Asif Afzal et al. International Journal of Recent Research Aspects ISSN: 2349-7688, Vol. 4,
Issue 4, Dec 2017, pp. 47-51

Comparative Heat Transfer Analysis in Different Minichannel Heat Sinks

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Abstract: **The present experimental investigation is mainly focused on thermal analysis of different geometry of minichannel heat sink subjected to flow of water as a fluid under steady state forced convection flow condition. The objective is to determine the effect of flow rate on heat transfer and fluid flow characteristics of rectangular, circular, trapezoidal and square shape minichannels with hydraulic diameter of 2mm and length 250 mm each with an array of ten numbers of channels. From the present experimental study it is observed that the flow rate has great impact on the heat transfer characteristics. The geometry of minichannel also plays a vital role on heat transfer and fluid flow behavior. It is also observed that pumping power required for circular geometry of minichannel is maximum compared to other type of minichannels and it is minimum for rectangular minichannels.**

Keywords: **minichannel, heat transfer, thermal analysis, pumping power, fluid flow.**

I. INTRODUCTION

For cooling several electronic devices heat sinks are employed. In many engineering applications and in biomedical devices a lot of interest is growing due to their enhanced heat transfer characteristics. Specially, many electronic devices have huge integration of components for high performance in very compact space. At the same time these heavily integrated electronic devices require increased power supply and hence indirectly more heat dissipation. If this heat is not properly managed/ removed, than it may lead overheating of the electronic component and failure.This led to development of reduced size and more efficient cooling devices like mini and micro channel heat sinks.

Various numerical and experimental investigations were carried out to study the thermal behavior of these channels and the performance of fluids considering different geometries like circular, rectangular, square, diamond, wavy, U-shaped minichannels etc. Xie et al., studied laminar heat transfer in water cooled rectangular minichannel and varied the channel height and width. They found improvement in heat transfer with acceptable pressure drop [1]. Dixit and Ghosh investigated pressure drop and heat transfer coefficient (HTC) for Re (Reynolds number) of 17–450. Straight, diamond and offset minichannels were used and found Nu (Nusselt number) linearly varying with Re [2]. Oblique type cylindrical fin minichannel was proposed by Fan et al., of angles varying between 20-45°They also proposed several Nu and friction factor correlations [3]. Marzougui et al., studied heat transfer charecteristics in mini and macro channels of 2mm and 0.18mm respectively and proved enhanced HTC in macro channels [4].For Re ranging between 1000 to 2300 conguate heat transfer in micro channels in laminar flow conditions was analyzed by Asadi et al. Cylidrical vortex generators were employed to study the effect on heat transfer [5]. To study the effect of flow distribution on heat transfer, Liu et al., provided mini baffles in the heat sinks.9.9-13.1% thermal resistance reduced which was shown using ANSYS software [6].To improve Nu, segmented flow was introduced by Betz and Attinger in water cooled microchannels. Nu improved upto 100% for 330-2000 kg/m^{2}s of mass velocity [7].In all these cases, water was employed as the working fluid in all the heat sinks usd for study.

Many other experiments were conducted for different nanoparticles suspended in water or ethlene glcol as base fluid to enhance the heat transfer. Al_2O_3nanoparticles were used to make nanofluid to analyse in minichannels considering water/ ethylene gycol as base fluid in either circular or rectangular minichannels [8]–[11]. Al_2O_3 and TiO_2nanoparticles were separately used to analyze thermal properties in minichannels as reported in [12]–[14]. CuO, SiO_2, ZnO, water-ethylene mixture and many other were also used in minichannels [3], [15]–[22]. However, any comparative analysis between rectangular, circular, trapezoidal and square shaped minichannels with water or any other fluid is not reported. The main intent of this investigation is to compare the thermal effects of these different channels and come out with the best shape which provides better heat trenafer charecteristics. A constant hydraulic diameter of 2mm for all the four types is used and fluid flow is considered under steady state forced convection under constant heat flux.

II. METHODOLOGY

Experimental setup

The figure 1 shows the different major parts of the heat sink used for the existing study. Rotometers are used as flowmeters here and they provide simple and efficient readings of flow rates. T-type (copper–constantan) thermocouple having a sensitivity of 43 µV/°C is used to measure the temperature of the flowing fluid at the inlet and exit of minichannel as they are suitable for a range of -220°C to 330 °C. K-type thermocouples are placed at several points on the channel to measure the channel surface temperature. They have range of about -220°C to 1400°C and are cheap. Electric heater employed is film heater which transforms alternating current into heat based on the principle of joule heating effect. To avoid any kind of transfer of heat from the surface of minichannel setup, it is insulated carefully with asbestos. A mini-pump is placed to supply the water from the reservoir to the heat sink. A heat exchanger is placed immediately after the flow of water from the minichannel in order to obtain the constant inlet temperature of the fluid. The minichannels are made of split aluminium plates of 2mm size rectangular channels. For the above mentioned set-up, the deionized water is pumped from the reservoir through the flow regulating valves. At the inlet of the minichannel, the temperature is measured and then allowed to pass through the channel so that it can carry heat from it. At different points of the minichannel, temperature is measured once the flow attains steady state. At the exit, again the temperature is recorded and made to pass through the heat exchanger so as to maintain the flowing fluid temperature at constant range.

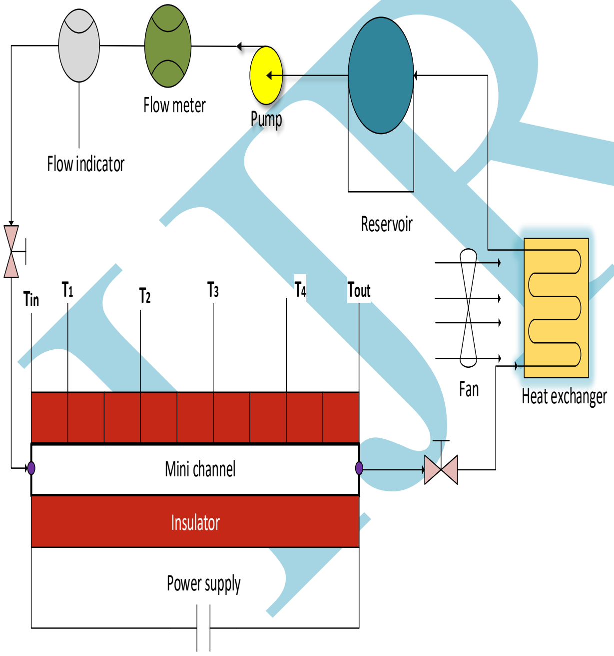

Figure 1. Schematic diagram of experimental setup

Relations Used

The following Equations 1-8 were used to estimate the different important thermal parameters of the minichannel heat sink.

Actual heat transfer: $$q = m_f C_p \left(T_{h,o} - T_{c,i}\right) \qquad (1)$$

Reynolds number: $$R_e = {}^{\rho D_h v}/_{\mu} \qquad (2)$$

LMTD : $$\Delta T_{lmtd} = {}^{(\Delta T_2 - \Delta T_1)}\Big/_{ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} \qquad (3)$$

Where $\Delta T_2 = \Delta T_b - \Delta T_{h,o}$, $\Delta T_1 = \Delta T_b - \Delta T_{c,i}$

Nusselt number: $$Nu = 0.023 Re^{0.8} Pr^{0.4} \qquad (4)$$

Heat transfer coefficient: $$h = {}^{N_u k}/_{D_h} \qquad (5)$$

Friction factor: $$f = {}^{Nu}/_{0.125 Re Pr^{0.33}} \qquad (6)$$

Pressure drop: $$\Delta P = f\rho\left({}^{L}/_{D}\right)\left({}^{v^2}/_{2}\right) \qquad (7)$$

Pumping power: $$P = \Delta P f v \qquad (8)$$

Where: m_f is mass flow rate in kg/s, C_p is specific heat in KJ/KgK, $T_{h,o}$ is hot water out, $T_{c,o}$ is cold water in, ρ is density in Kg/m3, D_h is hydraulic diameter in mm, v is velocity of water in m/s, μ is dynamic viscosity in Ns/m2, T_b is base temperature of the channel, L is length of the channel in mm and Pr is Prandtl number of water $Pr = \mu C_p / K$ here K is thermal conductivity of water.

III. RESULTS AND DISCUSSIONS

The experiment is conducted for an array of 10 minichannels of circular, rectangular, trapezoidal and square cross section which are of similar hydraulic diameter of 2mm, length of 250mm. For making the calculations and observations, the values are taken for four different flow rates(0.25, 0.5, 0.75 and 1lpm), forced convection in transition regime and with constant heat flux of 3.6W/mK. For each flow rates the temperatures are noted down when the flow reaches steady state and is taken for four different trials with a gap of 10 minutes.During the experiments the following results were obtained.

The graph shown in Figure 1 provides the variation in local Nu which decreases as the ratio of length to diameter (X/D) increases. There is a sudden decrease in local Nu up to a certain point and remains constant beyond that point. The length up to the point where the local Nu shows a sudden decrease to length to diameter ratio is called entrance region. The length from the point where the local Nu remains constant with the change in the ratio of length to diameter is called the developed region. It's from the point around X/D=10, the local Nu gives a constant value. The local Nu for circular section is higher than the local Nu for all shapes of channels for the same flow rate.Rectangular channels has shown least local Nu value. This analysis was carried out to know the variation in Nu in the entrance region and this also proves that the experimental study is matching with the variation of Nu as mentioned in literature with references too many to cite.

The variation of average Nu for different for different flow rates for all cross-sections is plotted in Figure 3. It is clear from the figure that, as the flow rate increases the value of average Nu increases in all cases. Comparatively circular section shows higher value of average Nu since the value of Reynolds number is high for circular section. Least is for rectangular, whereas square and trapezoidal are in between. Similarly convective HTC for circular shape is highest compared to other shapes and rectangular with least. Also the trend of these variations are similar in case of Nu and Convective HTC as seen from figure 4. Actual heat transfer rate is highest for square section because of its area whereas circular section is lowest which is again for the reduced area for heat flux as can be seen in Figure 5. At higher floe rate in case of circular section, the actual heat transfer rate is competitive with rectangular section.

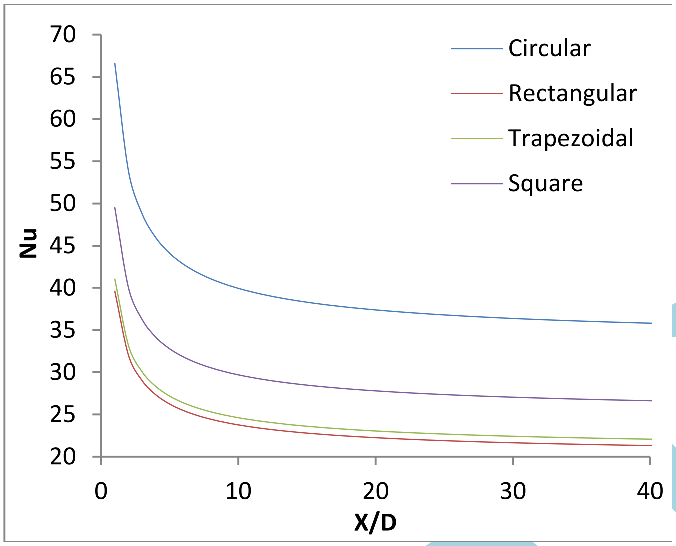

Figure 2. X/D vs Nu for 0.25 lpm in different minichannels

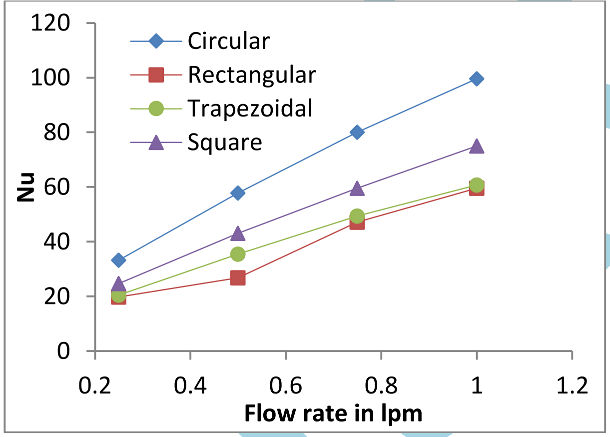

Figure 3. Variation of Nu with flow rate

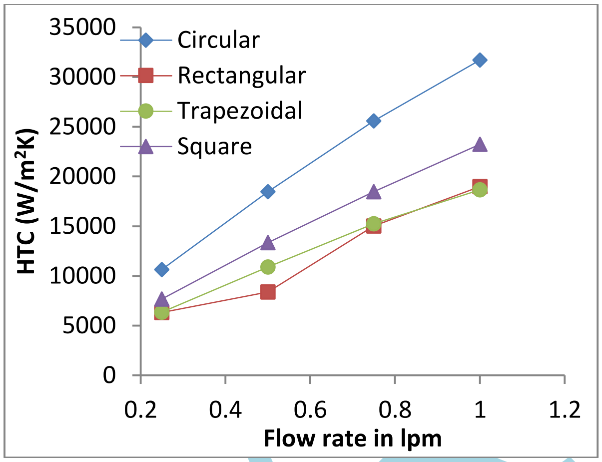

Figure 4. Heat Transfer Coefficient (HTC) for different flow rates

The variation of friction factor is quite enhanced in case of rectangular section due to more base area compared to other sections and hence more friction factor involved, See Figure 7. Square has the least friction factor and to it very close is circular section. Circular section hence has more pressure drop and inturn more pressure power required. As compared to all the sections, rectangular channel provides least enhancement in heat transfer but low pumping power required. Whereas, circular channel gives more heat transfer coefficient than any other, but at the cost of pumping power required. Square opts out to be a moderate in all the cases.

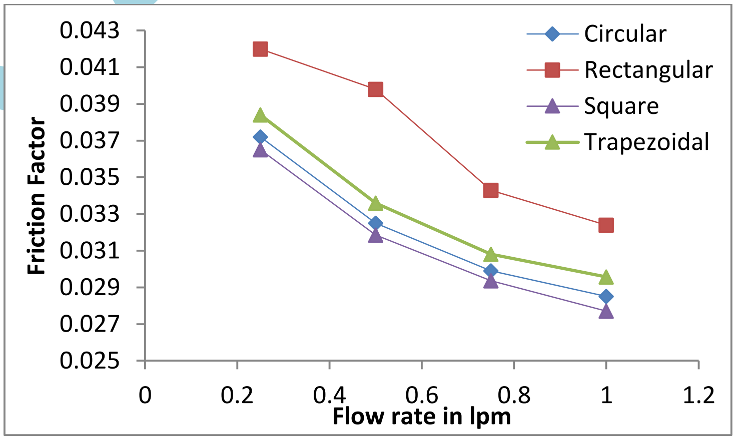

Figure 5. Friction factor variation with change in flow rates

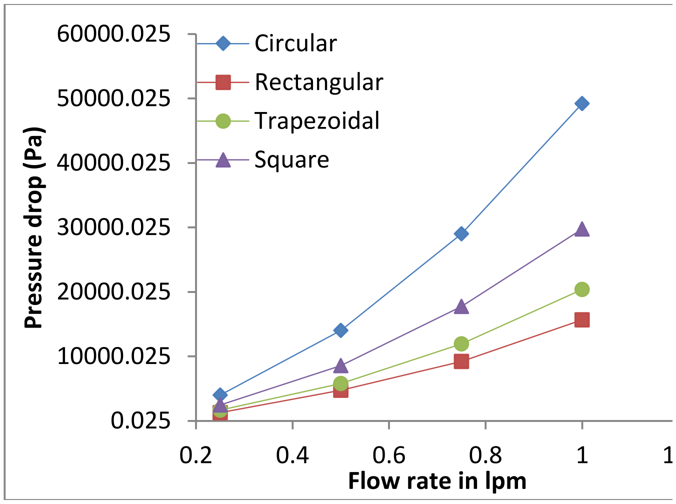

Figure 6. Varying pressure drop in different minichannels for various flow rates

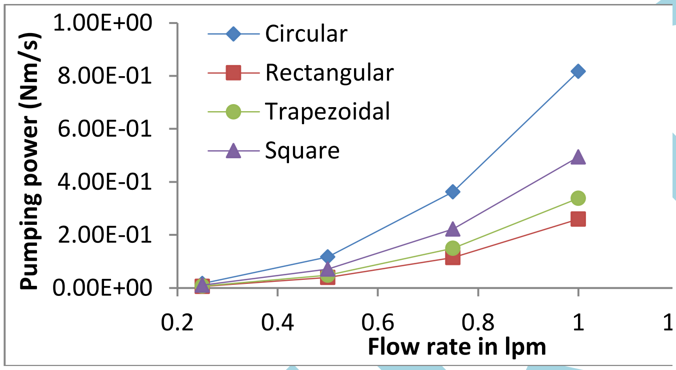

Figure 7. Flow rate vs pumping power required for water

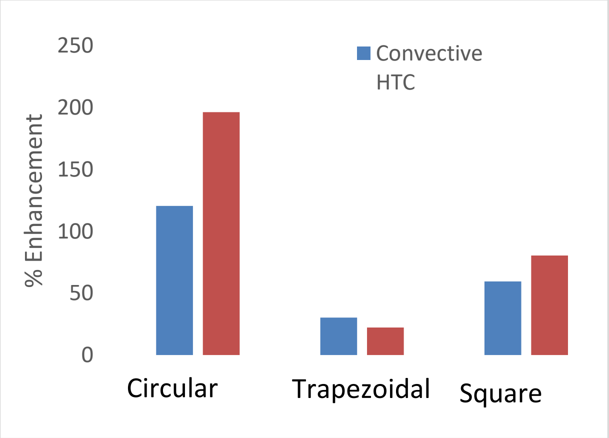

Figure 8. % Enhancement of Convective HTC and pumping power at 0.5 lpm

IV. CONCLUSION

An experimental investigation is carried out to find the effect of different shapes of minichannel on heat transfer characteristics subjected to flow of water under steady state forced convection condition. From the obtained results the following conclusions were exposed.

1. The geometry of channel plays a very important role in heat transfer characteristics, and circular minichannel gives more rate of heat transfer compared to other shapes considered in the present investigation.
2. With increase in the flow rate the Nusselt number also increases, and for rectangular minichannel it is minimum and for circular minichannel it is maximum.
3. For circular minichannel pumping power required is maximum whereas for rectangular minichannel it is minimum.
4. It can be conclude that from present experimental investigation in terms of better heat transfer rate circular shape minichannel are best and in terms of pumping power the rectangular minichannel is more suitable.

REFERENCES

[1] X. Xie, Z. Liu, Y. He, and W. Tao, "Numerical study of laminar heat transfer and pressure drop characteristics in a water-cooled minichannel heat sink," *Appl. Therm. Eng.*, vol. 29, no. 1, pp. 64–74, 2009.

[2] T. Dixit and I. Ghosh, "Low Reynolds number thermo-hydraulic characterization of offset and diamond minichannel metal heat sinks," *Exp. Therm. Fluid Sci.*, vol. 51, pp. 227–238, 2013.

[3] Y. Fan, P. S. Lee, L. W. Jin, B. W. Chua, and D. C. Zhang, "A parametric investigation of heat transfer and friction characteristics in cylindrical oblique fin minichannel heat sink," *Int. J. Heat Mass Transf.*, vol. 68, pp. 567–584, 2014.

[4] M. Marzougui, C. Nmiri, M. Hammami, and R. Ben Maad, "Experimental Investigation of Heat Transfer Characteristics and Cooling Performance of Mini- and Microheat Exchangers," *Heat Transf. Res.*, vol. 0, no. 0, pp. 1–17, 2016.

[5] M. T. Al-Asadi, F. S. Alkasmoul, and M. C. T. Wilson, "Heat transfer enhancement in a micro-channel cooling system using cylindrical vortex generators," *Int. Commun. Heat Mass Transf.*, vol. 74, pp. 40–47, 2016.

[6] X. Liu and J. Yu, "Numerical study on performances of mini-channel heat sinks with non-uniform inlets," *Appl. Therm. Eng.*, vol. 93, pp. 856–864, 2016.

[7] A. R. Betz and D. Attinger, "Can segmented flow enhance heat transfer in microchannel heat sinks?," *Int. J. Heat Mass Transf.*, vol. 53, no. 19–20, pp. 3683–3691, 2010.

[8] C. J. Ho and W. C. Chen, "An experimental study on thermal performance of Al2O 3/water nanofluid in a minichannel heat sink," *Appl. Therm. Eng.*, vol. 50, no. 1, pp. 516–522, 2013.

[9] M. Sohel, S. Khaleduzzaman, and R. Saidur, "An experimental investigation of heat transfer

enhancement of a minichannel heat sink using Al 2 O 3–H 2 O nanofluid," *Int. J. Heat Mass Transf.*, vol. 74, pp. 164–172, 2014.

[10] M. Ismail, S. Fotowat, and A. Fartaj, "Numerical Simulation of Al_2O_3/Automatic Transmission Fluid and Al_2O_3/Water Nanofluids in a Compact Heat Exchanger," *J. Fluid Flow, Heat Mass Transf.*, vol. 3, 2016.

[11] I. Zakaria *et al.*, "Thermal analysis of Al2O3-water ethylene glycol mixture nanofluid for single PEM fuel cell cooling plate: An experimental study," *Int. J. Hydrogen Energy*, vol. 41, no. 9, pp. 5096–5112, 2016.

[12] A. Ijam, R. Saidur, and P. Ganesan, "Cooling of minichannel heat sink using nanofluids," *Int. Commun. Heat*, vol. 39, no. 8, pp. 1188–1194, 2012.

[13] P. Naphon and L. Nakharintr, "Heat transfer of nanofluids in the mini-rectangular fin heat sinks," *Int. Commun. Heat Mass Transf.*, vol. 40, no. 1, pp. 25–31, 2013.

[14] M. Khoshvaght-Aliabadi, M. Sahamiyan, M. Hesampour, and O. Sartipzadeh, "Experimental study on cooling performance of sinusoidal-wavy minichannel heat sink," *Appl. Therm. Eng.*, vol. 92, pp. 50–61, 2016.

[15] G. R. V.-N. & A. Dorany and To, "INVESTIGATION OF THE EFFECT OF MULTIWALLED CARBON NANOTUBES ON THE VISCOSITY INDEX OF LUBE OIL CUTS Investigation of the Effect of Multiwalled Carbon Nanotubes on the Viscosity Index of Lube Oil Cuts," *Chem. Eng. Commun.*, vol. 196, no. October, pp. 997–1007, 2009.

[16] V. Kumaresan and R. Velraj, "Thermochimica Acta Experimental investigation of the thermo-physical properties of water – ethylene glycol mixture based CNT nanofluids," *Thermochim. Acta*, vol. 545, pp. 180–186, 2012.

[17] A. . Sakanova, J. . c Zhao, and K.-J. . Tseng, "Investigation on the Influence of Nanofluids in Wavy Microchannel Heat Sink," *IEEE Trans. Components, Packag. Manuf. Technol.*, vol. 5, no. 7, pp. 956–970, 2015.

[18] A. Sakanova, C. C. Keian, and J. Zhao, "Performance improvements of microchannel heat sink using wavy channel and nanofluids," *Int. J. Heat Mass Transf.*, vol. 89, pp. 59–74, 2015.

[19] N. Ahammed, L. G. Asirvatham, and S. Wongwises, "Thermoelectric cooling of electronic devices with nanofluid in a multiport minichannel heat exchanger," *Exp. Therm. Fluid Sci.*, vol. 74, pp. 81–90, 2016.

[20] V. Leela Vinodhan, K. S. Suganthi, and K. S. Rajan, "Convective heat transfer performance of CuO-water nanofluids in U-shaped minitube: Potential for improved energy recovery," *Energy Convers. Manag.*, vol. 118, no. April, pp. 415–425, 2016.

[21] C. Yang, K. Peng, A. Nakayama, and T. Qiu, "Forced convective transport of alumina-water nanofluid in micro-channels subject to constant heat flux," *Chem. Eng. Sci.*, vol. 152, no. September, pp. 311–322, 2016.

[22] M. Savari, S. Rashidi, A. Amiri, M. Shanbedi, S. Zeinali Heris, and S. N. Kazi, "Hydrodynamic and thermal performance prediction of functionalized MWNT-based water nanofluids under the laminar flow regime using the adaptive neuro-fuzzy inference system," *Numer. Heat Transf. Part A Appl.*, vol. 70, no. 1, pp. 103–116, 2016.