https://doi.org/10.33472/AFJBS.6.9.2024.5222-5230

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

A Review Of Single Layer Microchannel Heat Sinks And The Investigations Carried Out On Such Microchannels Through Experimental And Computer Simulation Methods

Dr. Dipak Debbarma*[1], Sunita Debbarma[2], Mousumi Goswami[2], Bappaditya Sarkar[2], Rajasree Debbarma[2]

[1]Tripura Institute of Technology, Agartala, Tripura, India

[2]Women's Polytechnic, Hapania, Agartala, Tripura, India

*Corresponding author. Email address: dipakdb.2003@gmail.com

Article History

Volume 6,Issue 9, 2024

Received: 26-04-2024

Accepted : 29-05-2024

doi: 10.33472/AFJBS.6.9.2024.5222-5230

Abstract: The contribution of structure of microchannel heat sink and geometry of channel passage have significant role in increasing cooling rate in electronics compact components amongst the passive enhancement techniques. Enhancement of heat dissipation at considerable pumping power penalty is the challenge for the researchers. Because in most cases of investigations, it is perceived that enhancement of performance of microchannels is possible by virtue of certain pumping loss. This paper is presenting the overview of the available literatures on such relevant research works. Intermixing of fluid layers, interception of boundary layer by introduction of roughness, bifurcation, secondary flow in the channel enhance performance deliberately in microchannel heat sink. In one of such studies, maximum Nu/Nu_o of 2.12 was evaluated at Re = 589.

.

Keywords: Microchannel, roughness, secondary flow, thermal resistance, Nusselt number.

1 Introduction

The ever-changing evolution of technology needs miniaturized and capable electronics devices in our present world in the context of domestic as well as industrial applications. Cooling of such micro-scale devices with suitable capacity rate is the real challenge today. After the novel experimental research work of Tuckerman and Pease [1] introducing the micro sink four decades ago, microchannel became the attractive means for the cooling of IC products and hence several investigations have been carried out by many researchers. Smaller the hydraulic diameter higher the heat transfer coefficient in a channel [2] is significant fundamental concept behind the use of microchannel. Small volume, but bigger surface area of microchannels makes the micro heat sink advantageous, but more additional efficient features of parallel channels in the heat sink are required to meet present challenges. For the example, the temperature of laptop CPU, must be maintained below 90°C in order to prevent it from damage [3]. Karayiannis and Mahmoud [4] highlighted that heat dissipation by 177 mm^2 die of Intel core processor produced by Intel in 2014 was 88 W and the heat flux of future computers could reach 2 MW/m^2 by 2026.

Therefore various mechanisms and techniques are predicted by the researchers for the purpose of enhancing micro sink. The researchers in the last four decades introduced innovative design and techniques to increase the removal of the heat generated in such devices. Numerous investigations were performed on the single layer micro sinks with the rectangular channel. Among the works, some were based on different channel shapes and others were on various channel wall structures, employment of cavity, rib, protrusions etc into the channels. The effect estimation of substrate materials such as aluminium, copper, silicon, brass, steel was also part of few investigations. In many studies different nanofluids as coolant were used. After the new micro sink with double layer [5] came into existence in 1997, investigational works started on this kind of novel heat sink to a large extent.

Most of the studies have been performed on channel of rectangular cross-section comparing to circular, triangular, trapezium channel. In the various research investigations such as [6], it was concluded that rectangular microchannels have advantages over circular microchannels in context of thermal as well as hydro performances in the micro heat sink domain. Because larger surface area, higher surface to volume ratio of rectangular microchannel lead to better performance results. In contrary, Ghazali-Mohd et al. [7] using genetic algorithm reported that for a minimized thermal resistance, the circular channel shows better performance than the square channel; it might be due to different design conditions applied for study.

This review work covers the investigational reports on rectangular micro sinks available in the literatures based on single-phase and forced convective flow to assess the parameters such as Nu/Nu_o, f/f_o, thermal factor etc. and to find the efficient constructional channel design of single layer microchannel heat sinks. The Fig. 1 shows single layer sink (S-MHS).

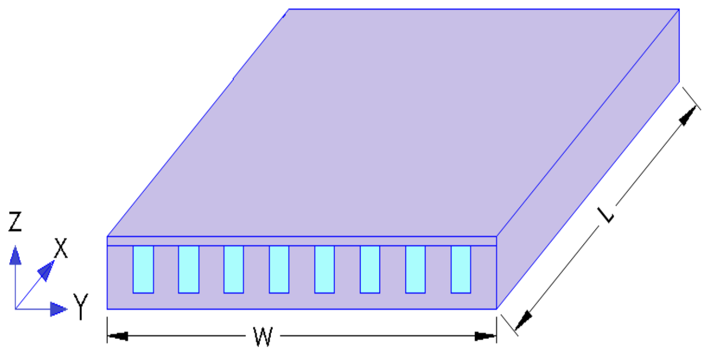

Fig. 1. Single layer microchannel heat sink (S-MHS)

2 Investigational procedure

Investigating the micro-scale devices is challenging and undertaking experiment is more challenging. In case of experimental study, accuracy during fabrication of microchannel, setting up of whole arrangement, measurement of data are to be maintained. Steinke and Kandlikar [8] addressed the experimental uncertainties which can become quite large due to complication in measurement in microchannel heat exchanger. Simulation i.e. numerical analysis is widely adopted by the researchers in this heat sink domain now-a-days due to high cost involved in experimental work. However, opting viable assumptions, mathematical equations along with suited numerical method are the factors which lead to the authentic results in Simulation. In some of the investigations, analytical method is utilized to evaluate the flow in channel. In experimental work, fabrication of microsink is the key part. Both additive and subtractive i.e., etching fabrication technologies are widely available for the purpose [9]. Most of the investigations experimental or numerical on micro heat sink are based on the conjugate heat transfer model. Like other researchers, Rosa et al.[3] suggested that solid axial heat conduction should not be neglected for study of parallel channels of microchannels.

3 Associated equations

The conservation equations of momentum and energy do apply to microchannel study as the general equations. The associated equations along with general equations are applicable in microchannels similar to the conventional channels for Knudsen numbers below 0.001 as stated by Kandlikar and Grande [10]. Fig. 2 depicts isometric view of single channel domain.

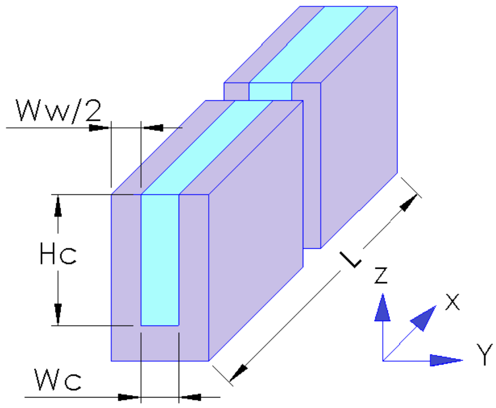

Fig. 2. Isometric view of single channel domain

(i) The Reynolds number (Re):

$$Re=\rho u_m d_h/\mu \quad (1)$$

(ii) The hydraulic diameter (d_h):

$$d_h= 2W_c H_c /(W_c + H_c) \quad (2)$$

(iii) The average friction factor (f) :

$$f=(2\Delta p d_h)/(\rho u_m^2 L) \quad (3)$$

(iv) Nusselt number(*Nu*) :

$$Nu = hd_h / k \tag{4}$$

(v) The average heat coefficient (h) is written as;

$$h = qA_b / \; (A_{con}(T_b - T_{\text{int}})) \tag{5}$$

(vi) The thermal enhancement factor (η) or performance evaluation criteria (PEC) :

$$\eta = (Nu/Nu_0)/(f/f_0)^{(1/3)} \tag{6}$$

(vii) Thermal resistance or heat resistance:

$$R_{th} = \Delta T_{max}/Q_{b,total} \tag{7}$$

In the investigations, heat transfer coefficient, R_{th}, bottom temperature were estimated and compared by the early researchers. Afterwards, investigators used more effective parameters for evaluation such as *f*, *Nu*, friction factor ratio, Nusselt number ratio. Since 2010, investigators emphasized on the parameter called thermal enhancement factor (η) which signifies the enhancement of *Nu* of the novel microchannel considering corresponding friction in comparison to that of simple straight microchannel.

4 Micro channel heat sinks with plain, rough, PCM mounted surfaces

The extensive investigations on the single layer microchannel heat sink recommend various effective design structures with suitable parameters. Qu and Mudawar [11] performed experiment on micro-sink made of copper to determine the applicability of conservation equations in micro-channel heat sinks. Lee and Garimella [12] varied the aspect ratio of the channel from 1 to 10 to calculate the local as well as average *Nu* with the applied heat flux on all external boundaries of channel. They proposed correlation of Nusselt number considering *Nu* as a function of aspect ratio and axial distance. Zhang et al.[13] simulated plain and U-shaped microchannels by varying the number of channels and some parameters of channel. Heat sinks with different channel cross sections were compared by Gunnasegaran et al. [14]. The geometrical parameters like height and width of these shapes of channel were evaluated. They revealed that the rectangular microchannel was the best, followed by trapezoidal and triangular shaped microchannels. Kim [15] in his experimental work observed the critical Re range as 1700 to 2400 for the aspect ratio from 1.0 to 0.25. He described that heat transferred was higher in inlet plenum as the axial heat conduction prevails in the solid. He however, mentioned discrepancies between the experimental and theoretical values of *Nu* at larger *Re*. Sahar et al.[16] made two experimental systems and validated the numerical results. Copper as substrate material and water, refrigerant R134a as coolant were selected. The conclusion from the experiment and numerical solution was that laminar to turbulent transition happens at *Re* = 1600 – 2000. Lee et al. [17] performed experimental investigation and attempted to validate classical correlations of simple rectangular microchannel. Some parallel channels made of copper were experimented for *Re* of range from 300 to 3500. Then numerical simulations were employed.

Gaikwad and More[18] choose the phase change materials (PCMs) to find their potential for cooling of computer processor. They experimented heat sink with air, water and PCM slurry as coolant and observed that PCM slurry was more beneficial than water and air in respect to surface temperatures and *Nu*. Shen et al. [19] took eight cases of microchannel with bifurcation of channel at different position. They reported that internal bifurcation disturbed the velocity of cooling fluid and helped in breaking boundary layer. Fedorov and Viskanta [20] analyzed the effects of three dimensional conjugate heat flow. In the context of reducing thermal stress which causes structural failure of the heat sink, they suggested that longitudinal and transverse temperature gradients should be controlled. A wide range of microchannel designs had been investigated experimentally using both water and fluorinate fluid by Colgan et al.[21]. Xu et al. [22] brought some new arrangements in the microchannel so that thermal boundary layer redeveloping could be demonstrated. Ambatipudi and Rahman [23] reported the common observation through their work that *Nu* was high near the entrance and reached constant asymptotic point when the flow was developed fully. Sahar et al. [24] emphasized on the influence of hydraulic diameter in the performance evaluation. In various research studies of the channel wall roughness [25-28], the investigators highlighted that roughness had remarkable adverse impact on pressure drop, but very little effect on improvement of *Nu*. Wei and Joshi [29] undertook the study of micro-fabrication defects and their effects in their experimental set up. On the thorough study of plain and taper channels they came with the view that control of the micro-fabrication process was inevitable and could deviate the performance.

5 Microchannel with secondary flow

The secondary flow through secondary sub-channel made into main channel has received wide attention recently. An idea of secondary flow through secondary small channel was well demonstrated by Steinke and Kandlikar [30]. Such design of sink with oblique sub-channels was proposed by Ghani et al. [31]. They reported brilliant results after their work. The secondary flow technique was found beneficial for enhancement of performance with minimum friction loss due to the fact that it led to rise the contact surface and elimination of the stagnant flow. The impressive performance factor of 1.98 had been determined at *Re* of 500. More elaborate investigations were carried out by Japar et al. [32] for the models with rectangular rib, triangular cavity and combination of rectangular rib, triangular cavity and secondary channel. The model combined with rectangular rib, triangular cavity and secondary channel showed excellent overall performance due to its ability to eliminate the friction penalty which arisen out of the rectangular rib. Yang and Cao [33] presented efficient microchannel with the idea of secondary channel. A novel design with secondary channel and manifold structure was modeled and simulated by them. They introduced a new performance parameter named design optimization area (DOA) and reported that their optimum design can decrease both pressure drop and thermal resistance which was not possible by any microchannel design so far. The largest decrease in thermal resistance was 19% at *Re* of 295.

Few review works on single layer heat sink are presented here to have brief note. In the review work of Datta et al[34], two main mechanisms causing the heat transfer enhancement for single-phase flow as mentioned are flow disruption and chaotic advection. Ghani et al. [35] conducted extensive review of various works. They too described the chaotic advection and flow disruption as the major strategies opted in heat sink for the performance enhancement. In their study parameters of wavy, corrugated channel which affect the chaotic advection and cavity, grooves, ribs, fins affecting the flow disruption were evaluated. Various effective research works utilizing passive cooling methods are reviewed lucidly by Sidik et al.

[36]. Adham et al. [37] reviewed and emphasized on the various methodologies implemented by the researchers in different stages of time. Vasilev et al. [38] had a work on the configuration composing of ten different inlet and outlets to study. Table 1 includes some summarized investigational works on single layered microchannel heat sinks.

Table 1: Comparison of few of the works on single layered microchannel heat sinks

SL	Author & Study details	Plate & channel size	Variables & other parameters	Findings & Best Result
1	**Qu and Mudawar [11]** (2001) Experimental and numerical analysis	**1. Sink Plate :** Width(W)= 10 mm, Length(L) = 44.8 mm **2. Channel :** Width(W_C)=0.231mm**,** Height(H_C)=0.713 mm	Flow rate : 93 - 1136 ml/min Heat flux= 100, 200 W/cm^2 *Re* = 139 - 1672 Copper sink with water as coolant	Higher Reynolds numbers helps in reducing water outlet temperature and temperatures within the heat sink. .
2	**Gunnasegaran et al. [14]** (2010) Numerical analysis	**1. Sink Plate :** W = 22 mm, L = 12 mm Height (H)= 1.5 mm **2. Channel :** W_C = varied**,** Length = varied	Channel height and width : varied *Re* = 100 - 1000 Aluminium sink with water as coolant	Rectangular microchannel is the best; followed by trapezoidal and triangular shaped microchannels.
3	**Kim et al.[15]** (2016) Experimental analysis	**1. Sink Plate :** W = 12 mm, L = 76 mm H= 2 mm	d_h = 155 – 580 µm Aspect ratios: 0.25 – 3.8 *Re*=30 - 2500 Aluminum alloy sink, water as coolant	The critical *Re* range:1700 to 2400. The axial heat conduction causes 10% more heat transferred to the fluid at inlet plenum.
4	**Ambatipudi and Rahman [23]** (2000) Numerical analysis	**1. Channel :** W_C = 0.251 mm**,** L = 25 mm H_C = 1.03 mm	Channel depth : varied *Re* = 270 – 645 Silicon sink with water as coolant	*Nu* increases with channel depth, attains a peak, and then decreases with further increase of channel depth.
5	**Japar et al. [32]** (2018) Numerical analysis	**2. Channel :** W_C = 0.1 mm, Length = 10 mm H_C = 0.20 mm	Channel with TR, RR, combined TR,RR and SC *Re* = 100 -450 Copper sink with water as coolant	The model combined with rectangular rib, cavity and secondary channel shows superior performance. The maximum PF is 1.65 at *Re*=450.

6 Conclusion

- The beneficial impact of flow disturbance by the application of roughness on the flow surface are subject to suitable fluid mixing and breaking up of boundary layer inside the flow passages of channel. The surface roughness attributes towards flow recirculation and better heat transfer into channel which in turn develops performance.
- The application of phase change materials (PCMs) in the microchannel as utilized by different researchers indicates that PCM has high potential for cooling of computer processor.

As per the experimentation, microchannel heat sink with PCM slurry was more beneficial than water and air in respect to surface temperatures and *Nu*.

References

[1] D.B. Tuckerman, R.F.W. Pease, High-Performance Heat Sinking for VLSI, IEEE Electronic device letters 2(5) (1981) 126-129.

[2] L. Collins, J.A. Weibel, L. Pan, S.V. Garimella, A permeable-membrane microchannel heat sink made by additive manufacturing, International Journal of Heat and Mass Transfer 131 (2019) 1174–1183.

[3] P. Rosa, T.G. Karayiannis, M.W. Collins, Single-phase heat transfer in microchannels: The importance of scaling effects, Applied Thermal Engineering 29 (2009) 3447–3468.

[4] T.G. Karayiannis, M.M. Mahmoud, Flow boiling in microchannels: Fundamentals and applications, Applied Thermal Engineering 115 (2017) 1372–1397.

[5] K. Vafai, L. Zhu, Analysis of two layered microchannel heat sink concept in electronic cooling, International Journal of Heat and Mass Transfer 42 (1999) 2287-2297.

[6] N. Liu, J.M. Li, J. Sun, H.S. Wang, Heat transfer and pressure drop during condensation of R152a in circular and square microchannels, Experimental Thermal and Fluid Science 47(2013) 60–67.

[7] N. Ghazali-Mohd, O. Jong-Taek, N.B. Chien, C. Kwang-Il, R. Ahmad, Comparison of the optimized thermal performance of square and circular ammonia-cooled microchannel heat sink with genetic algorithm, Energy Conversion and Management (2015).

[8] M.E. Steinke, S.G. Kandlikar, Single-phase liquid friction factors in microchannels, International Journal of Thermal Sciences 45 (2006) 1073–1083.

[9] S.G. Kandlikar, W.J. Grande, Flow Passages—Thermohydraulic Performance and Fabrication Technology Evolution of Microchannel, Heat Transfer Engineering, 24(1) (2003) 3–17.

[10] S.G. Kandlikar, W.J. Grande, Evolution of Microchannel Flow Passages—Thermohydraulic Performance and Fabrication Technology, Heat Transfer Engineering 24(1) (2003) 3–17.

[11] W. Qu, I. 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) 2549–2565**.**

[12] P.S. Lee, S.V. Garimella, Thermally developing flow and heat transfer in rectangular microchannels of different aspect ratios, International Journal of Heat and Mass Transfer 49 (2006) 3060–3067.

[13] J. Zhang, P.T. Lin, Y. Jaluria, Design and Optimization of Multiple Microchannel Heat Transfer Systems, Journal of Thermal Science and Engineering Applications 6 011004.

[14] P. Gunnasegaran, H.A. Mohammed, N.H. Shuaib, R. Saidur, The effect of geometrical parameters on heat transfer characteristics of microchannels heat sink with different shapes, International Communications in Heat and Mass Transfer 37 (2010) 1078–1086.

[15] B. Kim, An experimental study on fully developed laminar flow and heat transfer in rectangular microchannels International Journal of Heat and Fluid Flow (2016) 1–9.

[16] A.M. Sahar, M.R. Özdemir, E.M. Fayyadh, J. Wissink, M.M. Mahmoud, T.G. Karayiannis, Single Phase Flow Pressure Drop and Heat Transfer in Rectangular Metallic Microchannels, Accepted Manuscript, Applied Thermal Engineering.

[17] P.S. Lee, S.V. Garimella, D. Liu, Investigation of heat transfer in rectangular microchannels, International Journal of Heat and Mass Transfer 48 (2005) 1688–1704.

[18] V. P. Gaikwad, S. P. More, CPU Processor Cooling by using Microchannel Heat Sink with PCM as Coolant, International Journal of Engineering Research & Technology 6(11) 2017.

[19] H. Shen, C.C. Wang, G. Xie, A parametric study on thermal performance of microchannel heat sinks with internally vertical bifurcations in laminar liquid flow, International Journal of Heat and Mass Transfer 117 (2018) 487–497.

[20] A.G. Fedorov, R. Viskanta, Three-dimensional conjugate heat transfer in the microchannel heat sink for electronic packaging, International Journal of Heat and Mass Transfer 43 (2000) 399-415.

[21] E.G. Colgan, B. Furman, M. Gaynes, N. LaBianca, J.H. Magerlein, R. Polastre, R. Bezama, K.R. Marston, R. Schmidt, High Performance and Subambient Silicon Microchannel Cooling. Journal of Heat Transfer 129 (2007) 1046- 1051.

[22] J.L. Xu, Y.H. Gan, D.C. Zhang, X.H. Li, Microscale heat transfer enhancement using thermal boundary layer redeveloping concept International Journal of Heat and Mass Transfer 48 (2005) 1662–1674.

[23] K.K. Ambatipudi, M.M. Rahman, Analysis of conjugate heat transfer in microchannel heat sinks. Numerical Heat Transfer, Part A: Applications, An International Journal of Computation and Methodology 37 711 –731.

[24] A.M. Sahar, J. Wissink, M.M. Mahmoud, T.G. Karayiannis, M.S.A. Ishak, Effect of Hydraulic Diameter and Aspect Ratio on Single Phase Flow and Heat Transfer in a Rectangular Microchannel, Accepted Manuscript, Applied Thermal Engineering (2017).

[25] A.S. Rawool, S.K. Mitra, S.G. Kandlikar, Numerical simulation of flow through microchannels with designedroughness, Microfluid Nanofluid 2 (2006) 215–221.

[26] G. Croce, P. D'agaro, C. Nonino, Three-dimensional roughness effect on microchannel heat transfer and pressure drop International Journal of Heat and Mass Transfer 50 (2007) 5249–5259.

[27] G. Gamrat, M. Favre-Marinet, S.L. Person, Modelling of roughness effects on heat transfer in thermally fully-developed laminar flows through microchannels, International Journal of Thermal Sciences 48 (2009) 2203–2214.

[28] R. Bavière, G. Gamrat, M. Favre-Marinet, S.L. Person, Modeling of Laminar Flows in Rough-Wall Microchannels, Journal of Fluids Engineering 128 (2006) 735- 741.

[29] X. Wei, Y. Joshi, Experimental and numerical study of sidewall profile effects on flow and heat transfer inside microchannels, International Journal of Heat and Mass Transfer 50 (2007) 4640–4651.

[30] M.E. Steinke, S.G. Kandlikar, Single-phase heat transfer enhancement techniques in microchannel and minichannel flows, Proceedings of ICMM2004 The 2nd International Conference on Microchannels and Minichannels (2004) Rochester, New York, USA.

[31] I.A. Ghani, N.A.C. Sidik, R. Mamat, G. Najafi, T.L. Ken, Y. Asako, W.M. A. A. Japar, Heat transfer enhancement in microchannel heat sink using hybrid technique of

ribs and secondary channels, International Journal of Heat and Mass Transfer 114 (2017) 640–655.

[32] W.M.A.A. Japar, N.A.C. Sidik, S. Mat, A comprehensive study on heat transfer enhancement in microchannel heat sink with secondary channel, International Communications in Heat and Mass Transfer 99 (2018) 62–81.

[33] M. Yang, B.Y. Cao, Numerical study on flow and heat transfer of a hybrid microchannel cooling scheme using manifold arrangement and secondary channels, Applied Thermal Engineering 159 (2019) 113896.

[34] A. Datta, D. Sanyal, A. Agrawal, A.K. Das, A review of liquid flow and heat transfer in microchannels with emphasis to electronic cooling, Indian Academy of Sciences, Sådhanå, 44 (2019) 234.

[35] I.A. Ghani, N.A.C. Sidik, N. Kamaruzaman, Hydrothermal performance of microchannel heat sink: The effect of channel design, International Journal of Heat and Mass Transfer 107 (2017) 1–44.

[36] N.A.C. Sidik, M.N.A.W. Muhamad, W.M.A.A. Japar, Z.A. Rasid, Overview of passive techniques for heat transfer augmentation in microchannel heat sink, International Communications in Heat and Mass Transfer 88 (2017) 74–83.

[37] A.M. Adham, N.M. Ghazali, R. Ahmad, Thermal and hydrodynamic analysis of microchannel heat sinks: A review, Renewable and Sustainable Energy Reviews 21 (2013) 614-622.

[38] M.P. Vasilev, R.S. Abiev, R. Kumar, Effect of microchannel heat sink configuration on the thermal performance and pumping power, International Journal of Heat and Mass Transfer 141 (2019) 845–854.

Nomenclature

A_b	Cross sectional area of bottom wall, m^2	d_h	Hydraulic diameter, m
A_{con}	Convection heat removal area, m^2	f	Friction factor
H	Total height of heat sink, mm	h	Heat transfer coefficient, W/(m^2 K)
Hc	Height of channel, mm	k	Thermal conductivity of fluid, W/mK
W	Total width of heat sink, mm	u_m	Mean fluid velocity, m/s
Wc	Width of channel, mm	q	Heat flux applied at bottom wall, W/m^2
Ww	Wall thickness, mm		*Greek*
H_b	Base height, m	ρ	Fluid density, Kg/ m^3
L	Total length of the micro-channel, mm	η	Thermal enhancement factor
N	Number of channels	Δ p	Pressure difference across channel, Pa
Nu	Nusselt number	ΔT_{max}	Maximum bottom wall temperature difference, K
$Q_{b,total}$	Total heat applied at bottom wall, W	μ	Fluid viscosity, Pa.s
R_{th}	Thermal or heat resistance, K/W		*Subscript*
Re	Reynolds number	0	Base Heat sink
T_b	Average temperature of bottom wall, K	m	Mean
T_{int}	Channel interior temperature, K	int	Interior