Computational Investigation of Micro-channel Heat Sink with Rectangular Shape Obstacles

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Abstract. Nowadays a lot of interest is given to the geometrical modification of heat sink systems to cool down the electronic components. To improve the performance index of the heat sinks, the use of geometrical features with different shapes and at different locations on the surface can be a valuable approach. In this paper, the effect of rectangular shape obstacles on the micro channel heat sink (MCHS) performance is studied. Due to surface features, vortex is developed which helps to increase the heat transfer rate. Numerical modeling software Comsol Multiphysics with heat transfer in fluid physics is used to investigate the characteristics of a micro-channel heat sink. The numerical result shows that the heat transfer rate can be improved through an appropriate arrangement of rectangular shape obstacles, on the heat sink. Numerical analysis and the comparison is carried out for micro-channel heat sink with and without obstacles. In this paper, various parameters like temperature rise, cell Peclet number and Mean effective thermal conductivity are studied.

1. INTRODUCTION

Nowadays as the electronics gadget becomes more and more innovative and compact in size, the thermal engineers getting challenges for high heat generation reduced surface area. Because of the absence of enough heat removal techniques, the temperature of electronic equipment with which it works, may increase beyond a designed temperature which then increases the chances of failure of this apparatus. Therefore, current electronic gadgets are having more heat generation rate which needs a high heat dissipation rate and compact in size for cooling electronics device for better operation.

In order to cool these electronic devices, there is the need to increase heat transfer surface area and heat transfer coefficient of the devices. The heat transfer coefficient is related to the heat dissipation rate, temperature difference and channel hydraulic diameter, so it’s not a good option to work on it. Increasing the surface area can be thought as another option available. To increase the heat transfer area one option is use of micro channels with various types of obstacles on surface. The thickness, width and channel height of micro-channel are some parameters which affects the performance of the heat sink.

Chen [1] investigate the characteristics of flow in micro-channels numerically. Naphon [2] investigate the pressure drop and convective heat transfer in the micro-channel heat sink. Ambatirudi and Rahman [3] investigate the heat transfer phenomena in micro-channel heat sinks. Kayehpour [4] analysed the micro-channels for effects of rarefaction & compressibility on the gas flows. Ng and Poh [5] analysed the liquid flow in the two layer micro-channel by using Computational Fluid Dynamics. Hao and Tao [6] applied a numerical model to analyse the phase change flow in micro-channels. Zhao and Lu [7] investigated the thermal performance of micro-channel heat sink by considering the effect of porosity.
by using analytical and numerical method. Xuan [8] analysed the effect of the thermal and contact resistances of ceramic plate in thermoelectric micro-coolers. Bhowmil [9] investigate the convective heat transfer of water in steady-state from four in-line electronic chips in a vertical rectangular channel. Wang et al. [10, 11] studied the gas flow and heat transfer in a micro-channel using DSMC with uniform heat flux boundary condition. Zhang et al. [12] analyzed a single-phase heat transfer of micro-channel heat sink for electronic gadgets. Didarul [13] studied the impact of characteristics of fluid flow on heat transfer with finned surfaces. Shinde et.al. [14] analysed the behaviour of fluid using FEA based COMSOL Multi-physics software. Zhen et al. [15] investigated comparative studied of 3-D and 2-D DSMC heat transfer of flow-speed short micro-channel flows.

In this paper, micro-channel configuration of heat sink is studied for channel with rectangular shape obstacles and channel without obstacles. The various parameters like temperature rise of cooling agent, cell Peclet number and mean effective thermal conductivity is studied for both the cases.

2. PROBLEM DEFINITION

In this paper, micro-channel heat sink having aspect ratio of 1 is used. The schematics diagram of micro-channel heat sink without obstacles are exposed in figures 1 and 2. The bottom surface of heat sink is subjected to constant heat flux. It is expected that the top surface of the heat sink is not dissipating any heat. Which simply means that total heat is transferred to the cooling water by using channel base and vertical walls.

![Figure 1. The graphical representation and overall dimensions of the micro-channel heat sink](image1)

![Figure 2. Schematics of the microchannel heat sink](image2)

Table: 1 shows the schematics drawing for channel with and without obstacles. The entire bottom area of the heat sink is act as heat source with constant heat flux. The total 11 channels having 10 mm total length of the channel. In this study it is assumed that the entire heat will be transferred to the water
(coolant) from the bottom surface and the side walls of the channel. Silicon material is used for heat sink having thermal conductivity of 160 W/mK. Water is used as cooling medium with inlet temperature is 20 degree C. The bottom surface of heat sink is subjected to constant heat flux of 1000 W/m². The investigation is carried out for different fluid flow velocity of water varying between 0.1 mm/s to 1 mm/s.

3. COMPUTATIONAL ANALYSIS

3.1 Governing Equation

The Heat Transfer in Fluids interface uses the following version of the heat transfer equation to model heat transfer in fluids in micro channels:

\[ \rho C_p \frac{\partial T}{\partial t} + \rho C_p u \cdot \nabla T = \nabla \cdot (k \nabla T) + Q \]

For a steady-state problem the temperature does not change with time and the first term disappears.

3.1.1 Parameters Used

Parameters used for the study of Micro Channel Heat Sink are listed in the following table which includes wide range of aspects, based on the following parameters analysis of MCHS is carried out.

| Parameters | Dimension | Value          | Description                  |
|------------|-----------|----------------|------------------------------|
| W1         | 1[mm]     | 0.0010000 m    | Width of channel             |
| H1         | 1[mm]     | 0.0010000 m    | height of channel            |
| L          | 10[mm]    | 0.010000 m     | length of channel            |
| Q          | 1000[W/m²]| 1000.0 W/m²    | Constant Heat flux           |
| Ti         | 293[K]    | 293.00 K       | Inlet Temperature            |
| w          | .5[mm]    | 5.0000E-4 m    | Width of obstacle            |
| l          | 1[mm]     | 0.0010000 m    | Length of obstacle           |
| sp         | 2[mm]     | 0.0020000 m    | Spacing between obstacle     |
| Ar         | 5         | 5.0000         | Number of obstacles in one side |
| ex         | H         | 0.0010000 m    | height of obstacle           |
| v          | 1[mm/s]   | 0.0010000 m/s  | Flow velocity                |

3.2 Geometry

![Geometry of Micro-channel without and with obstacle](image)

Figure 3. Geometry of Micro-channel without and with obstacle
In this work, geometrical feature of rectangular shape at specific interval on the surface is studied and analyzed. The total length of the channel is 10 mm, with height and width of 1 mm. The specifications of the geometry and the boundary conditions used are described below. Figure 3a shows the rectangular micro channel without obstacle and Figure 3b shows rectangular micro channel with obstacles.

Table 2 lists all the boundary conditions used for the study.

| Boundary          | Flow Boundary Condition | Thermal Boundary Condition |
|-------------------|-------------------------|---------------------------|
| Inlet at Front Side| Velocity Inlet          | Inflow                    |
| Outlet at Back Side| Pressure Outlet         | Outflow                   |
| Left Side Wall    | Wall                    | Adiabatic                 |
| Right Side Wall   | Wall                    | Adiabatic                 |
| Bottom Surface Wall| Wall                   | Constant Heat Flux         |
| Top Surface Wall  | Wall                    | Adiabatic                 |

3.3 Simulation Results

Numerical modeling software Comsol Multiphysics with heat transfer in fluid physics is used to analyze the characteristics of a micro-channel heat sink for various parameters listed in Table 1. The results of the simulation are discussed in detail, in the following figures 4.

Figure 4 shows temperature distribution in channel with and without obstacles. Figure 4a shows temperature distribution for normal shape channel. Red color shows minimum temperature zone and white color indicates maximum temperature zone. In case of normal channel, at 0.9 mm height of channel, 296K maximum temperature is observed. At the same time, 298K temperature is observed in case of channel with rectangular shape obstacles as shown in figure 4b. Similarly heat transfer analysis is done for variable height of channel. At height of 0.1mm, it is observed that 316 K and 336 K temperature rise is observed in micro-channel without obstacle and with rectangular shape obstacles respectively as shown in figure 4c and 4d.
Figure 5. Effect of fluid flow velocity on temperature rise in fluid as water

Figure 5 shows the effect of fluid flow velocity on temperature rise of the fluid in normal channels and in channel with rectangular obstacles. The temperature of 315K was observed at the fluid flow velocity of 1.00E-04 mm/sec in normal channel, whereas the temperature of 327 K was recorded for the same fluid flow velocity for channel with rectangular obstacles. It can also be noted that at the reduced fluid flow, the temperature rise is more and more effectiveness of microchannel with rectangular obstacles is observed.

4. Results and Discussion

In this paper, analysis of heat sink micro-channel with and without rectangular shape obstacles is carried out by considering the effect of inlet fluid flow velocity and height of micro-channel. The flow velocity is varied from 0.1mm/s to 1mm/s. The effect of flow velocity on temperature rise and cell Péclet number is studied.

Figure 6. Effect of fluid flow velocity on cell Péclet number

From figure 5, it is clear that, as fluid flow velocity increases, temperature rise decreases. It is also observed that, temperature rise is is more in case of micro-channel with rectangular shape obstacles.
The maximum temperature rise is observed at 0.1 mm/s velocity of fluid flow. It is clear that as velocity is less, more heat transfer rate can be achieved.

From figure 6, it is observed that, as fluid flow velocity increases, temperature rise increases linearly. It is also observed that, cell Peclet number is more in case of micro-channel with normal shape. The maximum cell Peclet number is observed at 1 mm/s velocity of fluid flow. It is clear that as velocity is more that is 1 mm/s, 2.8 cell Péclet number is achieved.

Similarly height of channel is varied from 0.1 mm to 1 mm. The effect of height of channel on temperature rise and cell Peclet number is studied. From figure 7, it is observed that, as height of channel increases, temperature rise decreases nonlinearly. It is also observed that, temperature rise is more in case of micro-channel with rectangular shape obstacles. The maximum temperature is observed at 0.1 mm height of micro-channel. It is clear that as height of channel is more that is 1 mm, 339 K temperature rise is achieved in case of channel with obstacles.

Figure 7. Effect of height of channel on temperature rise in fluid as water

Figure 8. Effect of height of channel on cell Péclet number
5. CONCLUSION
The temperature rise and cell Peclet number of micro-channel heat sink (MCHS) with water coolant has been analysed thoroughly and based on the results, following conclusions can be made for heat sink with and without obstacles. Using heat transfer in fluid equation, present CFD model of normal channel and channel with obstacles is simulated and compared. It is found that, temperature rise and cell Peclet number is influenced by fluid flow velocity and height of channel of heat sink. Due to presence of rectangular shape obstacles in micro-channel, turbulence is created and heat transfer rate is increased as compared with micro-channel with normal shape.

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