Design and Analysis of Micro-channel Heat Sink with Rectangular Shape Obstacles

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Abstract -*A lot of interest is given to the geometrical modification of heat sink systems. To improve the performance of heat sinks, the use of surface features with different shapes and at different locations on the surface can be a valuable approach. In this paper, effect of rectangular shape obstacles, on the heat sink 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 analyze 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 is carried out for micro-channel with and without obstacles. In this paper, various parameters like temperature rise, cell Peclet number, and Mean effective thermal conductivity studied.*

Keywords: ***Micro-channel Heat Sink, Rectangular Shape Obstacles, temperature rise, Mean effective thermal conductivity***

1. INTRODUCTION

As the electronics apparatus becomes more sophisticated and smaller in size, it faces thermal engineering challenges from heat generation and the decrease of available surface area. In the absence of enough heat removal, the working temperature of electronic equipment may go beyond a desired temperature level which then increases the critical failure rate of apparatus. Therefore, advanced electronic equipment with high heat generation requires an efficient and compact cooling device to provide system operation.

In order to meet the cooling requirement, one need to increase the product of heat transfer coefficient (h) and heat transfer surface area (A). Since heat transfer coefficient is related to the channel hydraulic diameter, increasing surface area is another available option. The heat transfer surface area can be increased by incorporating micro channels with various types of obstacles on the chip surface. Micro-channel width, thickness and channel height such a parameters also affects the performance of the heat sink.

Naphon et al. [1] studied the convective heat transfer & pressure drop in the microchannel heat sink. Kayehpour et al. [2] studied the effects of compressibility and rarefaction on the gas flows in micro-channels. Chen [3] numerically analyzed the flow characteristics in micro-channels. Ambatirudi and Rahman [4] analyzed the heat transfer in micro-channel heat sinks. Ng and Poh [5] applied the CFD for analysis of liquid flow in the double layer microchannel. Zhao and Lu [6] presented the analytical and numerical study effect of porosity on the thermal performance a micro-channel heat sink. Xuan [7] investigated the effect of the thermal and contact resistances of ceramic plate in thermoelectric micro-coolers. Hao and Tao [8] applied a numerical model to analyze the phase change flow in micro-channels. Bhowmil [9] studied on the steady-state convective heat transfer of water from an in-line four electronic chips in a vertical rectangular channel. Zhang et al. [10] reported the study of a single-phase heat transfer of micro-channel heat sink for electronic packages. Didarul [11] investigated the heat transfer and fluid flow characteristics of finned surfaces. Zhen et al. [12] compared the 3-D and 2-D DSMC heat transfer of flow-speed short micro-channel flows. Wang et al. [13, 14] numerically studied the gas flow and heat transfer in a micro-channel using DSMC with uniform heat flux boundary condition.

In this paper, micro-channel 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 cases.

2. PROBLEM DEFINITION

In this paper, micro-channel heat sink having aspect ratio 1 is used. The schematic of the heat sink without obstacles and their dimensions are shown in figures 1 and 2. The heat flux is supplied at the bottom of the heat sink. It is assumed that the top surface of the heat sink is not participating in the heat transfer. In other words, the entire heat flow is transferred to the coolant (water) through the channel base and vertical walls.

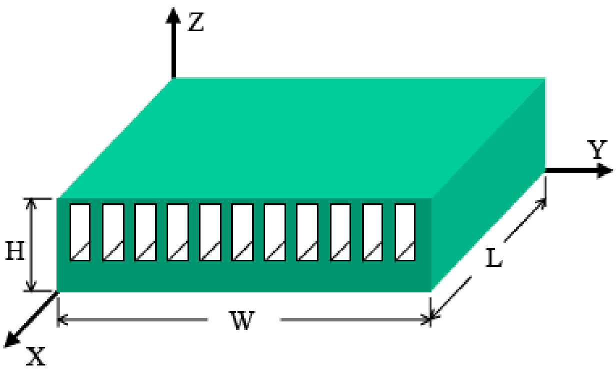


Fig 1: The schematic and overall dimensions of the micro-channel heat sink

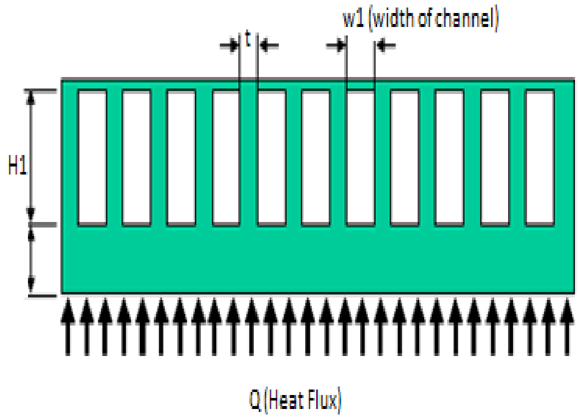


Fig 2 : Dimensions of the microchannel heat sink (The drawing is not to scale)

Table 1 shows the geometrical parameters used for channel with and without obstacles. The heat flux is supplied to the entire bottom area of the heat sink. The total number of channels is 11 and the total length of the channels is 10 mm. Since it is assumed that the total heat will be transfer to the coolant (water) from the base and the vertical walls of the channel. The heat sink material is silicon with thermal conductivity of 160 W/mK. The cooling liquid is water and the water inlet temperature is 20
degree C. A uniform heat flux of 1,000 W/m² is applied at 4.
the bottom of the heat sink. The analysis is done for
various fluid flow velocity of water ranging from 0.1 mm/s 5.
to 1 mm/s.

6.

3. CFD ANALYSIS

3.1 GOVERNING EQUATION 7.

The Heat Transfer in Fluids interface uses the following 8.
version of the heat equation to model heat transfer in fluids:

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

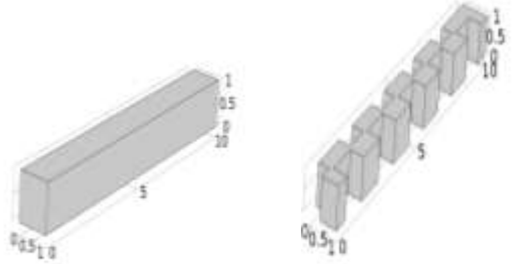
For a steady-state problem the temperature does not change with time and the first term disappears.

3.2 PARAMETERS USED

Table 1: parameters used for analysis

Name	Expression	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/m^2]	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

4. GEOMETRY



Micro channel without obstacle — Micro-channel with rectangular shape obstacles

Figure 3. Geometry of Micro-channel without and with obstacle

Table 3. Boundary conditions used

Boundary	Flow Boundary Condition	Thermal Boundary Condition
Front Inlet	Inlet	Mass Flow Inlet
Back Outlet	Outlet	Outflow
Left Wall	Wall	Adiabatic
Right Wall	Wall	Adiabatic
Bottom Wall	Wall	Constant Heat Flux
Top Wall	Wall	Adiabatic

5. SIMULATION RESULTS

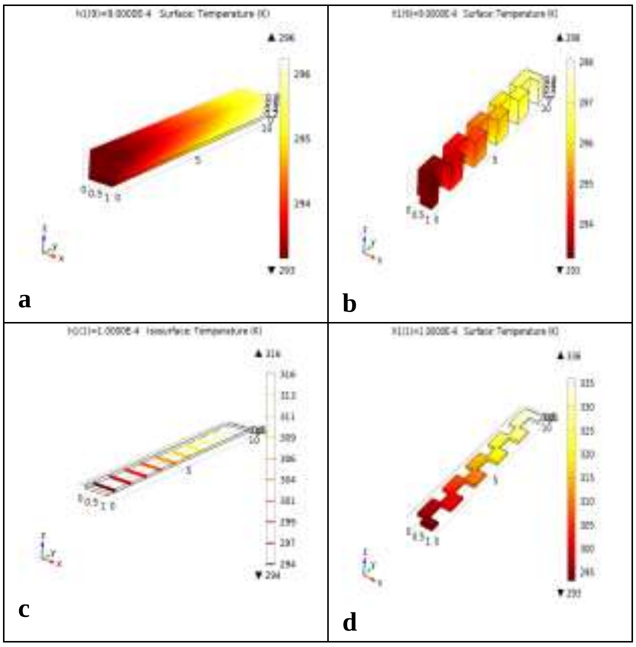


Figure 4.Temperature distribution in channel with and without bstacles

Figure 4: shows temperature distribution for micro-channel with and without rectangular shape 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.

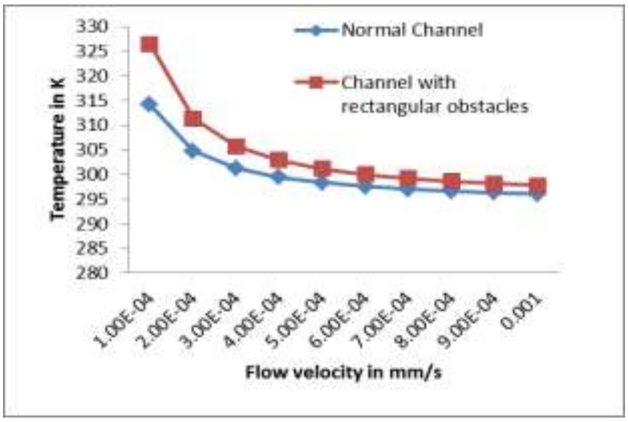


Figure 5. Effect of fluid flow velocity on temperature rise in fluid as water

6. 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 peclet number is studied.

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.

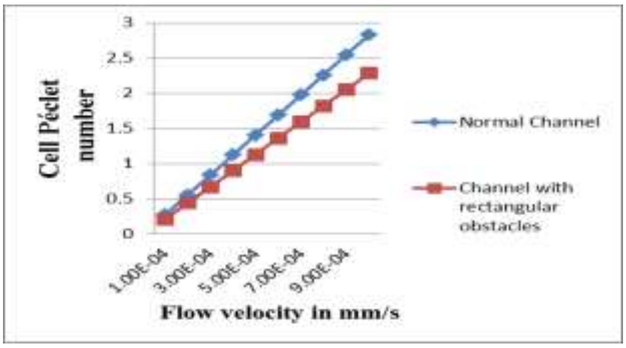


Figure 6. Effect of fluid flow velocity on cell Peclet number

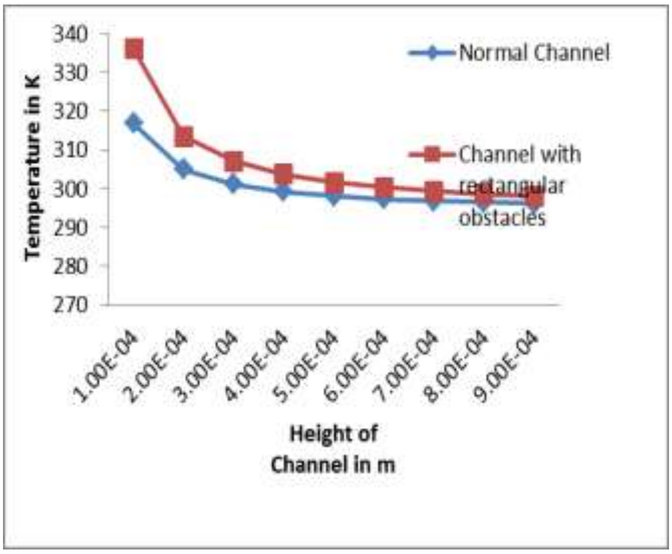


Figure 7. Effect of height of channel on temperature rise in fluid as water

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 peclet number is achieved.

Similarly height of channel is varied from 0.1mm to 1mm. 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 case4 of channel with obstacles.

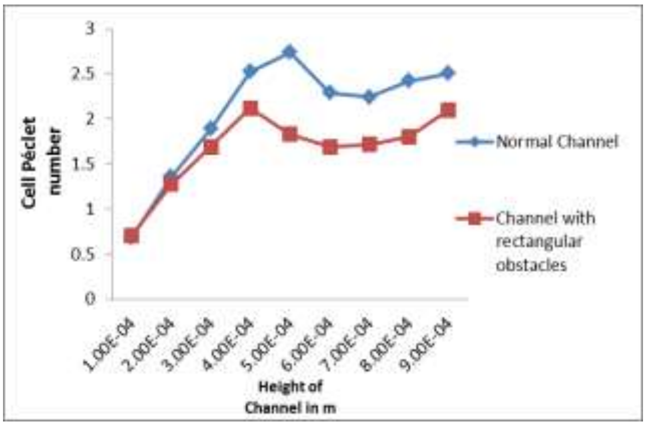


Figure 8. Effect of height of channel on cell Peclet number

From figure 8, it is observed that, as heigth increases, cell Peclet number increases non-linearly. It is also observed that, cell Peclet number is more in case of micro-channel with normal shape. It is clear at 0.1 mm of height of channel, there is less peclet number.

7. CONCLUSION

The temperature rise and cell Peclet number of micro-channel of heat sink with water coolant has been analyzed. Based on the results following conclusions can be made for heat sink with and without obstacles studied. 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.

8. REFERENCES

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