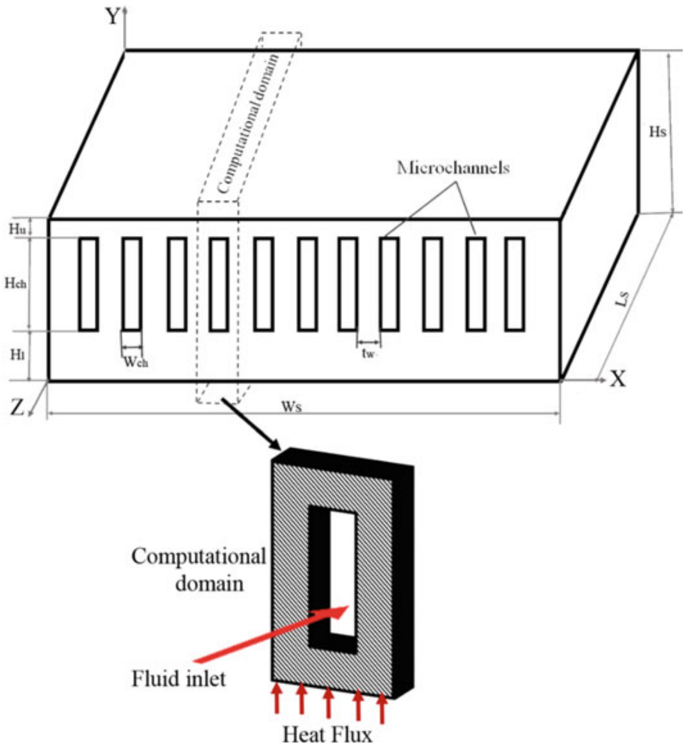

Fig. 66.1 Schematic diagram of microchannel heat sink

Mathematical Formulation

To find the thermal and hydraulic characteristics of microchannel heat sinks (MCHS) and for solving heat transfer problems, the following assumptions are made.

1. The fluid poses laminar characteristics.
2. The fluid is incompressible and in steady-state condition.
3. At walls of the fluid, zero slip boundary condition is assumed.
4. The impact of gravity and radiation heat transfer are assumed to be negligible.
5. Properties of the solid and fluid are assumed as constant except the viscosity of coolant water (viscosity of fluid varies with fluid temperature).
6. The influence of viscous dissipation of fluid flow is negligible.
7. The governing equations for the fluid and solid are modified to evaluate the thermal and hydraulic characteristics of MCHS [8].

Conservation of mass,

$$\nabla \vec{\mathbf{V}} = 0 \tag{66.1}$$

Conservation of momentum,

$$\rho_{fd}\left(\vec{\mathbf{V}}.\nabla\vec{\mathbf{V}}\right) = -\nabla P + \nabla.\left(\mu_{fd}\nabla\vec{\mathbf{V}}\right) \tag{66.2}$$

Conservation of energy,

$$\rho_{fd}C_{pf}\left(\vec{\mathbf{V}}.\nabla T_{fd}\right) = k_{fd}\nabla^2 T_{fd} \tag{66.3}$$

For the solid region, the energy equation is as follows,

$$k_{sd}\nabla^2 T_{sd} = 0 \tag{66.4}$$

where $\vec{\mathbf{V}}$ is velocity vector, μ_{fd} is dynamic viscosity of fluid, ρ_{fd} is density of fluid, k_{fd} is thermal conductivity of fluid, P is pressure, k_{sd} is thermal conductivity of fluid, Tfd is temperature of channel, and Tsd is temperature of solid.

To calculate hydraulic diameter for rectangular microchannel,

$$D_h = \frac{4A_C}{P_{ch}} = \frac{4(H_{ch} \times W_{ch})}{2(H_{ch} + W_{ch})} \tag{66.5}$$

where A_C is cross-sectional area of channel, P_{ch} is perimeter of channel, H_{ch} is height of channel, and W_{ch} is width of channel.

The velocity can be obtained from,

$$\mathrm{Re} = \frac{\rho_{fd} D_h v}{\mu_{fd}} \tag{66.6}$$

where ρ_{fd} is density of fluid, D_h is hydraulic diameter, v is velocity of fluid, and μ_{fd} is dynamic viscosity of fluid. The mass flow rate of fluid can be calculated from [9],

$$\dot{m} = \rho_{fd} A_C v \tag{66.7}$$

where $\dot{m}$ is mass flow rate of fluid and A_C is cross-sectional area of fluid. From post-processing module, the shear stress (τ_{wall}) can be obtained to calculate the friction factor. The friction factor can be estimated from,

$$f_r = \frac{8\tau_{wall}}{\rho_{fd} v_{avg}^2} \tag{66.8}$$

where f_r is friction factor and τ_{wall} is shear stress.

The convective heat transfer coefficient can be calculated from,

$$h_c = \frac{Q}{A_{srf} \times (T_{wall} - T_{bulk})} \tag{66.9}$$

where h_c is convective heat transfer coefficient, Q is heat transfer, A_{srf} is surface area, T_{wall} is wall temperature of fluid, and $T_{bulk} = (T_{inlet} + T_{outlet})/2$ is bulk temperature of fluid.

The cooling capacity of fluid can be estimated from,

$$Q_{cc} = \rho_{fd} c_{pf} \dot{V} (T_{outlet} - T_{inlet}) \tag{66.10}$$

where Q_{cc} is cooling capacity of fluid, c_{pf} is specific heat of fluid, T_{outlet} is outlet temperature of fluid, T_{inlet} is inlet temperature of fluid, and $\dot{V}$ is volume flow rate.

The temperature difference of fluid can be calculated by,

$$T_d = T_{outlet} - T_{inlet} \tag{66.11}$$

Results and Discussion

Grid independence study has been done and considered one mesh size for further simulations. Hydraulic characteristics and thermal characteristics of the MCHS have been studied.

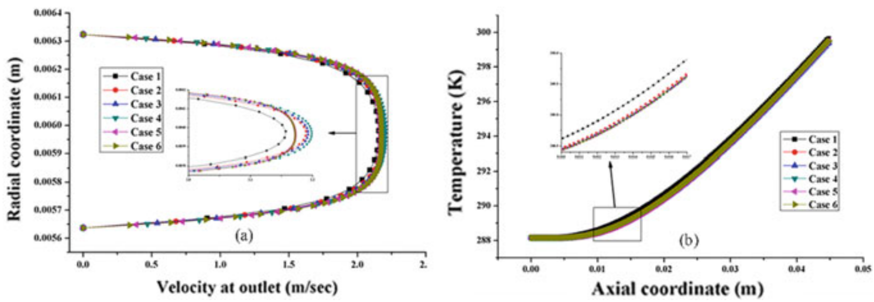

Fig. 66.2 Grid independence study on microchannel heat sink for six different cases

Table 66.1 Description of mesh body

Case	Number of divisions	Number of elements
Case 1	10 × 20 × 160	120,960
Case 2	20 × 30 × 180	388,800
Case 3	30 × 40 × 200	842,400
Case 4	40 × 50 × 220	1,520,640
Case 5	50 × 60 × 240	2,462,400
Case 6	60 × 70 × 260	3,706,560

Grid Independence Test

To maintain the accuracy in results, a grid independence study was studied on the microchannel. The obtaining results are sensitive to the mesh size; hence, the variation in the mesh size leads to the variation in result. However, at some point, the variation in values would be very small to consider that mesh would be suitable for simulation to obtain more accurate results.

In this work, six different cases have been considered for grid independence test as shown in Fig. 66.2 and the description of mesh body is as given in Table 66.1. The percentage difference of velocity at outlet are 2.34%, 0.15%, 0.36%, 0.13%, and 0.09%. While the percentage of difference in temperature are 0.055%, 0.051%, 0.054%, 0.013%, and 0.002%. Among the six different cases, percentage difference is very small for case 5 and case 6. Hence, case 5 has considered for simulations.

Hydraulic Characteristics

Friction factor and pressure drop have been considered for investigation. The characteristics were investigated with respect to Reynolds number.

The variation of friction factor with respect to Reynolds number is shown in Fig. 66.3. The variation of friction factor among the five cross-sectional areas is

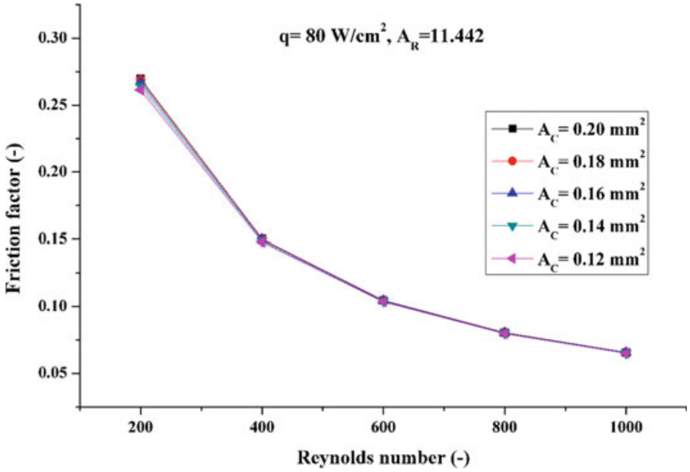

Fig. 66.3 Friction factor versus Reynolds number for five different cross-sectional areas

minor. However, as the Reynolds number increases, friction factor decreases. At Reynolds number 200, the friction factor is higher and for Reynolds number 1000, the friction factor is lower. Considering the higher Reynolds number which leads to the lower friction factor.

Figure 66.4 shows the variation of pressure drop with respect to Reynolds number. As the Reynolds number increases, pressure drop also increases. Cross-sectional area 0.12 mm^2 shows high pressure drop among five different cross-sectional areas. At

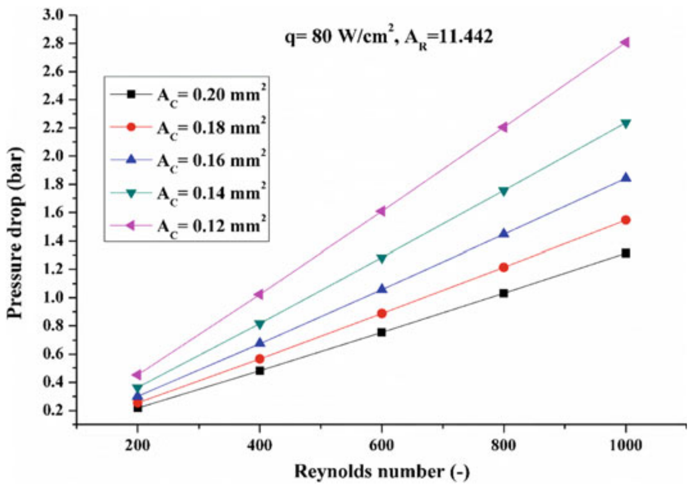

Fig. 66.4 Pressure drop versus Reynolds number for five different cross-sectional areas

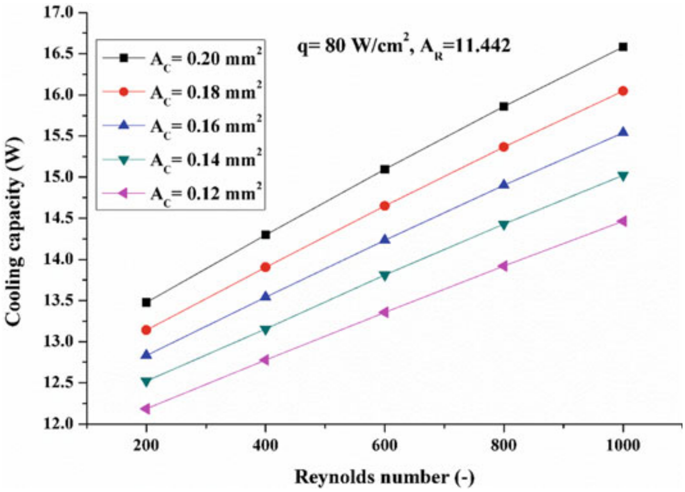

Fig. 66.5 Cooling capacity versus Reynolds number for five different cross-sectional areas

Reynolds number 200, the pressure drop is lower and for Reynolds number 1000, the pressure drop is higher. Higher Reynolds number leads to the pressure drop.

Thermal Characteristics

Figure 66.5 shows the variation of cooling capacity with respect to Reynolds number. As the Reynolds number increases, cooling capacity also increases. Cross-sectional area 0.20 mm^2 shows higher cooling capacity among five different cross-sectional areas. At Reynolds number 200, the cooling capacity is lower and for Reynolds number 1000, the cooling capacity is higher. Higher Reynolds number leads to the higher cooling capacity.

Figure 66.6 shows the variation of temperature difference with respect to Reynolds number. As the Reynolds number increases, temperature difference decreases. Cross-sectional area 0.12 mm^2 shows higher temperature difference among five different cross-sectional areas. At Reynolds number 200, the temperature difference is higher and for Reynolds number 1000, the cooling capacity is lower. Lower Reynolds number leads to the higher temperature difference.

Conclusion

The influence of variation in cross-sectional area ranging from 0.20mm^2 to 0.12mm^2 has been investigated. Hydraulic and thermal characteristics have been calculated and

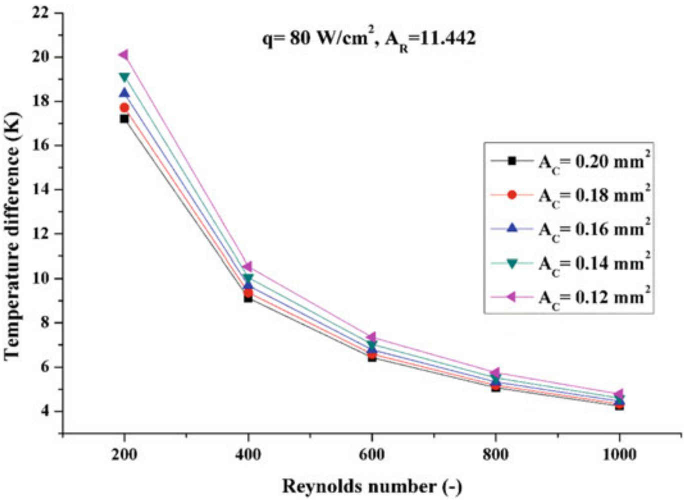

Fig. 66.6 Temperature difference versus Reynolds number for five different cross-sectional areas

the conclusions have been made. Higher Reynolds number is preferable to reduce the friction factor and there is very small variation in friction factor among five different cross sections. Larger cross-sectional area poses least pressure drop among the cross-sectional areas. For cooling capacity, larger cross-sectional area poses higher cooling capacity.

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