The effect of manifold zone parameters on hydrothermal performance in different shape microchannel heat sink

Khushbu patel[1]

[1] Assistant Professor, Mechanical Department, Vadodara Institute of Engineering, Gujarat, India

ABSTRACT

Designers are always finding out new ways to improve heat transport techniques in many engineering fields because they can improve the energy utilization efficiency or reduce the weight and size of the heat transfer equipment. Micro channels are current attention for use in microelectronic device, compact heat exchanger, micro heat sink, micro reactor, and micro bio-chips where very high heat transferred performance is considered necessary. This worked is performed for objective to influence of channel geometry or flow passage of microchannel heat sink. For the analyses a three-dimensional Computational Fluid Dynamics (CFD) model was built using the commercial package, FLUENT, to investigate the conjugate fluid flow and heat transfer phenomena in different shape of manifold microchannel for single phase convective flow and heat transfer performance. The present work is focused on laminar flow for different shapes of microchannel fluid flow passage with manifold for single-phase liquid flow. Water has been considered as working fluid. Copper is used as the material of the microchannel heat sink. Three dimensional numerical models is developed and validated to study the effect of geometric parameters such as microchannel depth and width, and operating condition such as inlet velocity of fluid on the performance of manifold microchannel heat sink. The computational analysis is performed on a simple unit-cell model. The temperature distribution at given length is calculated and for different velocity and heat flux for different shape of manifold microchannel.

Keyword : - *Microchannel, Reentrant, Heat Flux, Manifold Microchannel*

1. Introduction

Excess heat is generated in many electrical and mechanical applications of micro miniature devices. Heat exchangers are provided for the flow of thermal energy and allow heat transfer between two fluids at different temperatures separated by a flow passage wall. Heat transfer is the exchange of thermal energy between physical systems, depending on the temperature and pressure, by dissipating heat[1]. The basics of heat transfer involve the second law of thermodynamics, which basically states that two thermodynamic systems, when allowed to interact, will move towards a thermodynamic equilibrium. In other words, when hot and cold substances are brought into contact with one another, the hot substance will cool and the cool substance will heat up, resulting in a median temperature.

1.1 Heat Exchanger

Heat exchangers are provided for the flow of thermal energy and allow heat transfer between two fluids at different temperatures separated by a flow passage wall. The fundamental modes of heat transfer are conduction or diffusion, convection and radiation. Conduction is defined by a microscopic scale, heat conduction occur as hot, rapidly moving or vibrating atoms and molecules interact with neighboring atoms and molecules, transferring some of their energy to these neighboring particles. Heat exchangers are widely used in industry both for cooling and heating large scale industrial processes. The type and size of heat exchanger used can be tailored to suit a process depending on the type of fluid, its phase, temperature, density, viscosity, pressures, chemical composition and various other thermodynamic properties. Heat transfer always occurs from a region of high temperature to another region of lower temperature [1]. Entropy is generated by the heat transfer across a finite temperature difference due to irreversible friction flow [2]. Expand of energy demands, space limitations for device packaging, material and energy savings, etc; have focused the demand for small, light weight heat exchanger which can provide high heat transfer.

1.2 Sub Microchannel Heat Exchanger

High heat flux cooling is required in many applications such as power electronics, plasma-facing components, high heat-load optical components, laser diode arrays, X-ray medical devices, and power electronics in hybrid vehicles. In general, the exposed area that needs to be cooled for these systems is limited, and the amount of heat that needs to be removed is extremely high, thus requiring cooling of high heat fluxes. While high heat flux cooling is essential for creating an efficient cooling system, there are usually also other system requirements, such as low thermal resistance, surface temperature uniformity, low pumping power, compact design, suitability for large area cooling, and compatibility for use with dielectric fluids. Micro-Channel coil technology began with the automotive industry, which faces similar problems to the HVAC industry [3]. These problems include the costs of production, the size of the equipment and the weight of the equipment. Faced with these issues, the auto industry decided to discover what other coil alternatives were available so that the problem with size, cost and corrosion could be curtailed. It is around that time that they discovered the benefits of using an all-aluminum coil design [4]. This became the standard in the automotive industry. Microchannel heat exchangers (MCHE) are finding applications in industries such as microelectronics, aerospace, biomedical, robotics, telecommunications and automotive. At very small sizes, the processes of heat and mass transfer occurring in the dynamic and thermal boundary layers are very effective [5]. These new types of heat exchangers provide high heat transfer coefficients and thus they are up to 45% more compact than the classic ones, at the same thermal performances The two factors that limit the heat transfer coefficients in a MCHE are: reductions in channel dimensions were accompanied by higher pressure drop; and the amount of heat transfer was limited by the heat transfer fluids used [6]. The rate of heat transfer depends on the surface area to volume ratio, which means the smaller channel dimensions provide the better heat transfer coefficient. The different types of Microchannel heat exchangers are same as different classifications of conventional heat exchangers.

1.3 Manifold Microchannel

Manifold-Microchannel technology has demonstrated substantial promise for superior performance over state of the art heat exchangers, with potential to reduce pressure drop considerably while maintaining the same or higher heat transfer capacity compared to conventional Microchannel designs. The manifold design uses multiple channel sizes to minimize pressure drop, maximize heat transfer, and improve temperature uniformity across the area of the cooled device. A significant reduction is achieved in thermal resistance between the device and the cooling fluid. This is a critical need in modern electronic components because of the increasing demand for higher power levels and packaging densities.

2. NUMERICAL STUDY OF MICROCHANNEL

Here numerical simulation is carried out to solve 3D developing of fluid flow shape geometry with heat transfer of heat flux. Water is use as working fluid in Copper microchannel heat sink.

2.1 Governing equation

The goal is to simulate accurately the smallest continuum scales for multiphase systems that are sufficiently large so that meaningful averages can be obtained and the results used to help generate insight and closure models for engineering tools. Computational Fluid Dynamics (CFD) is the simulation of fluids engineering systems using modeling (mathematical physical problem formulation) and numerical methods (discretization methods, solvers, numerical parameters, and grid generations, etc.). To solve this problem, we should know the physical properties of fluid by using Fluid Mechanics. Then we can use mathematical equations to describe these physical properties. This is Navier-Stokes Equation and it is the governing equation of CFD. The translators are numerical discretization methods, such as Finite Difference, Finite Element, Finite Volume methods. Consequently, we also need to divide our whole problem domain into many small parts because our discretization is based on them. The conjugate heat transfer and the fluid flow inside the microchannel structure were numerically modeled. Steady state continuity, momentum (Navier-stokes Equation) and energy equations are solved. Laminar incompressible flow assumed.

Several simplifying assumptions are made before establishing the governing equations for the fluid flow and heat transfer in the unit cell:

- Steady fluid flow and heat transfer;
- in-compressive fluid and laminar flow;
- The effect of gravity force is considered;
- Temperature dependent fluid properties;
- Negligible radiation heat transfer;
- All solid walls of the channel are no slip and impermeable;
- Negligible viscous dissipation effect.

The governing equations consist of the continuity equation, the momentum equation and the energy equation for the liquid, which are listed respectively as follows:

Continuity Equation,

$$\frac{\partial u_j}{\partial x}+\frac{\partial v_j}{\partial y}+\frac{\partial w_j}{\partial z}=0 \qquad (2.1.1)$$

Momentum equations,

$$u_j\frac{\partial u_j}{\partial x}+v_j\frac{\partial u_j}{\partial y}+w_j\frac{\partial u_j}{\partial z}=-\frac{1}{\rho_j}\frac{\partial p}{\partial x}+\frac{\mu_j}{\rho_j}\left(\frac{\partial^2 u_j}{\partial x^2}+\frac{\partial^2 u_j}{\partial y^2}+\frac{\partial^2 u_j}{\partial z^2}\right) \qquad (2.1.2)$$

$$u_j\frac{\partial v_j}{\partial x}+v_j\frac{\partial v_j}{\partial y}+w_j\frac{\partial v_j}{\partial z}=-\frac{1}{\rho_j}\frac{\partial p}{\partial y}+\frac{\mu_j}{\rho_j}\left(\frac{\partial^2 v_j}{\partial x^2}+\frac{\partial^2 v_j}{\partial y^2}+\frac{\partial^2 v_j}{\partial z^2}\right) \qquad (2.1.3)$$

$$u_j\frac{\partial w_j}{\partial x}+v_j\frac{\partial w_j}{\partial y}+w_j\frac{\partial w_j}{\partial z}=-\frac{1}{\rho_j}\frac{\partial p}{\partial z}+\frac{\mu_j}{\rho_j}\left(\frac{\partial^2 w_j}{\partial x^2}+\frac{\partial^2 w_j}{\partial y^2}+\frac{\partial^2 w_j}{\partial z^2}\right) \qquad (2.1.4)$$

Energy Equation,

$$u_j\frac{\partial T_j}{\partial x}+v_j\frac{\partial T_j}{\partial y}+w_j\frac{\partial T_j}{\partial z}=\frac{k_j}{\rho_j C_{p_j}}\left(\frac{\partial^2 T_j}{\partial x^2}+\frac{\partial^2 T_j}{\partial y^2}+\frac{\partial^2 T_j}{\partial z^2}\right) \qquad (2.1.5)$$

2.2 Geometry of micro channels considered for the modelling

For numerical simulation of different shapes of microchannel an individual heat exchange unite consists of Single phase convective flow with same hydraulic diameter reentrant or rectangular microchannel and surrounding solid proposed by D.deng [6] has been considered. In order to fully understand the liquid flow and heat transfer in the microchannel heat sinks, numerical simulations are conducted for both reentrant and rectangular microchannels utilizing the fluid of water. A unit cell containing a single reentrant or rectangular microchannel and surrounding solid with the full flow length. Microchannel have the different shape of geometry for analysis for same mass flow rate of fluid to show the temperature distribution and pressure drop in the fluid section of microchannel. Fig shows the microchannel fluid shape for validation of the shape passage Temperature distribution and pressure drop.

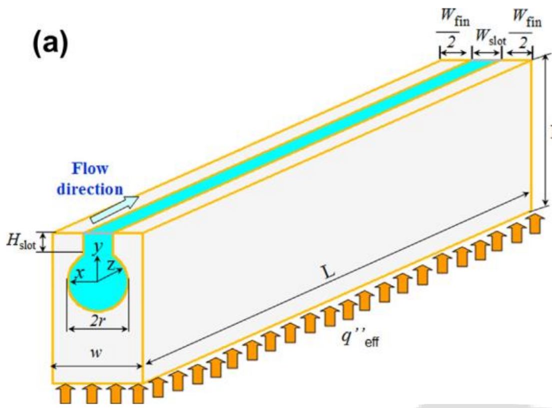

Fig -1: Schematic diagram of computational domain: (a) reentrant microchannels; (b) rectangular microchannels [6]

2.3 Numerical simulation

The following assumptions were considered during simulation [6]:

- In compressive fluid and laminar flow;
- Steady fluid flow and heat transfer;
- The effect of gravity force are considered;
- Temperature-dependent fluid properties;
- Negligible radiation heat transfer;
- All solid walls of the channel are no slip and impermeable;
- Negligible viscous dissipation effect.

Table- 1 : Boundary Conditions

Fluid inlet	velocity inlet at 306 k
Fluid outlet	Pressure outlet at 0 pa (gauge)
Bottom surface	Uniform heat flux (w/m^{2}K)
Top surface of fluid	Adiabatic (0 heat flux)
Both outer vertical plane	Symmetry

A computational fluid dynamic code was used to calculate flow velocity, pressure and temperature Finite volume method (FVM) was used to convert the governing equations to algebraic equations accomplished using an “upwind” scheme. The SIMPLE algorithm was used to enforce mass conservation and to obtain pressure field. The segregated solver was used to solve the governing integral equations for the conservation of mass, momentum and energy. Convergence criterion was less than 10^{-3} for the energy equation it was 10^{-6}.

3. MODELLING FOR MANIFOLD MICROCHANNEL ANALYSIS

A multi-pass manifold-microchannel plate heat exchanger consists of numerous flow paths and is far too complex and time consuming to be entirely modelled. Therefore, to simplify the model, only a portion of a heat exchanger consisting of a single pass and a single manifold (SPSM) was modelled. The SPSM model is shown in Figure 3-2. To further simplify, only one side of the heat exchanger was modelled and considered for the calculation of the heat exchanger volume, while the other side is assumed to have the same geometry and flow rate. Manifold-microchannel technology has demonstrated substantial promise for superior performance over state of the art heat exchangers. For the single manifold-microchannel simulation were used to calculate the temperature dissipation and pressure drop. Which was calculated by assuming the mass flow rate is uniformly distributed over all microchannels. The computational domain and boundary condition of the single manifold-microchannel model are shown in Figure 3-2. The manifold channel inlet was set to mass flow rate boundary condition and constant inlet temperature.

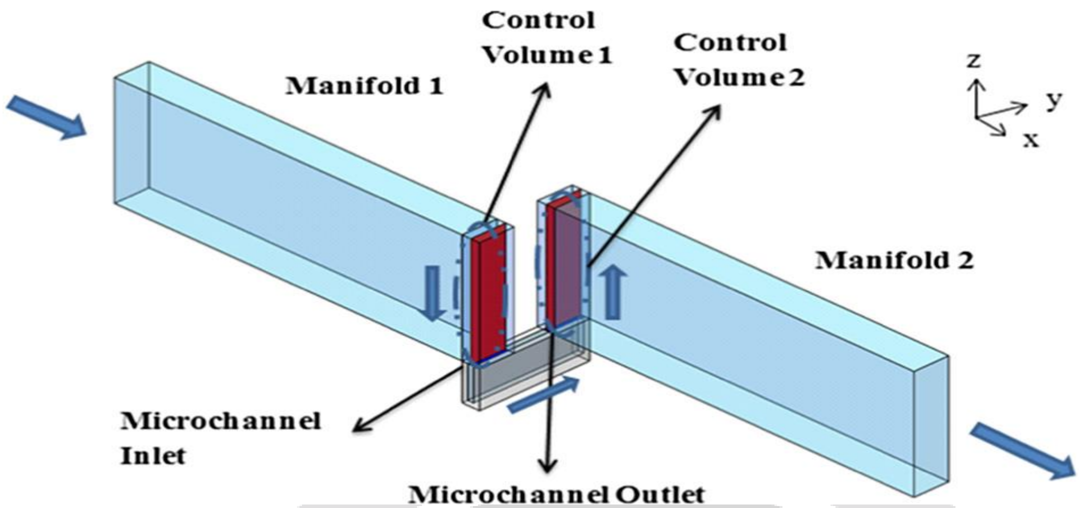

Fig-2: Fluid flow shape in manifold microchannel [34]

3.1 Geometry for the different fluid passage

The dimensions of the fluid flow passage are given in the table for the 300 μm hydraulic diameter [D_h = 300 μm] [6, 16, 32, 34] for the different fluid passage. The microchannels have the fixed value of W_{slot} for the different geometry of fluid section which gives the different hydraulic diameter. After the reference of the Figure 3-1 Shape of the fluid passages are given in the Fig- 3 to Fig-8.

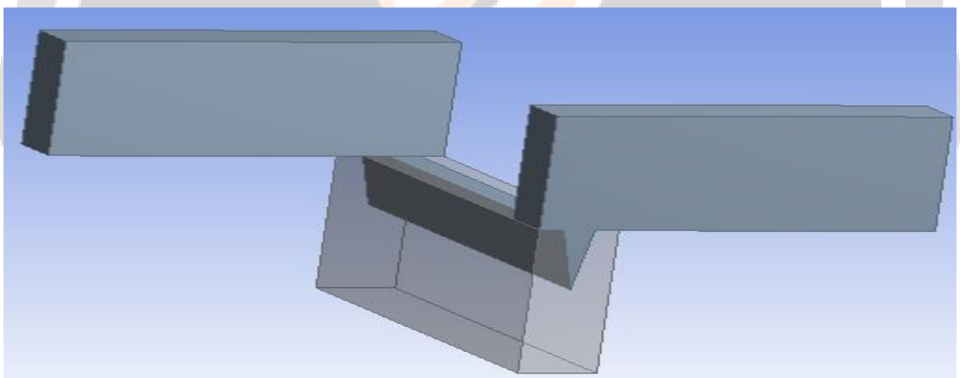

Fig-3: Triangle cross section microchannel

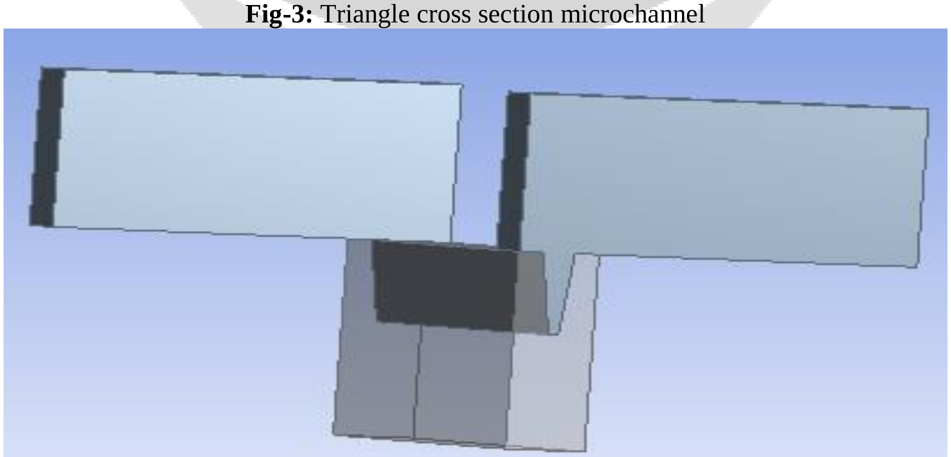

Fig-4: Trapezoidal cross section microchannel

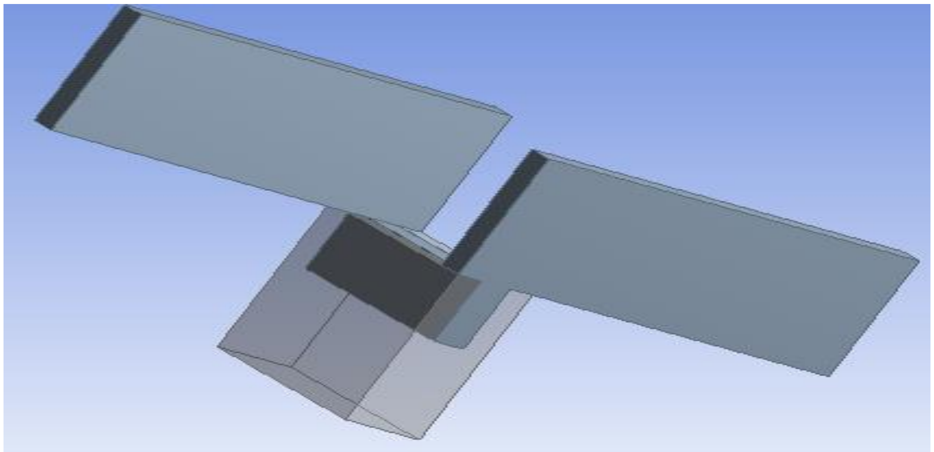

Fig-5: Rectangular cross section microchannel

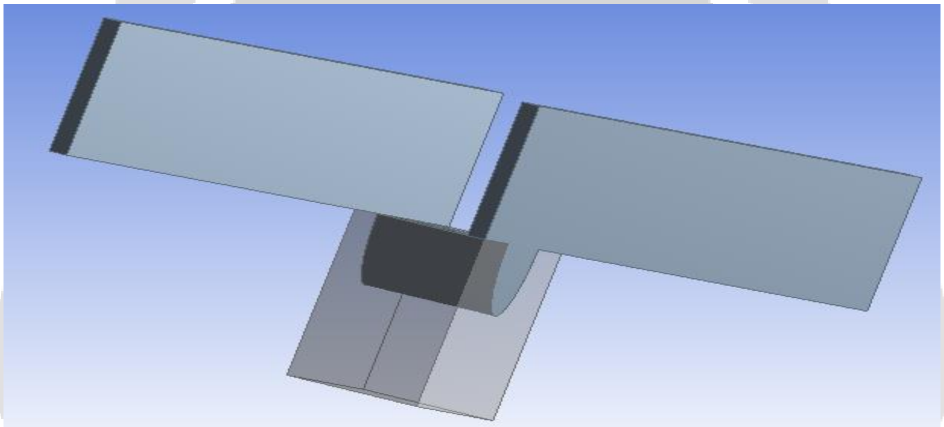

Fig-6: Elliptical cross section microchannel

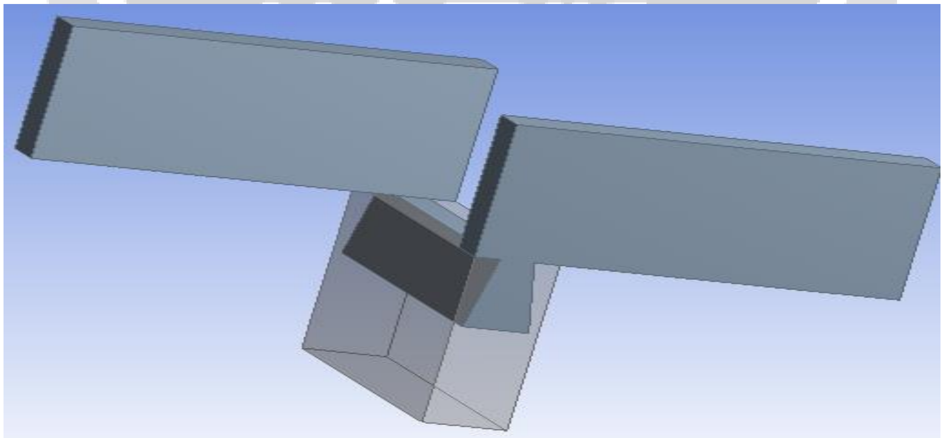

Fig-7: Trapezoidal_V cross section microchannel

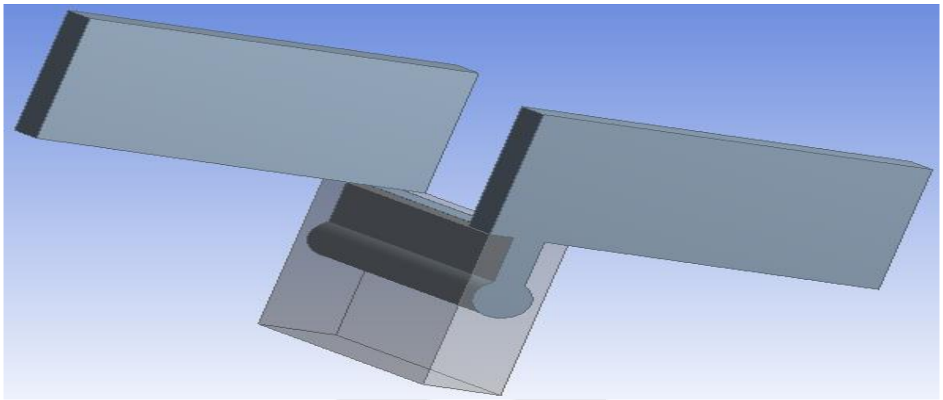

Fig-8: Reentrant cross section microchannel

3.2 The simulation results of the SPSM model

The simulation results of the SPSM model can be expanded to the whole plate surface by considering the total number of passes and manifold channels .The results also can be further expanded into multiple stacks by considering the total number of stacks.

To achieve this, four simplifying assumptions are considered:

1. Mass flow rate in all manifold channels and stacks (in the y and z directions) is uniform.
2. $\Delta T = (T_{base} - T_{in})$ constant over all passes. This assumption is a fair approximation for counter flow heat exchangers.
3. Geometry and volume remain unchanged from one pass into another.
4. Symmetric condition exists for side and top planes of the SPSM model.

4. RESULT AND DISCUSSION

4.1 Results and Validation

Chart-1 shows a comparison of the simulation and experiments results of the average Nusselt numbers for reentrant microchannel with D. Deng et al [2], in which the inlet fluid temperature of 33 °C and the heat flux of 267 kW/m2 are utilized. The variation between the simulation results of present work and that of D.Deng et al [6] is 8.352%.

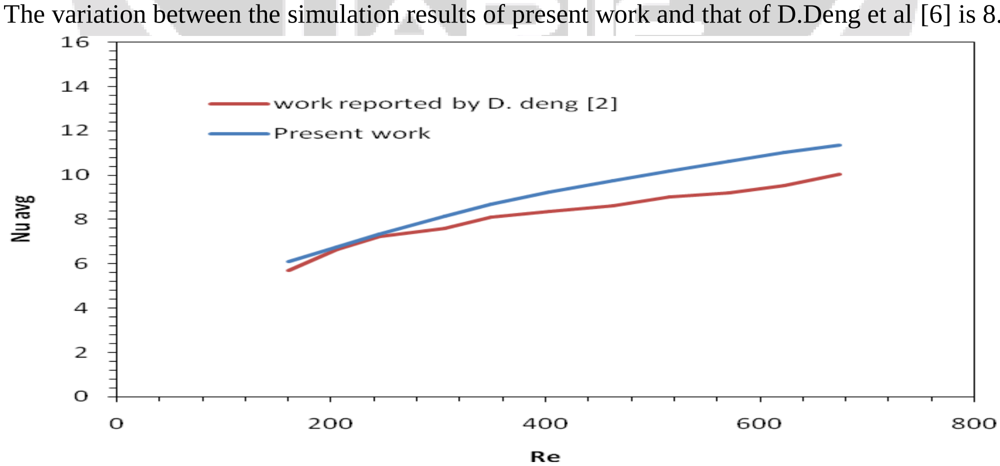

Chart -1: Comparison of Nusselt number versus Reynolds number with D. Deng [6]

Top surface of microchannel is assumed to be adiabatic in the numerical simulations, there may still exist slight heat loss from the fluid to the glass cover in the experiments. The reentrant microchannel induces slightly larger heat loss in the experiments. Therefore, the reentrant microchannel presented slightly larger discrepancies between the experimental results and numerical simulation.

4.2 Temperature Contour

From the graph we can show the variation of the temperature at different point in the fluid flow section and also in the microchannel. Due to different heat flux applied at the bottom surface temperature dissipation in the manifold microchannel increase with increase the value of heat flux.

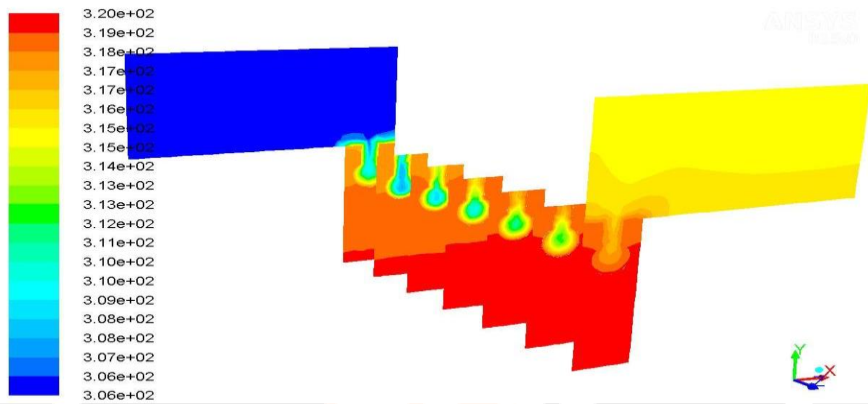

Fig-9: Reentrant cross sectional microchannel Temperature Counter

4.3 Variation in Temperature

Variation and effect for the temperature in the different geometry of fluid passage with same hydraulic diameter is as shown in Chart-2. Value of the temperature can find out from the temperature counter given in Chart-2.

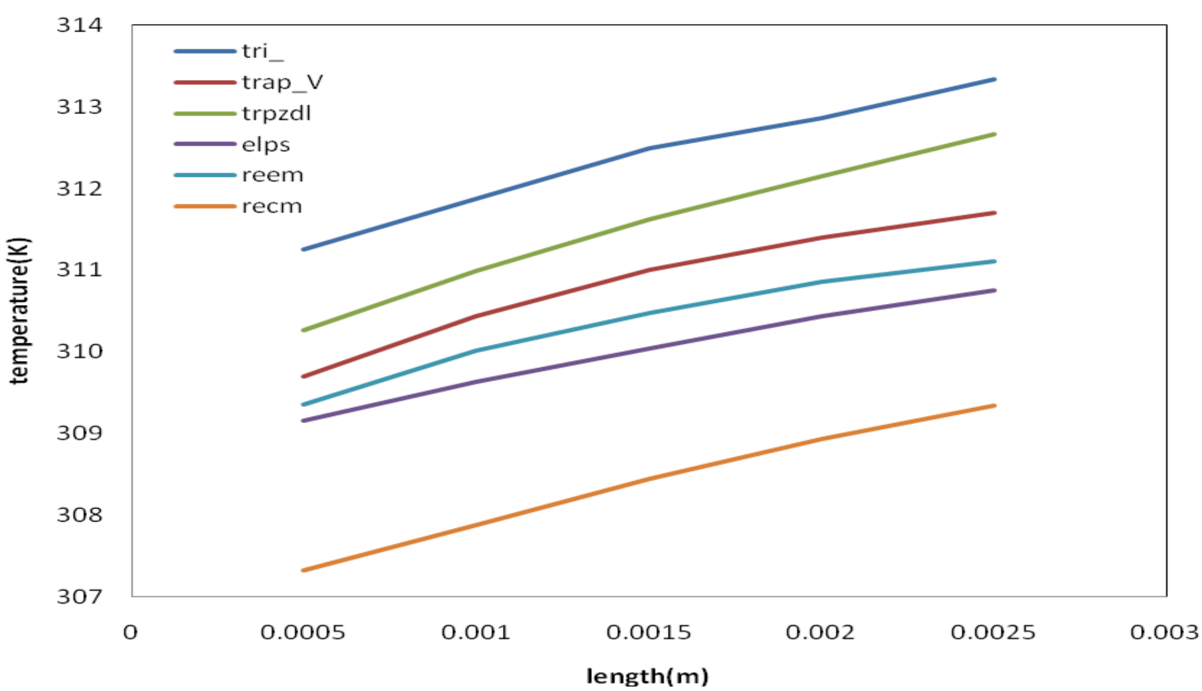

Chart -2: Variation in Temperature with length for different shape geometry

Temperature is increase with increasing the velocity, for higher rate of velocity the temperature difference is higher. The heat transfer enhancement of reentrant micro channels can be attributed to the alteration of flow and thermal behaviour inside the unique reentrant configurations is average as compared to another geometry shape of fluid passage of manifold microchannel. Heat flux is applied at the bottom surface of the microchannel at the inlet velocity and temperature contour for different fluid passage channel geometry is shown in Chart-2.

5. CONCLUSIONS

In the present study the attempt has been made to understand the effect of geometry of microchannel fluid flow passage on the performance of micro channel heat exchanger using the CFD code. Also the concept of manifold by heat transfer rate and pressure drop in micro channel heat exchanger by analysis. Following conclusions can be drowning from the present study.

- Without manifold microchannel Elliptical gives the higher 3.93% pressure drop than other geometry consider in present study.
- With manifold microchannel and without microchannel average re-entrant microchannel gives the better 0.4781% temperature difference comparable to other geometry.
- Re-entrant shape with manifold microchannel gives best performance followed in the trend Triangular channel, Trapezoidal channel, Rectangular channel, Trapezoidal_V channel, and Elliptical channel.

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