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# Effect of Various Geometrical Configurations on Pressure Drop through Micro Channel

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**ABSTRACT**

**As shape and size of micro-channel surface has significant effect on enhancement of heat transfer performance and the pressure drop variations. Uniform flow distribution is desirable in numerous engineering Devices, Flow uniformity within a microchannel array can be a significant factor affecting the performance of micro-devices. This article mainly focuses on the effect of various surface geometries of micro-channel heat sink on Reynolds number, Pressure drop for various flow rates of cooling water. In this work four geometrical configuration were tested while experimentation & results are validated by using COMSOL Multi physics 4.4. At the end the performance of those geometrical configuration was compared with regards with Reynolds number, Pressure drop & other related parameters.**

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## I. INTRODUCTION

In the last few decades, due to the rapid developments in micro-electronics and biotechnologies, the applied research in micro-coolers, micro-biochips, micro-reactors, and micro-fuel cells as well as in nuclear fission & fusion reactors have been expanding at a tremendously. Among these micro-fluidic systems, micro-channels have been identified to be one amongst the essential elements to transport large amount of heat fluxes through a miniature area. Micro-channels combine the attributes of very high surface area to volume ratio, large convective heat transfer coefficient, small mass and volume, and small coolant inventory. These attributes render these heat sinks very suitable for cooling such devices.

In the field of micro-heat sinks, the main emphasis has been traditionally placed on the thermal performance of the system, although there are other issues that influence viability. One of these is the pressure drop, which affects the power required by the pump, the weight and size of the device & uniform flow through microchannel. Flow distribution among individual microchannels plays an important role in the performance of microchannel. In microchannel heat sinks used for cooling electronic chips, a nonuniform flow distribution can cause nonuniform heat transfer conditions and produce undesirable transverse temperature gradients which lead to lower performance. Hence it could be said that thermal efficiency is a natural requirement but pressure drop is a strong design constrain to be dealt with. For example, in modern fighter aircraft designs in which micro-heat sink devices are used to cool electronics systems (like radar) that dissipate a large amount of power, the onboard fluid management system provides a fixed flow rate of cooling fluid with a prescribed pressure drop. Therefore, it is important to minimize the local pressure drop associated to the different micro-cooling devices.

The micro-channel heat sink cooling concept was first introduced by Tuckerman and Pease in the early 1980s [1]. Due to their inherent advantages, micro-channel heat sinks have received considerable attention since Tuckerman and Pease's pioneering study. A comprehensive review of the literature dealing with heat sink optimization with regard to heat transfer and pressure drop appears in the article published by Khan et al. [2]. In this article, the authors stress the importance of accounting with these two effects when practical engineering applications are foresighted. In particular, in the technical chapters, the authors numerically asses combined thermal resistance and pressure drop behaviour when optimizing a heat sink accounting for channel aspect ratio, fin spacing ratio, heat sink material,and Knudsen number. A very detailed experimental study on the pressure drop and heat transfer in a micro-channel has been published by Qu and Mudawar [3], who considered an array of rectangular micro-channels

231 microns wide and 713 microns deep in the Reynolds number span from 139 to 1672, for two different heat fluxes: 100 and 200 W/cm2. They provided an interesting set of conclusions. i.e a) The conventional NaviereStokes equations adequately predict fluid flow and heat transfer behaviour inside micro-channel heat sinks. b) Higher Reynolds number are beneficial for the heat transfer standpoint at the expense of a greater pressure drop.

Naphon et al. [4] studied the convective heat transfer & pressure drop in the micro- channel heat sink. The pressure drop in a micro-channel depends on a number of factors. For example, Croce et al. [5] have reported a significant influence of surface roughness on pressured drop and provided correlations among the Nusselt and Reynolds numbers, the friction factor, and various geometry parameters; Reyes et al.[6] presented an experimental study on the optimization of micro-heat sink configurations when both thermal effects and pressure drop are accounted.

Among others, Knight et al. [7,8] presented an optimization scheme that included both laminar and turbulent flow. Their results indicated that when the pressure drop is small, laminar flow prevails, yielding low thermal resistance.

| Nomenclature | |
|---|---|
| Acs | Cross sectional area of microchannel, ($m^2$) |
| Re | Reynolds number |
| $D_h$ | hydraulic diameter, m |
| F | Friction factor |
| σ | Aspect ratio for michrochannel |
| h<br>w | Height of microchannel, mm<br>Width of microchannel, mm |
| ΔP | pressure drop, (kPa) |
| M | mass flow rate, (kg/s) |
| P | wet perimeter, (m) |
| ν | Kinematic viscosity of water |
| T | temperature, (°C) |
| U | Water velocity, (m/s) |
| P | density, ($kg/m^3$) |
| W | Water |
| | |

Harms et al. [9] tested a 2.5 cm long, 2.5 cm wide silicon heat sink having 251 lm wide and 1030 lm deep micro-channels. A relatively low Reynolds number of 1500 marked transition from laminar to turbulent flow, which was attributed to a sharp inlet, relatively long entrance region, and channel surface roughness. They concluded the classical relation for local Nusselt number was fairly accurate for modeling micro-channel flows.

As mentioned above, the too much works have been carried out concerning heat transfer as well as pressure drop with various geometrical configurations. However there still remains scope for discussion on various parameter which affects on heat transfer characteristics & pressure drop in the micro- channel. The main objective of this paper is to study effect of various geometrical configurations such as straight, square, triangular, circular of micro- channel on the parameters such as Reynolds number, velocity of cooling fluid and pressure drop and to compare the results obtained and give the best suited geometrical configuration for uniform flow through microchannels.

## II. EXPERIMENTAL SETUP

### 1. Test Module:

We have studied the four different Geometrical Configurations, using water as a cooling fluid. The experimental setup consists of mainly four parts i.e. different geometries of micro- channels, heater assembly, temperature measuring unit and pressure sensors with datalogger.

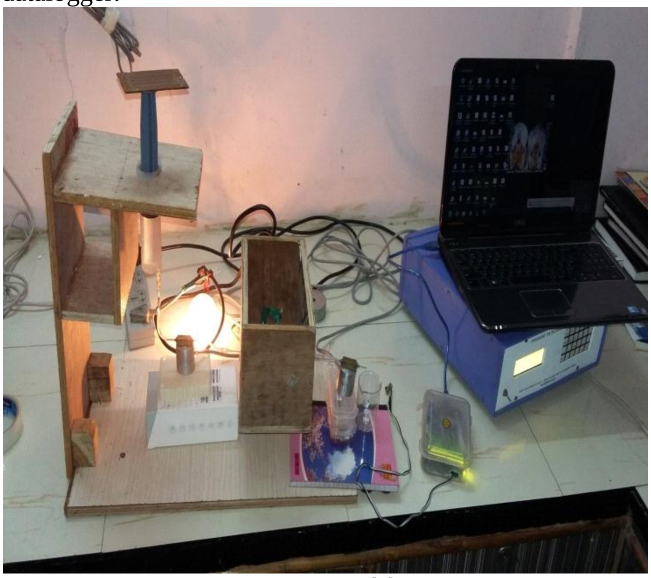


Fig.1 Test module

### A. Different Geometries of Micro- channel:

The micro-channel heat sink was fabricated from a Copper plate of 70×50 mm by using photochemical machining. Selected material copper is having following material properties

Melting Point: 1084.620C,
Thermal Conductivity(K): 401 W/m0C,
Electrical Resistivity: 16.78 nΩ.m(200C),
Size: 50mm*70mm, Channel width: 2 mm,
Channel height: 400 µm, Channel length: 50mm.

While designing micro-channels optimum dimensions have been taken to minimize the overall thermal resistance of micro-channels for a given pressure drop. The small hydraulic diameter of a micro-channel can lead to appreciable heat dissipation which is undesirable in electronic systems. Therefore, a strong understanding of the heat transfer rate, Reynolds number, flow rate and velocity change have more importance in design of micro-channel. Design of microchannel has been prepared by keeping surface area & depth of microchannel for various geometrical configurations of microchannel as a constant parameter. The various geometries such as straight, square,

triangular, circular are generated on the surface of copper plates.
The various geometries of micro-channels are shown below:

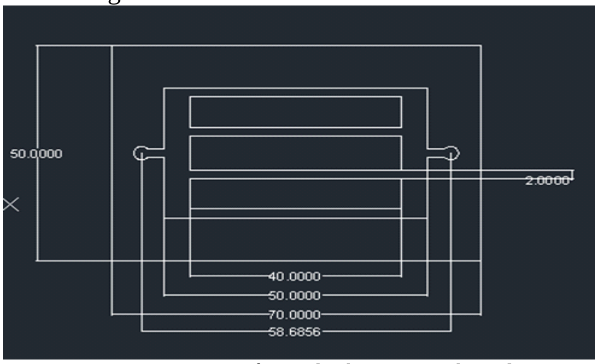


Fig.2 Drawing of Straight shape micro channel


Fig.3 Straight shape micro channel

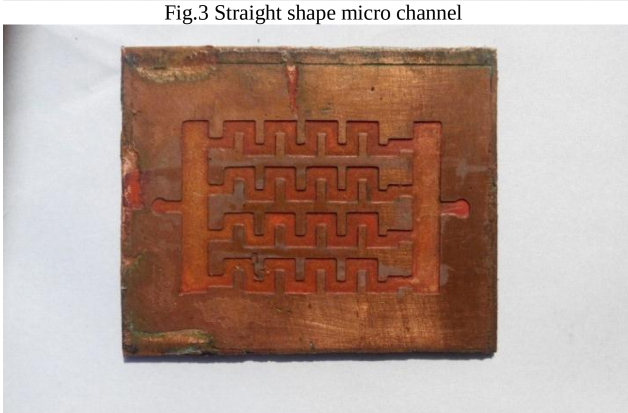


Fig.4 Square shape micro channel

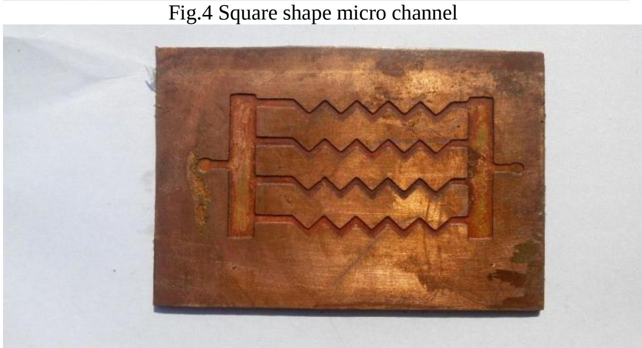


Fig.5 Triangular shape micro channel

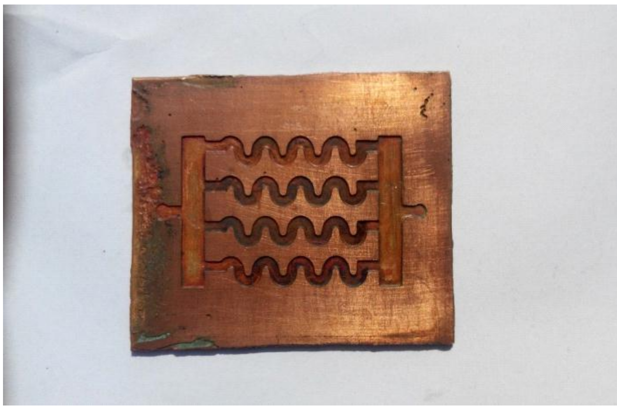


Fig.6 Circular shape micro channel

**B. Heater assembly:**

Heater assembly is prepared by taking wooden block of dimension 130×70 mm as a base. On this wooden base asbestos sheet of 130×70 is placed as insulating material. Now on this asbestos sheet heating coil covered with Mica sheet is placed. Finally over this surface Aluminum sheet of thickness 0.5mm is placed for uniform heating.

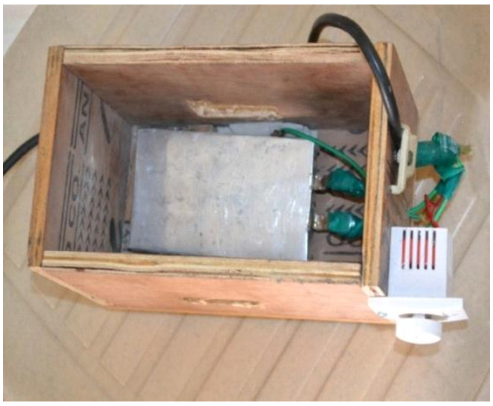


Fig.7 Heater assembly

**C. Temperature Measuring Unit:**

For measuring inlet & outlet temperature of water this unit is used. It consists of electronic components like LM35 (Integrated Circuit Temperature Sensor), Microcontroller Board, Potentiometer.

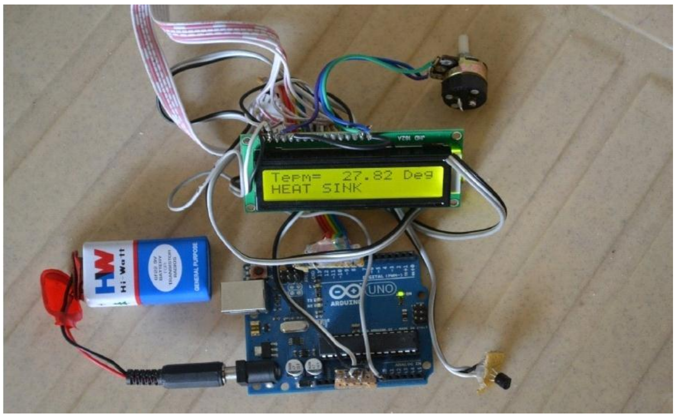


Fig.8 Temperature Measuring Unit

**D. Pressure Sensor:**

The pressure sensors used for measurement of inlet and outlet pressures are silicon diaphragm actuated sensor along with 4 channels pressure datalogger having range of 0-100 mlbar.

### 2. Methodology:

After preparation of different configurations of micro- channels they are placed on the heater element and to avoid heat leakage between the test plate & heater element Teflon tape is used. An AC supply is supplied as a power source for heaters. The rear side of heater is insulated with a thick Mica resistant sheet followed by acrylic sheet & wooden plate. The LM35 thermocouples are used to measure the inlet & outlet temperature of water. And also thermocouples are mounted to measure the surface temperature of Cu plate. Pressure sensors are used to measure the pressures at inlet and outlet.

### 3. Operating Conditions:

Experiments were conducted with various flow rates of water entering the test section by keeping inlet temperature of water & surface temperature of microchannel as a constant parameter. And set of experiments were conducted to measure inlet water pressure, outlet water pressure, mass flow rates for each of the geometry.

## III. CALCULATIONS FOR PRESSURE DROP

For a non-circular cross section of the flow channels, the calculated hydraulic diameter $D_h$ of a rectangular channel is computed by the following equation:

$D_h$ = ....(1)

Where

= Cross sectional Area of microchannel

p = Wetted perimeter

The Reynolds number based on hydraulic diameter of micro- channel is,

$Re = D_h / \nu$ ….(2)

Where,

= Water velocity

$\nu$ = Kinematic viscosity of water

It should be noted that the fluid properties were estimated at the average temperature of water obtained from the experimental data.

The friction factor f for the curved microchannel is given by equation proposed by **Shah and London.** For a single phase, incompressible and fully developed laminar flow in microchannel, the friction factor f is given by

$$f R_e = 24(1- 1.3553\sigma + 1.9467 \sigma^2 - 1.7012 \sigma^3 + 0.9564 \sigma^4 - 0.2537 \sigma^5) \quad ….(3)$$

Where,

$f$= Fricton factor

$\sigma$= Aspect ratio (h/w)

For the incompressible flow through the horizontal channels of the constant cross-sectional area, the pressure drop $\Delta P$ through microchaanel based on Fanning friction factor $f$ is calculated by

$\Delta P$ = ….(3)

Where,

$f$ = Fricton factor

L= length of microchannel

=density of water

= Water velocity

$D_h$= hyadraulic diameter

## IV. SIMULATIONS OF MICROCHANNEL BY COMSOL 4.4

The following assumptions were considered while using the Comsol Multiphysics software:

- Fluid flow is fully developed and fluids are Newtonian.
- Flow in the micro-channel is steady and laminar.
- Surface roughness of internal walls was considered zero.
- Gravity was assumed as zero due to the horizontal setup of the microchannel.

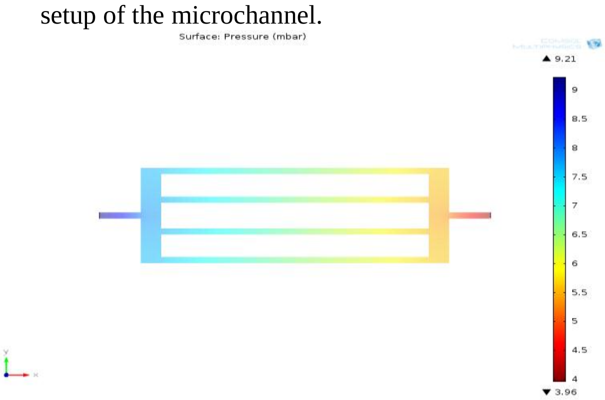
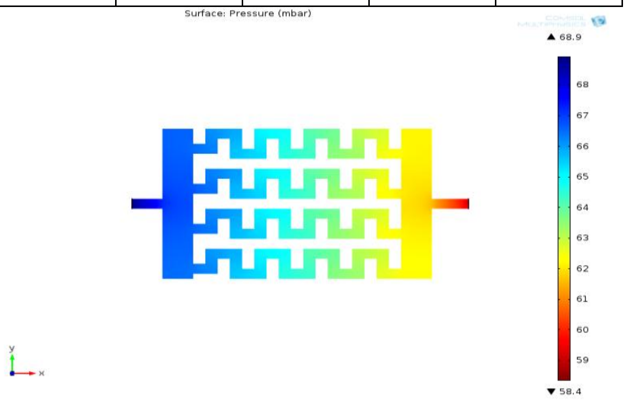
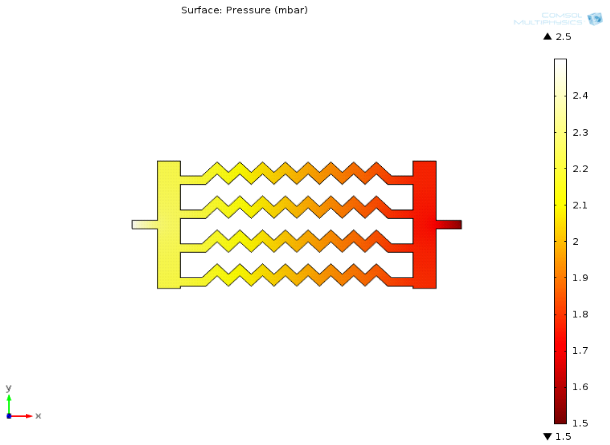



Fig shows simulation results of rectangular (straight) microchannel for having mass flow rate of water as a 1×10-5 kg/sec , inlet temperature of water as a 301.15 K & surface temperature as a 321.15 K. Similarly for the same same operating parameter the simulated results for square, triangular & circular microchannels respectively are as follows;

| Sr. No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Mass flow rate (Kg/sec) | $1\times 10^{-5}$ | $1.5\times 10^{-5}$ | $2\times 10^{-5}$ | $2.5\times 10^{-5}$ |
| $T_i$(K) | 301.15 | 301.15 | 301.15 | 301.15 |
| $T_s$(K) | 321.15 | 321.15 | 321.15 | 321.15 |
| | **Rectangular (Straight) Microchannel** | | | |
| ΔP (mbar) Exp | 5.24 | 12.53 | 31.23 | 33.23 |
| ΔP (mbar) Numerical | 5.2499 | 12.6522 | 26.7221 | 26.7221 |
| | **Square Microchannel** | | | |
| ΔP (mbar) Exp | 13.3 | 70.13 | 216.65 | 834.02 |
| ΔP (mbar) Numerical | 10.5488 | 52.8443 | 170.855 | 928.856 |
| | **Triangular Microchannel** | | | |
| ΔP (mbar) Exp | 1.23 | 2.64 | 6.8 | 9.5 |
| ΔP (mbar) Numerical | 0.9999 | 2.4836 | 4.6891 | 8.0004 |
| | **Circular Microchannel** | | | |
| ΔP (mbar) Exp | 2.39 | 3.61 | 8.93 | 18.93 |
| ΔP (mbar) Numerical | 1.6854 | 3.92118 | 7.5836 | 13.1133 |



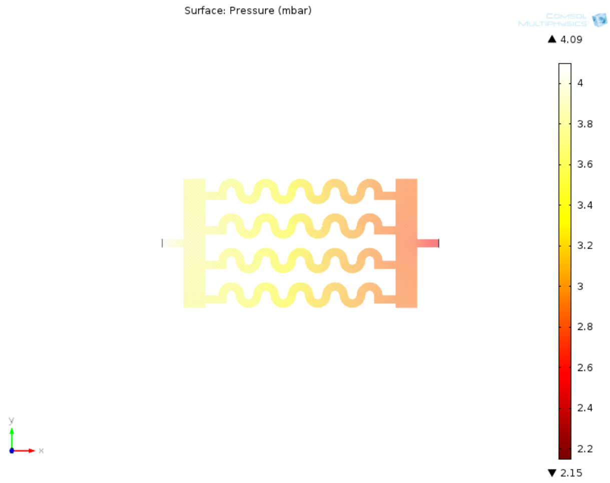




TABLE 1. Observation & Results Table for Different Configurations of Micro- channel

## V. CONCLUSION

The analysis of micro-channel heat sink is very important due to its increased utility in the micro cooling applications. Various parameter related to micro-channel have pronounced effect on its performance. We have studied the effect of various surface geometrical configuration of micro-channel on Pressure drop. It was found that For Triangular geometry the Pressure drop value is much lower as compared with rest three configurations. Hence for getting uniformlity in flow Triangular Geometry is best than other geometry.

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