Original Article

THERMAL ANALYSIS OF FLUID FLOW THROUGH MICROCHANNELS WITH VERTICAL BIFURCATIONS FOR NON-UNIFORM HEAT FLUXES

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Abstract

A power-efficient composite heat sink is an element for optimization of temperature, pressure drop, and power requirements in electronic devices cooling. A micro-channel with sub-channels which has the potential to develop hybrid heat sinks is analyzed numerically and compared with a simple micro-channel along with sub-channel for various heat fluxes and mass flow rates of water. The base temperature, pressure drop, and pumping power are calculated at various base and hot spot heat fluxes for different Reynolds numbers. Laminar flow region is considered for this analysis. It has been found that by the introduction of sub-channel above hotspot regions, the base temperature can be maintained within the safe limits and saves the power requirements of heat sinks, with a saving of 49.65% in pumping power. The sub-channels in comparison with uniform width micro-channels maintain the base temperature of the sink within the safe limits.

Keywords: Micro-channel heat transfer, Electronics Cooling, Hotspot Mitigation.

1. INTRODUCTION

In Present day electronic devices which dissipates high heat energy through components and air-cooling technology becomes inefficient. External attachment by way of heat sinks becomes essential for dissipation of heat. An energy-efficient micro-channel heat sink is required for modern electronic devices which are getting compact day by day, while functions and complexity have rapidly grown over the past four. Therefore, the heat dissipation of electrical components has grown to somewhere between 102 and 106 W/m2 [1]. Compact electronic system design must take heat dissipation into account in order to avoid system failure or malfunction owing to electronic component temperatures above the permitted threshold. Even while air heat sinks have typically been used to cool CPUs and graphics processing units, this won't be enough for the newest generation of microchips to keep them cool. As an additional point of comparison, as compared to liquids, the pumping power required by gases is much higher for the same thermal performance as for the same thermal performance. In order to overcome this issue, a lot of research has been done to develop more effective cooling technologies that can meet the needs of new electronic equipment and huge electronic systems, and also the needs of old electronic equipment.

Developed by Tuckerman and Pease[2] for the cooling of integrated electronic circuits, micro-channel heat sinks have evolved into an active cooling technology that allows for the evacuation of enormous volumes of heat from a compact enclosed space. The fabrication procedure favours rectangular micro-channels, which have been examined experimentally and numerically [2–4]. It was found that the classical Navier-Stokes equations may be used to estimate flow and heat transfer in rectangular micro-channels numerically and experimentally by Leeet al. [3]. Furthermore, the pressure drops, and heat transfer characteristics were investigated by Qu and Mudawar [4] of a single micro-channel heat sink made of copper. When it came to predicting future events, the classic Navier-Stokes and energy equations provided excellent accuracy. As a result, the Navier-Stokes equation is most frequently applied to microscale fluid systems.

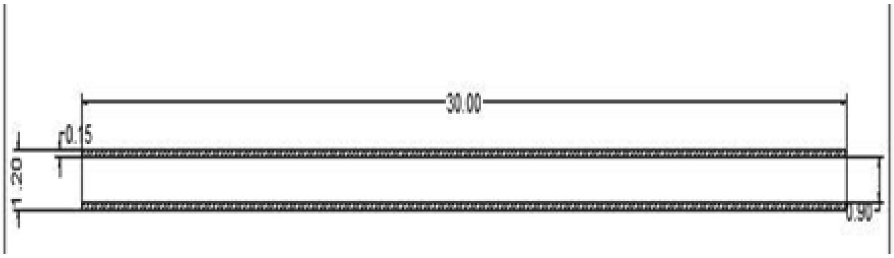
Different configurations were studied by Wu and Cheng [5], studies on wavy micro-channels with rectangular cross-sections were performed by Sui et al. [6], Kurnia et al. [7], Xie et al. [8], Wee et al[9]. It was discovered that while designs provide a faster and more uniform heat transfer rate, they also have a higher pressure drop penalty. On the other side, heat transfer devices like ribbed pins, dimples, and dimpling can be utilized to increase the heat transfer coefficient or decrease thermal resistance. Hung et al. ; Zhu et al. ; Yan et al. The double-layer straight or wavy micro-channel, on the other hand, hasn't had a significant impact on the industry. In recent years, it has been realised that a well planned bifurcation flow (in which the flow is split into numerous downstream flows) can increase heat transfer by re-establishing the boundary layer at a constant flow rate, hence increasing the overall heat transfer. In this view, the existence of bifurcation results in the destruction of the formation of the boundary layer and the subsequent redirection of the flow into several flow channels, with each boundary layer restarting from the bifurcated point [15,16].

In the present study, the use of bifurcation of micro-channels for hotspot applications is studied numerically. The analysis is carried out in three different cases. In the first instance, the channel width is according to background heat flux, in the second instance the channel width is according to hot spot heat flux however both these cases are having internal difficulties. The first case cannot cool the hotspot zone and the second case creates a large pressure drop. To overcome these shortcomings bifurcation is considered only in the hotspot zone thus the channel is divided into sub-channels to obtain higher heat fluxes at the hotspot zone. This will tackle the hotspot fluxes with minimum pressure drop. The numerical analysis is carried out for a laminar flow conditions using Computational Fluid Dynamics (CFD).

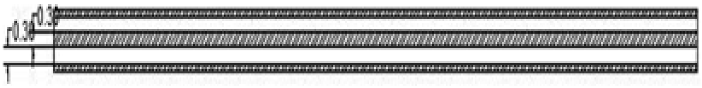
2. THERMAL ANALYSIS OF FLUID FLOW THROUGH A SINGLE

1. MICROCHANNEL

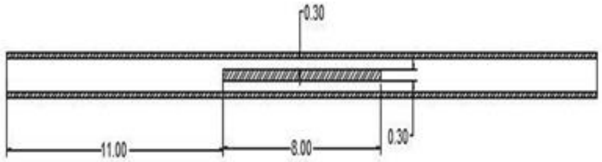
Fig 1. shows diagrams of a single rectangular micro-channel considered for thermal analysis subjected to a non uniform heat fluxes at bottom of the surface. Fig1(a) depicts the geometric dimensions of a channel of 0.9 mm with a uniform cross-section. Fig1(b) shows a channel with a uniform cross-section of 0.3 mm width. Fig1(c) depicts Micro-channel with a sub-channel located above the hotspot zone. The geometric parameters and heat fluxes of the base are as shown in Fig1(d)



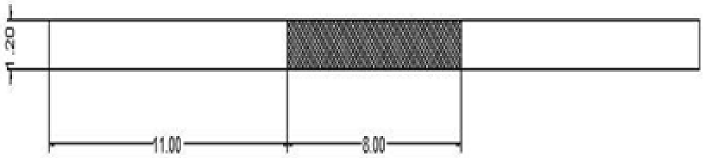
(Fig 1a) A Micro-channel with 0. 9 mm width and 0.15 mm wall thickness,30mm length.



(Fig 1b) A Micro-channel with 0.3 mm width and 0.15 mm side wall and 0.3 mm center wall



(Fig 1c) A Micro-channel with 0.9 mm width and 0.15mm wall thickness,30 mm length with a sub-channel at the center



(Fig 1d) Heat flux Zones are represented as shaded area is the hotspot zone 11.0 mm zone is the background area All dimensions are in mm

Fig 1. Single Micro-channel showing heat flux zones at the base (three case)

Reynolds number ranges from 600 to 1200, and the flow is supposed to be constant and laminar. The gravitational effect as well as heat transfer owing to radiation is not taken into consideration. In COMSOL Multiphysics 5.6, the numerical simulations of the process are carried out using the discretization approach of the finite element method (FEM) finite element method. A total of 2,88,067 elements are taken to solve temperature, velocity, and pressure through the channel. Different element sizes of maximum 0.112 and minimum of 0.0211 are implemented depending on the type of surface. Symmetry is considered, as the side walls are half of the width of the channel. Adiabatic conditions are applied on the top surface. The partial differential equations are solved by using the Galerkin method. Boundary conditions are considered by assigning the input mass flow rate of 0.0005167 kg/s(Re=774),0.0006172 kg/s(Re=924) and 0.000772 kg/s(Re=1156) and inlet temperature of water is assumed as 300K. Heat flux at the base of the channel is defined as Hotspot area and the background area. The heat inputs of 100 W/ cm2, 200 W/ cm2, 300 W/ cm2 at the Hotspot area and 12.5 W/ cm2 ,25 W/cm2 , 37.5 W/ cm2 at the background area respectively have been considered for analysis. The numerical simulations are solved using the steady-state standard governing equations for the conservation of mass, momentum, and energy in the fluid domain, which are derived from the literature.

3. VALIDATION OF THE NUMERICAL RESULTS

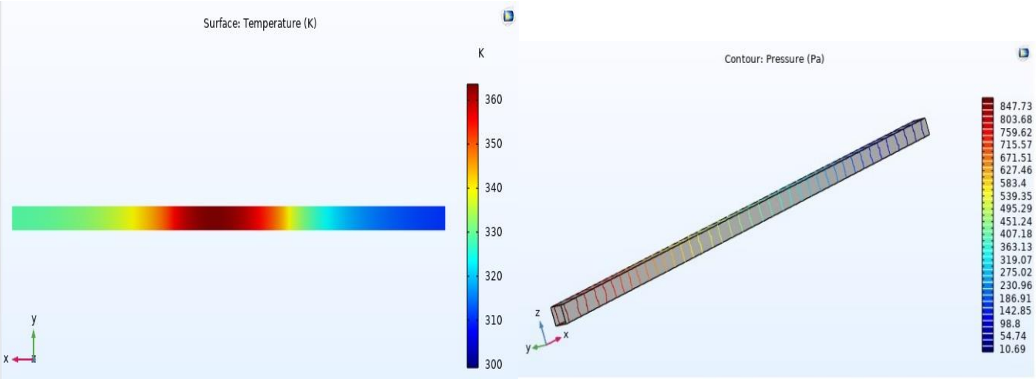
The Numerical simulation results were validated using energy balance method. The outlet temperature of the water is calculated using Q=mCPdT, which is heat input given at the base is completely absorbed by water. The temperature values as shown in the Table1 gives complete agreement with numerical simulation data. All the results obtained through the present numerical scheme showed reasonable agreement with Analytical results

Table 1. Comparison of outlet temperatures of water obtained with energy balance method And Numerical simulations.

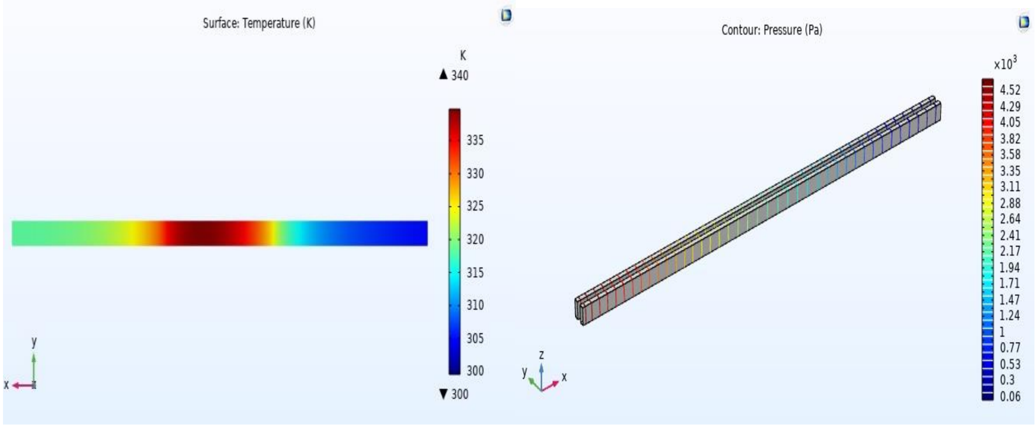
Details	**Re=774**			**Re=924**			**Re=1156**		
	Case-I	Case-II	Case-III	Case-I	Case-II	Case-III	Case-I	Case-II	Case-III
Outlet Temperature as per Energy Balance Method (^{O}C)	12	12	12	10	10	10	8	8	8
Outlet Temperature of present Numerical Simulation (^{O}C)	12	11.2	11.8	10	9.6	9.9	8	7.5	7.8

4. RESULTS AND DISCUSSION

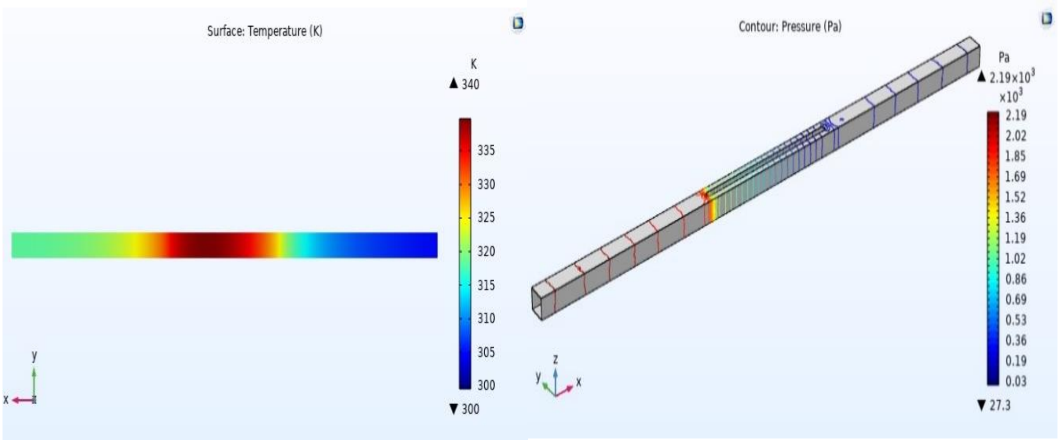
Several studies were conducted to design a heat sink for hotspot conditions. However, the present study is focused on predicting the performance of bifurcating channel. The study is divided into three cases, in the first case channel of 0.9 mm width is analyzed, the second case considered a channel of 0.3 mm, and finally, a micro-channel with a sub-channel is analyzed. The base temperature, pressure drops were obtained through numerical simulations, and Pump power is calculated using the standard formula Ppump= Qflow * ΔP.



Case i) uniform channel of 0.9 mm width



Case ii) uniform channel of 0.3 mm width



Case iii) Micro-channel with sub-channel

Fig 2. Temperature zones at the base of the Micro-channel and Pressure along the flow in the channel (for the three cases).

It is found that the maximum base temperature is 360 K,335 K, and 335 K (Fig 3) for the three cases respectively, It can be inferred that the sub-channel is effective in maintaining base within the safe temperature limits. As sub-channel is for shorter length it gives the advantage of a low-pressure drop in comparison with 0.3 mm channel. The same phenomenon is observed in the pressure drop calculations. It is found that the pressure drop for the sub-channel is considerably less compared with 0.3 mm micro-channel at Reynolds number of 774 (Fig 4), the pressure drop in 0.3 mm channel is 4520Pascals, whereas the pressure drop in a micro-channel with sub-channel is 2190 Pascals. Thus, it can be concluded that sub-channels have the advantage of maintaining the base temperature within the safe limits with less pressure drop. The pumping power requirements for the three cases at Reynolds number 1156 are 1.15 microwatts, 5.8 microwatts, and 2.94 microwatts (Fig 5).There is a 49.65% saving in pump power with a micro-channel for maintaining the base of the sink within the safe temperature limits.

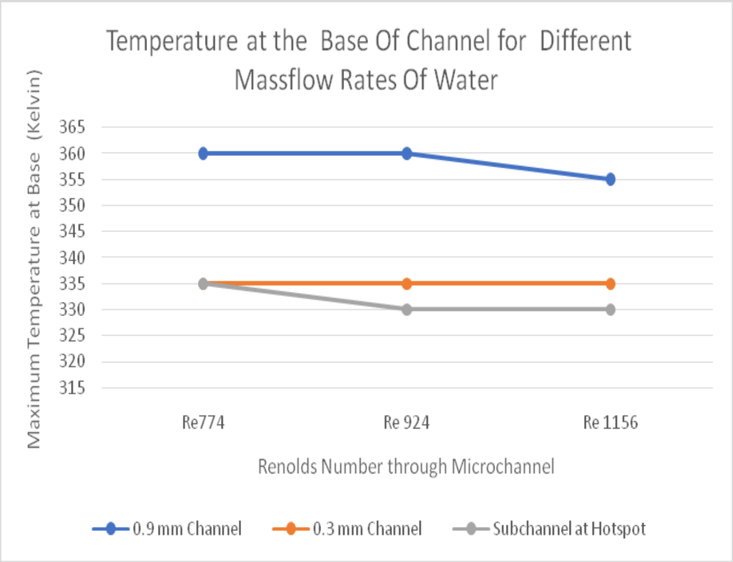


Fig 3. Micro-channel base temperature variation for heat input of 200 W/ cm2 at the Hotspot area and 25 W/cm2 at the background area.

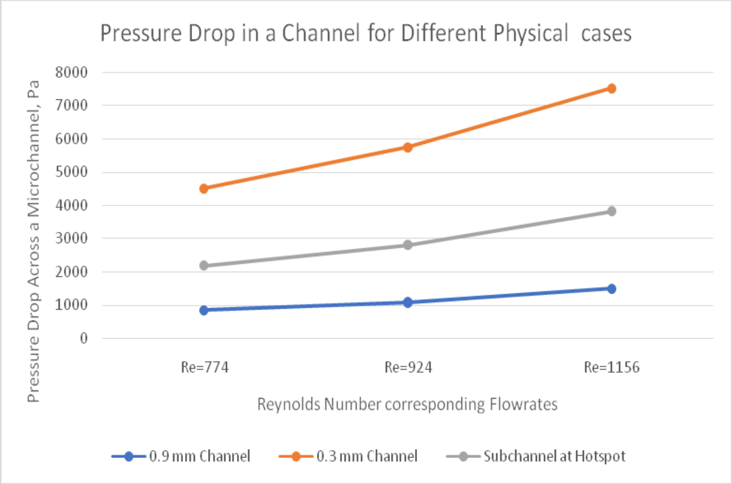


Fig 4. Micro-channel Pressure drop variation for heat input of 200 W/ cm2 at the Hotspot area and 25 W/cm2 at the background area

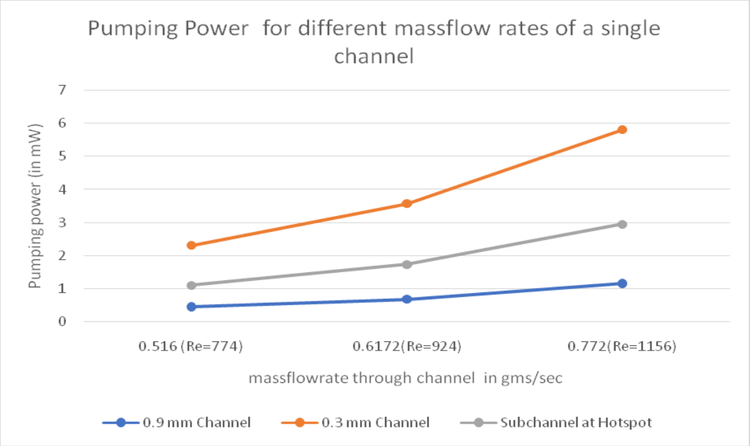


Fig 5. Micro-channel Pumping Power variation for heat input of 200 W/ cm2 at the Hotspot area and 25 W/cm2 at the background area.

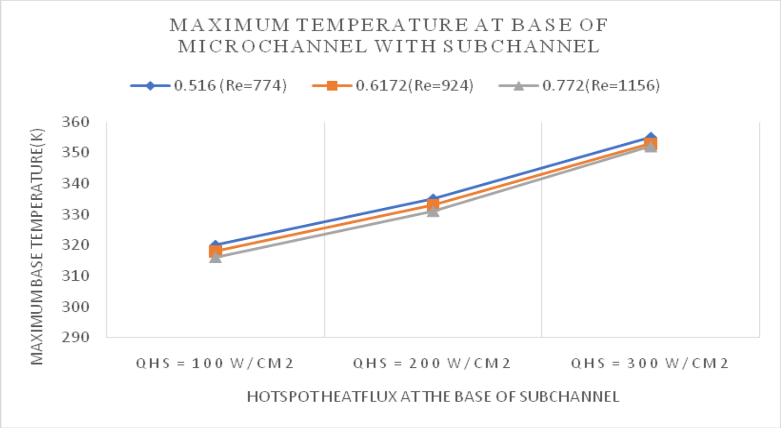


Fig 6. Micro-channel maximum base temperature variations for heat inputs of 100 W/ cm2,200 W/ cm2,300 W/ cm2 at the Hotspot area and 12.5 W/ cm2,25 W/cm2,37.5 W/ cm2 at the background area (resp).

It has been observed through numerical simulations that, for various heat inputs at the background area and hotspot area, the base temperatures are in the safe operating limit of 373 K. For a hotspot heat flux of 300W/cm2, the temperature is found to be 355 K. It can be concluded that the proposed micro-channels with sub-channels of 0.9 mm and 0.3 mm can be utilized for the cooling of electronic components. However, it can be inferred that by reducing the channel dimensions while considering the manufacturability of channels, heat sinks can be developed for non uniform heat fluxes of modern electronic components.

5. CONCLUSIONS

This study presented a new concept of bifurcating the micro-channel for hotspot management of modern electronic systems. The proposed micro-channel with sub-channel is numerically analyzed for thermal performance using “COMSOL Multiphysics 5.6” software. The numerical results are validated with analytical data obtained through the energy balance method. It is found that micro-channels with sub-channels have the potential to maintain the base temperature within the safe limits and simultaneously not create large pressure drops. The performance has been studied at Reynolds No’s 774, 924, 1156.The laminar flow region has been considered for the analysis. Sub-channels have maintained 320 K,335 K and 355 K at base of the micro-channelfor heat inputs of 100 W/ cm2, 200 W/ cm2, 300 W/ cm2 at the Hotspot areas of 12.5 W/ cm2 ,25 W/cm2 , 37.5 W/ cm2 which is the safe operating condition for electronic components. In addition to maintaining the temperature within safe limits, there is a pumping power saving of 51.54 % ,51.3 %, and 49.9 % at Reynolds No’s 774, 924, and 1156 respectively.

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