International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 07 | July 2018 www.irjet.net p-ISSN: 2395-0072

Analysis of Heat Transfer through Micro Channel with Different Configurations

Mahesh Kothwal[1], D.P.Patil[2], V.S.Kulkarni[3]

[1]PG Student, MCERC, Nashik
[2]Assistant Professor, Dept of Mechanical, MCERC, Nashik,
[3]Professor, Dept of Mechanical, MCERC, Nashik

Abstract - *Micro channel heat sinks play a very important part in the functioning of the microelectronic components. Size reduction is the buzzword in the newly electronic industry. However, with the reduction in small size, different new problems like heat dissipation becomes difficult and sometimes these devices fails and damage due to overheating. Therefore, it is very much important to dissipate the heat developed by small equipment's with faster rate or within very short time. The most useful solution for this problem is the introduction of micro or mini channels into the heat sinks. The important purpose of micro- channel or mini channel is to increase the surface area, which is exposed for heat transfer. In this work, the focus is on the heat transfer performance of the micro channels with different geometrical configurations. The heat transfer performance is a function of surface area available for the heat transfer and the heat transfer coefficient for the component. The main objective of this work is to study the convective heat transfer in micro- channel and the effects of various parameters such as Reynolds number, inlet velocity of cooling fluid and rise in temperature of cold fluid. This paper mainly focuses on heat transfer through different configurations of micro- channels such as rectangular, square, triangular, and circular and the comparison between them.*

Key Words: Heat Exchanger, Microchannel, Heat Sink, Heat Transfer, Square Micro channel

1. INTRODUCTION

In the last few years, owing to the rapid developments in micro-electronics and biotechnologies, the applied research in micro - coolers, micro- biochips, micro- reactors, and micro - fuel cells have been expanding at a tremendous pace. Among this micro - fluidic systems, micro channels have been identified to be one of the essential elements to transport fluid within a miniature area. In addition to connecting different chemical chambers, micro channels are also used for reactant delivery, physical particle separation, fluidic control, chemical mixing, and computer chips cooling, cooling of microelectronic devices.

The designs of Micro – Electro – Mechanical Systems (MEMS) and micro-fluidic systems involved the impact of geometrical configurations on the temperature, pressure, and velocity distributions of the fluid. Therefore, in order to fabricate such micro devices effectively, it is extremely important to understand the fundamental mechanisms involved in fluid flow and heat transfer characteristics in micro channels since their behavior affects the transport phenomena for the large part of MEMS and micro-fluidic applications. The studies based on an extensive literature reviews include a variety of fluid types, micro channel cross-section configurations, flow rates, analytical techniques, and channel materials.

Size reduction of product is important in the modern electronic industry. However, with the reduction in component size, different new problems like those that heat dissipation becomes critical and sometimes these devices may fail due to overheating of instruments. Therefore, it is important to dissipate the heat developed by such small equipment's with faster rate or within very short span of time with minimum area requirement. The main purpose of introducing micro channel or mini channel is to increase the surface area, which is exposed to heat transfer. Micro channels are provided in order to increase the surface area, which in turn increases the heat transfer from small electronic components.

2. LITERATURE REVIEW

Xiao-Hu Yang et al [1] presented Flow and thermal modeling and optimization of micro/mini-channel heat sink and this paper is present a comprehensive comparison and discussion on the flow and thermal modeling of micro/mini-channel heat sink for better understanding Liquid metal exhibits much superior flow and thermal performance in mini-channel heat sink than that of water. Waqas Arshad et al [2] in this research the results indicate that TiO_2 nanofluid thermal performance is strongly dependent on heating power. However, pressure drop is found to increase with the decrease of heating power. D.D. Ma et al [3] present research paper on Multi-parameter optimization for micro-channel heat sink under different constraint conditions and This paper Results show the thermal resistance can reach smaller for fixed volume flow rates, but the pressure drop even increased to 350 kPa unacceptable in application.

Weerapun Duangthongsuk et al [4] are presented paper on an experimental investigation on the heat transfer and pressure drop characteristics of nanofluid flowing in microchannel heat sink with multiple zigzag flow channel structures. Both CZ-HS and CCZ-HS are made from copper material As flow rate increases, the pressure drop of the fluid will increase. D.R.S. Raghuraman et al [5] presented average convective heat transfer coefficient, outlet temperature, friction and pressure drop, pumping power and thermal resistance have been plotted against Reynolds number. Yeongseok Kim at al [6]are work on multistage mini-channel heat sink using water coolant was designed to obtain a larger cooling rate in a small area with a lower pressure drop. The result of the pressure drop was compared with the experimental result to confirm the validity of the hydrodynamic model. Luigi Ventola et al [7] presented Convective heat transfer enhancement by diamond shaped microprotruded patterns for heat sinks: This work is expected to introduce a new methodological approach for a more systematic and efficient development of solutions for electronics cooling.

D.D. Ma et al [8] are research on Design study of micro heat sink configurations with offset zigzag channel for specific chips geometrics. It can be interpreted that 4-port configurations reduce the channel length and increase channel number, which lead fluid distributes more uniformly to enhance thermal performance and reduce flow resistance. Bahram Rajabifar et al [9] presented Flow of heat transfer in micro Pin Fin Heat Sinks with Nano Encapsulated Phase Change Materials, a 3D-conjugated heat transfer model for nano-encapsulated phase change materials (NEPCMs) cooled micro pin fin heat sink (MPFHS) is presented. The former is due to higher heat transfer capability of coolant at temperatures over the melting range of phase change material (PCM).

Study of the convective heat transfer and pressure drop in micro channel heat sink is done by P. Naphon et al. [10]. Experiments have been performed to investigate the heat transfer characteristics and pressure drop through in the micro channel heat sinks under constant heat flux conditions and the ranges of Reynolds number and heat fluxes are of 200 to 1000 and 1.8 to 5.40 kW/m^2.

3. PROPOSED WORK

3.1 Design of Micro Channels

. The hydraulic diameter for micro - fluidic channels is calculated using the equation stated below

$$D_h = [4 * A_{cs}] / P \quad \text{.........1}$$

Where,

A_{cs} = cross section area of channel **(mm^2)**

P = wetted perimeter **(mm)**

The Heat transferred to the cooling water in the test section (Q_w) is given by,

$$Q_w = m_w Cp_w [(T_{w,ave})_{out} - (T_{w,ave})_{in}] \quad \text{.........2}$$

Where,

m_w = Mass flow rate of water (Kg/s)

Cp_w = Specific heat capacity of water (kJ/KgK)

$(T_{w,ave})_{out}$ & $(T_{w,ave})_{in}$ are average outlet and inlet water temperatures respectively. (^{0}C)

Heat added to the micro-channel is given by,

$$Q_{heater} = V * I \quad \text{................3}$$

Where,

V = Voltage supplied (Volts)

I = Current (Amperes)

The average heat transfer rate (Q_{avg}) used in the calculation is determined from the heat transferred to the cooling water and the heat supplied to the heat source as follows:

$$Q_{avg} = [(Q_w + Q_{heater}) / 2] \quad \text{................4}$$

The average heat transfer coefficient is given by,

$$Q_{avg} = h_m . A_m (\Delta T_{LMTD}) \quad \text{..........5}$$

Where,

$$\Delta T_{LMTD} = \{[T_{s,avg} - (T_{w,avg})_{in}] - [T_{s,avg} - (T_{w,avg})_{out}]\} / \ln\{[T_{s,avg} - (T_{w,avg})_{in}] / [T_{s,avg} - (T_{w,avg})_{out}]\} \quad \text{.........6}$$

Where,

$T_{s,avg}$ = average surface temperature **(^{0}C)**

A_m = surface area of the micro-channel **(mm^2)**

$(T_{w,avg})_{in}$ = Average inlet temperature of water **(^{0}C)**

$(T_{w,avg})_{out}$ = Average outlet temperature of water **(^{0}C)**

The average heat transfer coefficient is presented in terms of average Nusselt Number as given bellow,

$$Nu = [\, h_m * D_h \, \frac{hmDh}{K} \,] / K \quad \text{.............7}$$

Where,

K = Thermal Conductivity of water **(W/m^{0}C)**

D_h = Hydraulic diameter of channel **(mm)**

The hydraulic diameter is given by,

$D_h = [4 * A_{cs}] / P$ …………8

The Reynolds number based on D_h of micro- channel is,

$Re = [u * D_h] / \nu$ ……………9

Where,

u = Velocity of water (**cm/s**)

ν = Kinematic viscosity of water (**m^2/s**)

A_{cs} = Cross sectional area of micro channel(**mm^2**)

P = Wetted perimeter (**m**)

3.2 Selection of Geometries

The following geometries are selected,

1. Rectangular
2. Square
3. Triangular
4. Circular

3.3 Preparation of AutoCAD Drawing:

In order to design the different geometrical configurations micro channel heat sink very careful approach has to be adopted. By using AutoCAD 2015 CAD drawings are prepared for different configurations of micro channels.

1. Square Micro channel:

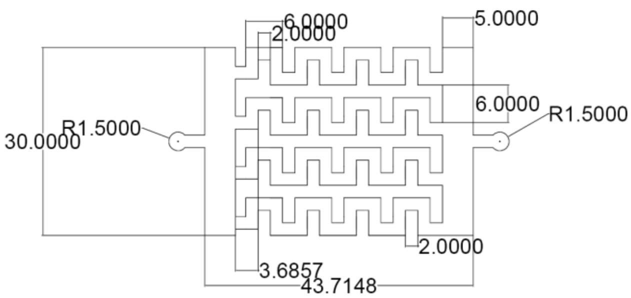

Fig.1 Square Micro channel (all dimensions are in mm)

Different geometrical configurations are designed in such a way that the surface area exposed to convective heat transfer is constant for each of the geometry. The height of the micro channel is kept constant which is equal to 500 µm.

2. Triangular Micro channel:

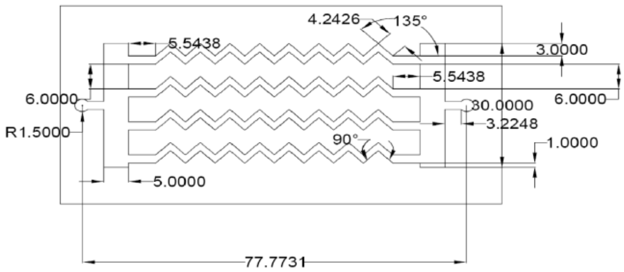

Fig.2 Triangular Micro channel (dimensions in mm)

3. Circular Micro Channel:

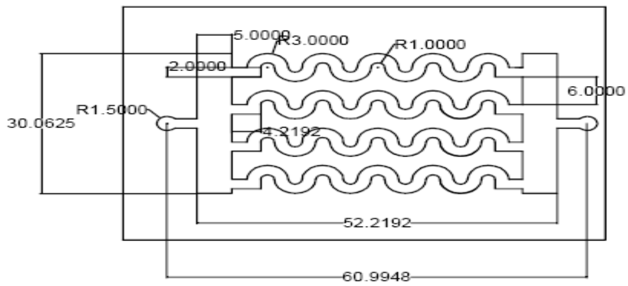

Fig.3 Circular Micro channel (dimensions in mm)

3.4. Selection of cold fluid*:*

To find the heat transfer rate through different geometrical configurations of micro channels water is considered as cooling fluid.

3.5 Selection of Material:

The Copper is selected as a raw material by considering following properties,

1. Melting temperature: 1084.62^{0}C
2. Thermal conductivity: 401 W/m.K
3. Electric resistivity: 16.78 nΩ.m(20^{0}C)
4. Size: 50mm*70mm
5. Channel width: 2 mm
6. Channel height: 500 µm

3.6 Fabrication of Micro Channels

Micro-channels can be generally fabricated by two different techniques which are,

1. Miniaturized Traditional Technique

2. Modern Technique

Traditional Technique, consists of conventional machining which are miniaturized to use them in micro regime e.g.

Micro EDM, Stereo lithoChartic fabrication, electroforming, molding, ultrasonic , water jet machining and electroforming are important processes of this type.

Photo Chemical Machining:

It is a type of non- conventional machining process. The main components of it are as explained below:

Introduction of etching:

Etching is used in micro fabrication to chemically remove layers from the surface of a wafer during manufacturing. Etching is a critically important process module, and every wafer undergoes as many etching steps before it is complete.

Photo-etching**:**

Manufacturing process:

- Initially cut the copper plate of required size (70mm*50mm) from metal sheet.
- Clean the metal plate using polish paper/chemical and ensure that it is free from dust and spatters.

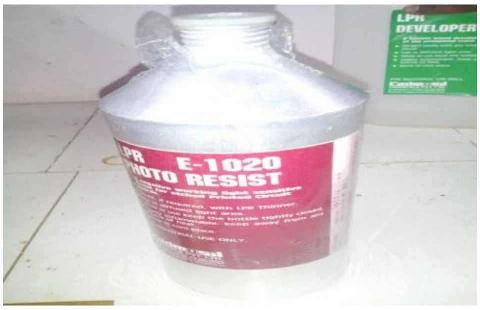

Fig.4 LPR E- 1020 Photo Resist

Exposing Unit:

Exposure is done under Ultra violet light source at the distance of 30cm under vacuum contact. The U. V. Exposure setup is as shown in figure (5).

Description*:*

In this unit, the light being used to expose the screen is ultraviolet (UV) light. Drawings on tress paper are placed on the metal plate and UV light is exposed. The area under the black region is protected from exposure of light and remaining region of plate is unprotected. This protected region is get oxidized during etching.

Fig.5 Ultraviolet Light exposure unit

Fig.6 LPR Developer and Photo Resist

Develop with photo resist developer for 60-90 seconds. Apply photo resist dye to the metal for good and clear visibility. For single step working, user can use this product. It saves time also quantity of product considerderably, developer for 90-120 seconds.

Etching

In this process actual removal of metal is done. Pheric-chloride solution is used as etchant; its concentration is near about 600 gm/lit. Metal plate is dipped into the solution at about 50^0C. Amount of time for which plate is dipped into the etchant gives different depth. Change in concentration of etchant may lead to variation in removal of material. However, there should be very good control over the oxidation at sharp edges.

Inspection Micro channels:

After manufacturing different geometrical configurations are inspected under Rapid-I Vision Inspection System. Table 1 shows technical Specification of RAPID I Vision measuring instrument which is shown in figure 7. Rapid I Vision Inspection system is operated with Rapid I 5.0 software and readings are being taken.

Fig. 7 Rapid-I Vision Inspection System

The dimensions of the manufactured components with the help of photochemical machining are tested under Rapid I for quality and the dimensions measured are,

Dimension given in input data to PCM Machine

- Width of the channel 2mm
- Height of the channel 500 micron

After the dimensional analysis, the width and height of the channel were found within ±1%.

4 EXPERIMENTAL WORK

A. Equipment's used in Experimental Setup:

1. Heater assembly
2. Temperature Indicator
3. Temperature Sensor
4. Syringe Pump
5. Tubing
6. Fittings (Connectors)
7. Sample

1. Heater Assembly:

The heater assembly is as shown in fig. 8. For the preparation of heater assembly, initially a wooden block is taken of dimension (130*70) mm as a base. On this wooden base asbestos sheet of (130*70) mm is placed as insulating material. Now on this asbestos sheet heating coil with Mica sheet is placed and finally over this surface Aluminum sheet of thickness 0.5 mm is placed for uniform heating.

Aluminium sheet is used for heater as heating surface because of its high melting temperature 659°C. This gives uniform heating to base of heat sink also aluminium is having high thermal conductivity (i. e. 204.2 W/m^{0}C). The thickness Aluminium sheet is 0.5 mm.

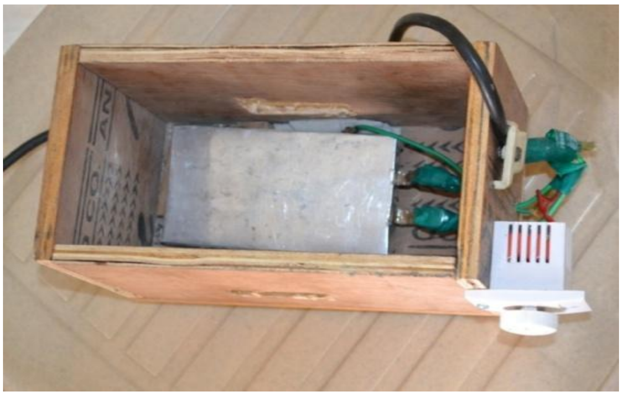

Fig. 8 Heater assembly

2. Temperature Measuring Unit:

This unit is used for measuring inlet & outlet temperature of water and from the micro channel heat sink. It consists of electronic components like

1. LM35 (Integrated Circuit Temperature Sensor),
2. Microcontroller Board,
3. Potentiometer.

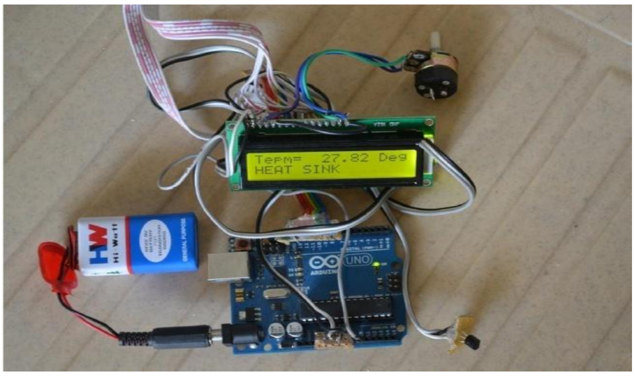

Fig. 9 Temperature Measuring Unit

3. Syringe Pump:

Syringe pump was used for continuous fluid flow through the inlets of micro channel at various flow rates. The flow rate was checked by measuring the volume of fluid flow through the pipe at a particular time. Fig. 10 shows the schematic of Syringe pump used for the experimentation.

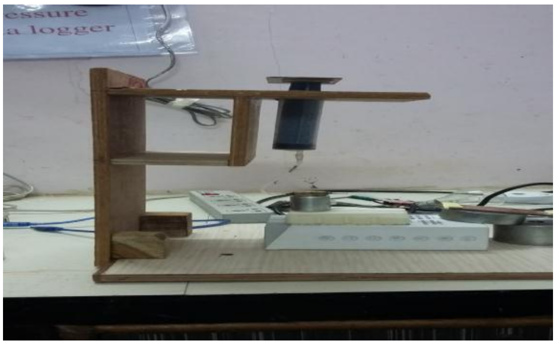

Fig. 10 Syringe Pump

Fig. 11 below shows the working zone of the experimental setup.

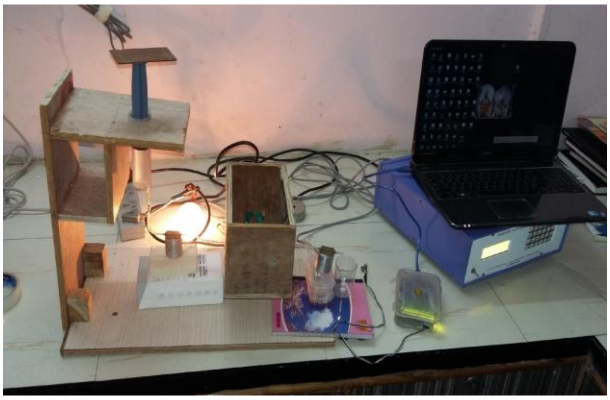

Fig. 11 Experimental Setup

Table 2 Observation Table of Square Micro Channel

Sr. No	M (Kg/s)	As (m2)	Ts (⁰C)	Tout (⁰C)	Tin (⁰C)	C (A)	V (V)
1.	0.00004	0.001072	48	35.19	29.81	0.287	90
2.	0.00006	0.001072	48	37.68	29.81	0.287	90
3.	0.00008	0.001072	48	38	29.81	0.287	90
4.	0.0001	0.001072	48	38.61	29.81	0.287	90

5. RESULTS

Table No. 4 Deviation of Experimental Heat Transfer Coefficient of Theoretical Value

Square Micro Channel		
% Deviation	**h (W/m2K) (Theoretical)**	**h (W/m2K) (Expt)**
31.608587	1204.05803	823.47229
28.785114	1379.240787	982.22474
30.882062	1516.991344	1048.51314
29.947601	1633.725639	1144.46398
Rectangular Micro Channel		
% Deviation	**h (W/m2K) (Theoretical)**	**h (W/m2K) (Expt)**
18.902531	1040.433005	843.764829
12.739925	1193.169632	1041.16070
15.547847	1432.914675	1210.12729
2.2715633	1545.559599	1510.45123
Circular Micro Channel		
% Deviation	**h (W/m2K) (Theoretical)**	**h (W/m2K) (Expt)**
24.487616	1136.218331	857.985545
20.916410	1301.45404	1029.23657
6.2298660	1292.465245	1211.94639
2.4254238	1414.991331	1380.67179
Triangular Micro Channel		
% Deviation	**h (W/m2K) (Theoretical)**	**h (W/m2K) (Expt)**
33.2563719	1625.295793	1084.78137
33.4779457	1858.008944	1235.98571
27.2451121	2045.49257	1488.19582
20.5994401	2202.650449	1748.91678

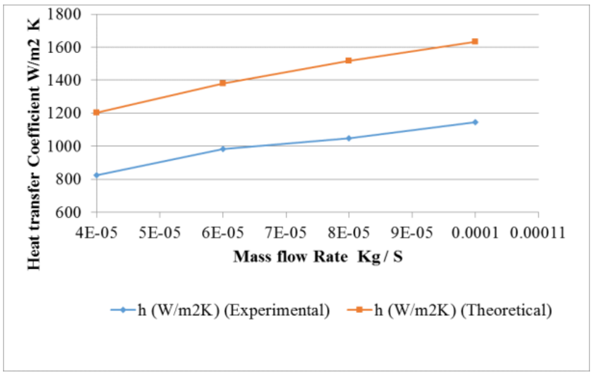

Chart. 1 Mass flow Rate VS Heat Transfer Coefficient (Square Micro Channel)

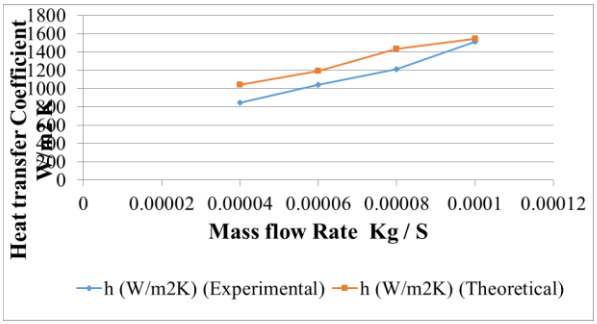

Chart. 2 Mass flow Rate VS Heat Transfer Coefficient (Rectangular Micro Channel)

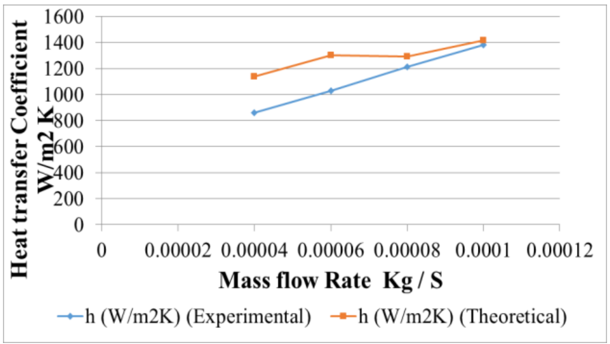

Chart. 3 Mass flow Rate VS Heat Transfer Coefficient (Circular Micro Channel)

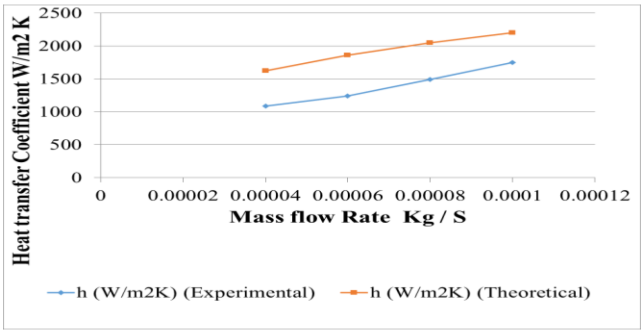

Chart. 4 Mass flow Rate VS Heat Transfer Coefficient (Triangular Micro Channel)

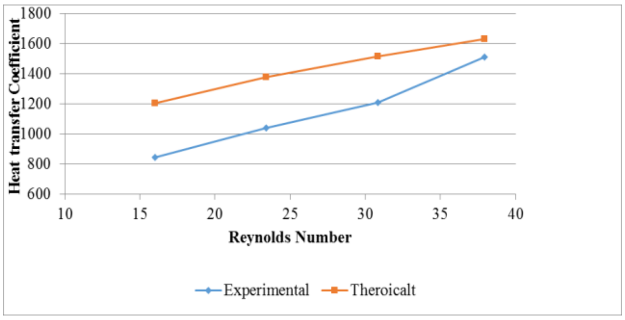

Chart. 5 Reynolds Number VS Heat Transfer Coefficient (Square Micro Channel)

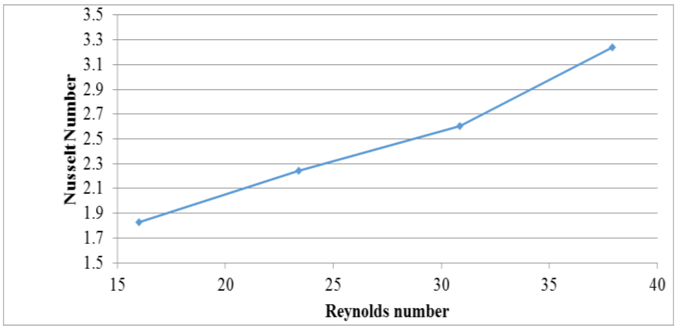

Chart. 6 Reynolds Number VS Nusselt Number

(Square Micro Channel)

6. CONCLUSIONS

From above table it is clear that for every geometrical configuration

1. With increase in outlet temperature of water there is increase in Nusselts number in turn increase in heat transfer.

2. When surface temperature of heat sink decreases there is increase in Nusselts number in turn increase in heat transfer.

3. With increase in heat transfer coefficient of water there is increase in Nusselts number in turn increase in heat transfer.

4. If temperature rise of cooling water in case of triangular micro channel is much higher as compared with rest three configurations.

5. The increase in heat transfer coefficient of cooling water in triangular micro channel is around 15 – 20 % more than rectangular micro channel, 25 – 30 % more than circular micro channel and 50 – 55 % more than square micro channel. As the value of heat transfer coefficient is more in triangular micro channel therefore, it is concluded that the triangular geometrical configuration is best suited to have higher heat transfer through the micro channel.

REFERENCES

1. Xiao-Hu Yang, Si-Cong Tan, Yu-Jie Ding, Jing Liu, “Flow and thermal modeling and optimization of micro/mini-channel heat sink”, Applied Thermal Engineering 117 (2017) 289–296.

2. Waqas Arshad and Hafiz Muhammad Ali, “Experimental investigation of heat transfer and pressure drop in a straight minichannel heat sink using TiO2 nanofluid” International Journal of Heat and Mass Transfer 110 (2017) 248–256.

3. D.D. Ma, G.D. Xia, Y.T. Jia, Y.F. Li, J. Wang, "Multi-parameter optimization for micro-channel heat sink under different constraint conditions" Applied Thermal Engineering 120 (2017) 247–256.

4. Weerapun Duangthongsuk and Somchai Wongwises, "An experimental investigation on the heat transfer and pressure drop characteristics of nanofluid flowing in microchannel heat sink with multiple zigzag flow channel structures" Experimental Thermal and Fluid Science 87 (2017) 30–39.

5. D.R.S. Raghuraman, R. Thundil Karuppa Raj, P.K. Nagarajan, B.V.A. Rao, "Influence of aspect ratio on the thermal performance of rectangular shaped micro channel heat sink using CFD code" Alexandria Engineering Journal (2017) 56, 43–54.

6. Yeongseok Kim, Myungjoon Kim, Chisung Ahn, Hyeong U. Kim, at al, "Numerical study on heat transfer and pressure drop in laminar-flow multistage mini-channel heat sink" International Journal of Heat and Mass Transfer 108 (2017) 1197–1206.

7. Luigi Ventola, Masoud Dialameh, Matteo Fasano, Eliodoro Chiavazzo, Pietro Asinari, "Convective heat transfer enhancement by diamond shaped microprotruded patterns for heat sinks: Thermal fluid dynamic investigation and novel optimization methodology" Applied Thermal Engineering 93 (2016) 1254–1263.

8. D.D. Ma, G.D. Xia, Y.F. Li, Y.T. Jia, J. Wang, "Design study of micro heat sink configurations with offset zigzag channel for specific chips geometrics" Energy Conversion and Management 127 (2016) 160–169.

9. Flow and Heat Transfer in Micro Bahram Rajabifar, Hamid Reza Seyf, Sanjeev K. Khanna, " Flow of heat transfer in micro Pin Fin Heat Sinks With Nano Encapsulated Phase Change Materials" Journal of Heat Transfer 2016, Vol. 138.

10. P. Naphon and O. Khonseur, "Study on the convective heat transfer and pressure drop in the micro-channel heat sink", International Communications in Heat and Mass Transfer 36 (2009) 39- 44.

11. Islam Md. Didarul, Oyakawa Kenyu, Yaga Minoru, Senaha Izuru, "Study on heat transfer and fluid flow characteristics with short rectangular plate fin of different pattern", Numerical Heat Transfer 59 (2009) 231–239.

12. H. Y. Zhang, "Single-phase liquid cooled micro channel heat sink for electronic packages", Applied Thermal Engineering 25 (2005) 1472–1487.

13. M. Reyes, J.R. Arias, A. Velazquez, J.M. Vega, "Experimental study of heat transfer and pressure drop in micro-channel based heat sinks with tip clearance" Applied Thermal Engineering 31 (2011) 887-893.

14. W. A. Khan, J. R. Culham, " optimization of micro channel heat sink using entropy generation minimization method", IEEE transactions on components and packaging technologies 32 (2009) 243-251.

15. Jaeseon Lee, Issam Mudawar, "Experimental Investigation and Theoretical Model for Subcooled Flow Boiling Pressure Drop in Microchannel Heat Sinks" Journal of Electronic Packaging 2009, Vol. 131.

16. M. Didarul, "Study on heat transfer and fluid flow characteristics with short rectangular plate fin of different pattern", Experimental Thermal and Fluid Science 31 (2007) 367–379.