Numerical study of thermal enhancement in a stacked micro channel heat sink with different flow arrangement

Sagar M. Narayanan[1], Pradeep M. Kamath[2]

[1] Research Scholar, [2] Associate Professor, Department of Mechanical Engineering, Government Engineering College, Thrissur, Kerala, India.

ABSTRACT

The heat transfer performance of a single phase stacked circular micro channel heat sink is investigated numerically. Numerical analysis is conducted for a different range of mass flow rates and numerical simulations carried out with the standard k-ω model used in the ANSYS Fluent. The velocity of the flow varies from 1.629m/s to 14.15m/s with water as the cooling medium. This paper presents the study of heat transfer enhancement in parallel flow and counter flow arrangements. The heat transfer enhancement is evaluated by the base temperature of the heat sink. Results showed that as the velocity increased, the minimized base temperature decreased and the maximum thermal conductance increased. For double layer circular micro channel heat sink, the counter flow arrangements have an obvious advantage over the parallel flow arrangements with the same flow condition. This study proved that Double-layer Micro channel Heat Sinks (MHSs) to be efficient ways to improve the cooling performance of electronic devices.

Keywords: *Circular, Counter flow, Double layer, Micro channels, Numerical, Parallel flow.*

I. INTRODUCTION

The technological advancements in the area of the chip on lab design brought electronic devices to microscale. This diminutive design tends to generate high heat flux, causing overheating of the electronic devices. Microchannels due to their small size and ability to dissipate heat make them one of the best choices for the electronic cooling systems. The high heat sinking capacity of the micro channel was first demonstrated by Tuckerman and Pease [1] in 1980s. They fabricated a rectangular micro channel heat sink in a 1 x 1 cm^2 silicon wafer. They found that small geometric sizes have higher heat transfer characteristics and lower cooling fluid requirement than the conventional heat sinks. Thereafter due to their inherent advantages, micro channel heat sinks received considerable attention. Following this more researchers Kandlikar and Grande [2] developed a new technology to fabricate small passages with very low hydraulic diameter for transitional and molecular nano channels. The heat transfer enhancement and pressure drop characteristics are studied by different authors [3-6].

Xia and Chan [7] numerically analyzed the heat transfer enhancement in rectangular micro channels. They varied the inlet area and found that the heat transfer per unit effective area is greater for the case of smaller inlet. Kuppusamy et al. [8] numerically analyzed the performance of micro channel heat sink with altering slanted passages and the results showed that the thermal resistance reduced by 76.8% and overall performance increased by 146% compared with the simple micro channel heat sinks. Shafeie et al. [9] numerically analyzed the performance of the micro pin fin heat sink. Result shows that the cases of highest depth have maximum heat removal for a specific pumping power. They also evaluated the effect of heights and layouts of the micro cylindrical fins on the hydraulic and thermal performance.

Kim [10] experimentally investigated the heat transfer in ten different rectangular micro channels of hydraulic diameter ranging 155 µm -580 µm with aspect ratio varying from 0.25 – 3.8 and Reynolds number ranging from 30 – 2500. They found that the laminar friction factor follows the conventional theory. The theoretical values of the Nusselt number were higher than the experimental value for low Reynolds number and at high Reynolds number the difference was less significant. Li et al. [11] conducted both numerical and experimental studies in micro tubes and found that the friction factor was well predicted with conventional theory.

In 1999 Vafai and Zhu [12] studied a new concept of enhancing heat transfer performance with double layer configuration. This new state of the art was first reported by and pointed out that a double layer micro channel heat sink (DL-MCHS) requires lower pressure drop and lesser pumping power compared to the single layered micro channel heat sink (SL-MCHS). Chong et al. [13] conducted numerical simulation by employing the thermal resistance network in a single layered flow and double layered counter flow with rectangular micro channel heat sink**.** The thermal resistance for laminar and turbulent flow for single layer was found to be 0.048 and 0.069 K/W respectively whereas for double layer it was observed to be 0.058 and 0.066 K/W respectively. Leng et al. [14] numerically studied a new design of DL-MCHS with different top channel truncation configuration. They found an optimum truncation position after obtaining the trade-off between the cooling and heating effects. Xu et al. [15] numerically and experimentally analyzed single and double layer heat sink. They found that single layered heat sink have 40% higher thermal resistance than the double layered heat sink.

Wei and Joshi [16] and Wei et al. [17] performed numerical and experimental studies on micro channel heat sink. They found that the pumping power and heat removal capability of stacked micro channel heat sink was lower than the single layer micro channel heat sink. The result shows a better uniform temperature profile for counter flow arrangement. Wong and Muezzin [18] numerically studied the thermal performance in a two layered rectangular micro channel heat sink. They found that parallel flow arrangement had better thermal performance than the counter flow arrangement. Patterson et al. [19] numerically studied conjugate heat transfer in stacked micro channels and found that the counter flow gives a more uniform temperature distribution than parallel flow.

The preceding literature review shows that double layer micro channel has lower thermal resistance than a single layer micro channel. Several researchers have numerically studied the heat transfer performance in single and double layer micro channel. Therefore the objective of the present study is to numerically analyze the thermal performance in the stacked double layer circular micro channel and find out the better one from counter flow and parallel flow arrangements.

II. NUMERICAL SIMULATION

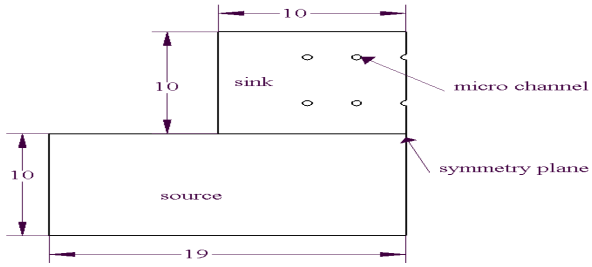

Fig.1 The Physical model of computational domain.

Fig. 1 represents a physical model of the computational domain. It consists of a heat source block over which the double layer circular micro channel heat sink is placed. Ten micro channels with 500 μm diameter each arranged in two layer one over the other. The length of the micro channel is 20 mm. Since it is a symmetric problem half of the geometry is taken for the analysis. The boundary conditions used for the simulation are as follows. At the inlets, uniform velocity and temperature conditions are given and the outlet is chosen as pressure outlet. A uniform heat flux of 55401 W/m^2 (80 W) is applied at the bottom of the heat source block. The top of the heat sink is assumed as convective with convective wall heat transfer coefficient of 8 W/m^2 K. All other walls are adiabatic. De-ionized water is used as the working fluid with inlet temperature of 303 K. The numerical analysis for different velocities was conducted. A residual of 10^{-7} was set as convergence criteria. The assumptions made for numerical study are steady state, incompressible, single phase, turbulent flow with constant thermo physical properties for fluid and solid. At the solid-fluid interface, no slip and no jump boundary conditions are applied for fluid and thermal analysis. The standard k-ω model is used to simulate the model.

III. GOVERNING EQUATIONS

The conservation equations for the fluid flow and heat transfer to solving the model are

Continuity equation, $\frac{\partial u_j}{\partial x_j} = 0$ (1)

Momentum equation, $\frac{\partial}{\partial x_j}\left[\rho u_i u_j\right] = \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[(\mu + \mu_t)(\frac{\partial u_i}{\partial x_i} + \frac{\partial u_j}{\partial x_i})\right]$ (2)

Energy equation, $\frac{\partial u_i T}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left[\frac{\mu}{\Pr} + \frac{\mu_t}{P_t r}\right]\frac{\partial T}{\partial j}\right]$ (3)

Transport equations for the standard k-ω Model are [20]

$$\frac{\partial}{\partial t}[\rho k] + \frac{\partial}{\partial x_i}[\rho k u_i] = \frac{\partial}{\partial x_j}\left[\Gamma_k \frac{\partial k}{\partial x_j}\right] + G_k - Y_k \tag{4}$$

$$\frac{\partial}{\partial t}[\rho \omega] + \frac{\partial}{\partial x_i}[\rho \omega u_i] = \frac{\partial}{\partial x_j}\left[\Gamma_\omega \frac{\partial \omega}{\partial x_j}\right] + G_\omega - Y_\omega \tag{5}$$

In these equations G_k represents the generation of the turbulence kinetic energy due to mean velocity gradients and G_ω represents the generation of specific dissipation. Γ_k and Γ_ω represents the effective diffusivity of k and ω, respectively. While Y_k and Y_ω represents the dissipation of k and ω due to turbulence.

The grid independence study was conducted with three different nodes 1002290, 4756500 and 887650 namely coarse, fine and superfine respectively. The percentage variation of the outlet temperature between coarse and fine is 0.025% so that the node 4756500 is selected.

IV. RESULTS AND DISCUSSION

The numerical analysis was performed to study the heat transfer characteristics of a double layer circular micro channel heat sink. The micro channels are arranged one over the other so as to make parallel flow arrangement and counter flow arrangement easier.

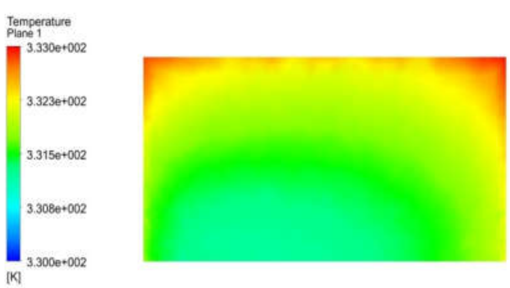

Fig.1 counter flow (Re 850)

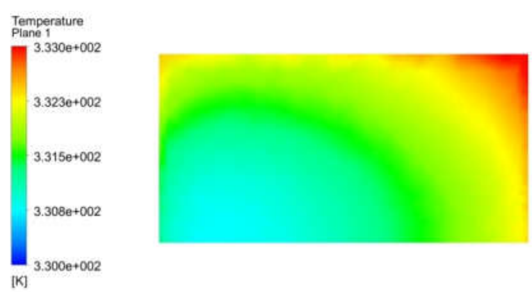

Fig.2 parallel flow (Re 850)

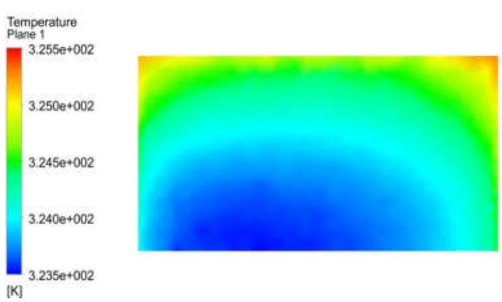

Fig.3 counter flow (Re 1700)

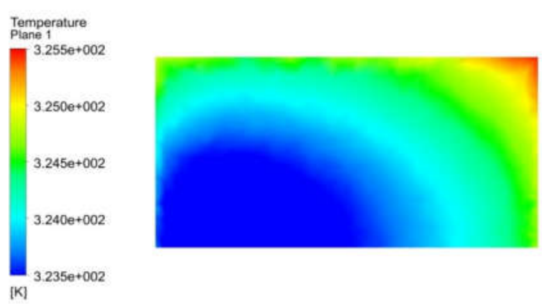

Fig.4 parallel flow (Re 1700)

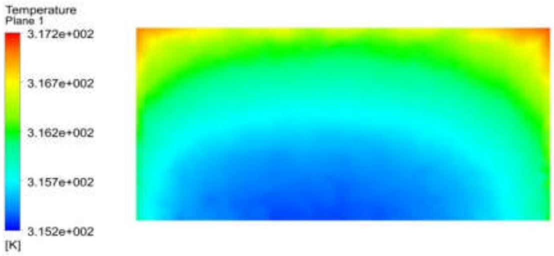

Fig.5 counter flow (Re 3500)

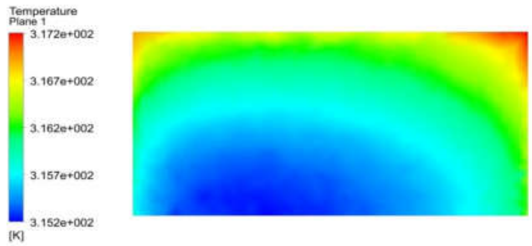

Fig.6 parallel flow (Re 3500)

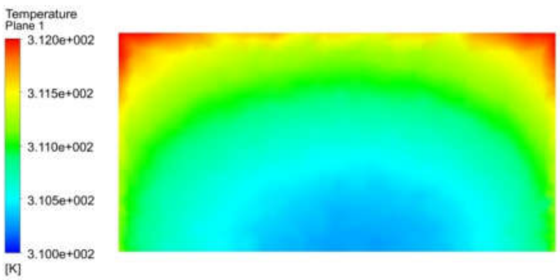

Fig.7 counter flow (Re 5000)

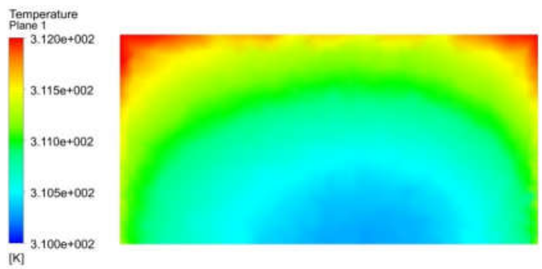

Fig.8 parallel flow (Re 5000)

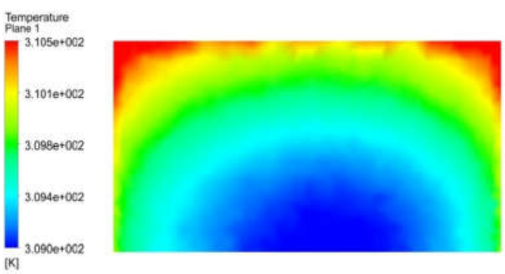

Fig.9 counter flow (Re 6500)

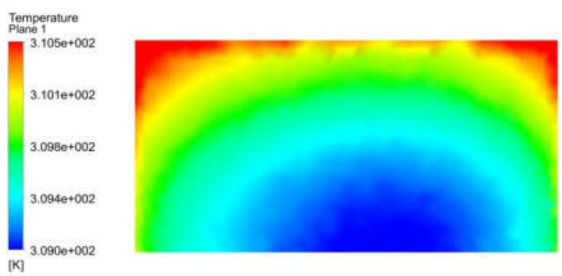

Fig.10 parallel flow (Re 6500)

From the fig.1 and fig.2 it is clear that the counter flow arrangement has lower temperature distribution than the parallel flow arrangement. The temperature contours plotted at the bottom of the heat sink. The variation of the temperature profile is may be due to the flow arrangement. Since the total heat input is same for all cases. The inlet boundary condition is also the same. Only the velocity of the flow in each Reynolds number is varied. The fig.1 fig.3 fig.5 fig.7 and fig.9 represents the temperature contours of the counter flow arrangements. The fig.2 fig.4 fig.6 fig.8 and fig.10 represents the temperature contours of the parallel flow arrangements. The highest temperature region is occurred more in parallel flow arrangement.

An average 60^0 C temperature is noticed at the base of the heat sink when the Reynolds number is 850. While increasing the velocity the heat sink base temperature is decreased. At Reynolds number 6500 the heat sink base temperature is about 33^0 C and which is nearly the surrounding temperature. It seems that the

Reynolds number increases the heat sink base temperature decreases. In all these cases the maximum and minimum temperature difference is around 2^0 to 3^0 C.

V. CONCLUSION

Numerically analyze the thermal enhancement of the stacked double layer circular micro channel heat sink. In this study, a three-dimensional numerical investigation was carried out with different Reynolds number in turbulent condition. The two-layer stacked micro channel heat sink with counter flow arrangement gave the best results in minimizing the heat sink base temperature. When the velocity of the fluid flow through the stacked circular micro channel was increased the heat sink base temperature decreased. This study proved that Double-layer Micro channel Heat Sinks (MHSs) to be efficient ways to improve the cooling performance of electronic devices. This new design of double layer circular micro channel heat sink is simple in the structure and can be easily integrated with the electronic devices.

REFERENCES

1. D.B. Tuckerman and R.F.W. Pease, "High-performance heat sinking for VLSI", *IEEE Electron Device Letters EDL-2,* 1981, *P 126-129.*
2. Satish G. Kandlikar and William J. Grande, "Evolution of Micro channel flow passages –Thermo hydraulic performance and fabrication technology", *Heat Transfer Engineering Vol.24 No.1,* (2016), *P 1–17.*
3. T.M. Adams, S.I.Abddel-Khalik, S.M. Jeter and Z.H. Qureshi "An Experimental Investigation of single phase forced convection in Micro channels"*, International Journal of Heat and Mass Transfer 41,* (1998), *P 851–857.*
4. Gnielinski V. "New equations for heat and mass transfer in turbulent pipe channel flow" *International Chemical Engineering, 16,* (1976), *P 359–368.*
5. Poh-SengLee, Suresh V. Garimella, Dong Liu, "Investigation of heat transfer in rectangular micro channels", *International Journal of Heat and Mass Transfer 48,* (2005), *P 1688–1704.*
6. Weilin Qu, Issam Mudawar, "Experimental and numerical study of pressure drop and heat transfer in a single-phase micro channel heat sink*", International Journal of Heat and Mass Transfer 45,* (2002) *P 2549–2565.*
7. Liang Xia and Yue Chan "Investigation of the enhancement effect of heat transfer using micro channels", The 7th International Conference on Applied Energy-ICAE2015, *Science Direct Energy Procedia 75,* (2015), *P 912-918.*
8. Navin Raja Kuppusamy, R. Saidur, N.N.N.Ghazali, H.A. Mohammed, "Numerical study of thermal enhancement in micro channel heat sink with the secondary flow", *International Journal of Heat and Mass Transfer 78,* (2014) ,*P 216–223.*
9. Haleh Shafeie, Omid Abouali, Khosrow Jafarpur, Goodarz Ahmadi ,"Numerical study of heat transfer performance of single phase heat sinks with micro pin-fin structures*", International Journal Applied Thermal Engineering 58,* (2013) ,*P 68–76.*

10. B.Kim, "An experimental study on fully developed laminar flow and heat transfer in rectangular microchannels", *International Journal in Heat and Fluid Flow Vol.00,* (2016), *P 1-9.*
11. Zhuo Li, Ya-Ling He, Gui-Hua Tang, Wen-Quan Tao, "Experimental and Numerical studies of fluid flow and heat transfer in micro tubes" *International Journal of Heat and Mass Transfer Vol.50,* (2007) ,*P 3447–3460.*
12. Kambiz Vafai and Lu Zhu, "Analysis of two layered micro channel heat sink concept in electronic cooling", *International Journal of Heat and Mass Transfer. 42,* (1999), *P2287– 2297.*
13. S.H.Chong, K.T.Ooi, T.N Wong, "Optimization of single and double layer counter flow micro channel heat sink", *Applied Thermal Engineering Vol.22,* (2002), *P 1569–1585.*
14. Chuan Leng, Xiao-Dong Wang, Tian-Hu Wang, "An improved design of double-layered micro channel heat sink with truncated top channel", *Applied Thermal Engineering 79 -54 ,* (2015), *E62.*
15. Shanglong Xu, Lili Yang, YueLi, Yihao Wu, Xinglong Hu, "Experimental and numerical investigation of heat transfer for two layered micro channel heat sink with non uniform heat flux conditions", *Heat and Mass Transfer, SPRINGER,* (2015), *DOI 10.1007/s 00231-015-1691-3.*
16. Xiaojin Wei and Yogendra Joshi," Stacked Micro channel Heat Sinks for Liquid Cooling of Microelectronic Components", (2004), *ASME 60-66/ Vol.126*
17. Xiaojin Wei, Yogendra Joshi and Michael K.Petterson "Experimental and Numerical Study of a Stacked Micro channel Heat Sinks for Liquid Cooling of Microelectronic Components", *ASME, 1432-1444,* (2007), *Vol.129.*
18. Kok-Cheong Wong, Fashli Nazhirin Ahmad Muezzin, "Heat transfer of a parallel flow two –layered microchannel heat sink", *International Communication in Heat and Mass Transfer,* (2013), *02865.*
19. Michael K Patterson, Xiaojin Wei, Yogendra Joshi, Ravi Prasher "Numerical Study of Conjugate Heat Transfer in Stacked Micro channels", *Inter Society Conference on Thermal Phenomena, IEEE* , (2004), *8357-5.*
20. A.F.Ansys.16 User's Guide, Ansys Inc.,2016