Double Layer Microchannel with Liquid Water Flow in Both Channel

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Abstract:- The performance of liquid water in the double layer microchannel has been analysed using three-dimensional conjugate heat transfer analysis. The effect of flow rate on the counter and parallel arrangement of each fluid is studied for three different lengths. Furthermore, cooling capability of liquid water is compared at the same length with flow rate and pumping power as governing parameters. The performance of fluid was judged on the basis of maximum temperature attained and minimum temperature variations at the heated region. Interesting results have been found showing the effect of specific heat on the type of arrangement for liquid water with similar observation for water for low Reynolds number and relatively longer length. Among liquid water, above certain pumping power use of liquid water is found to be favourable for a shorter length of the double layer microchannel. Furthermore, the range of flow rate and pumping power showing superior performance with water was found to increase with the length.

***Keywords**: Microchannel, Axial Heat Conduction, Conjugate Heat Transfer, Thermally Developing Flow, Optimum Nusselt Number.*

I. INTRODUCTION

In recent times, the demand for high computational speed has increased significantly. With market forces pushing for miniaturization and high performance, the current trend in microprocessor architecture has focused on shrinking the processor size, use of high-speed transistors, and increasing clock speeds (higher frequency) which has escalated power density levels [1]. Despite reduction in the voltage levels and capacitance with miniaturization, there has been a substan-tial growth in the spatial density and operating frequency of the microelectronic devices. According to the Interna-tional Technology Roadmap for Semiconductors (ITRS), peak power consumption in high performance desktop applications will rise to 198 W by 2015 [2]. High current values also generate large amount of heat due to Joule heating, (defined as I^2R , where is I current and R is resistance), within the electronic package and interconnection systems. These factors tend to increase operating temperatures above desired limit and thereby degrading the performance of active and passive components. Ram Viswanath et al. [3] described the need to maintain low operating temperature for two reasons. Firstly, the reliability of circuits (transistors) is exponentially dependent on the operating temperature of the junction. Secondly, microprocessors can operate at higher speeds at lower operating temperatures. These requirements have created demand for more efficient thermal manage-ment.

The conventional methods such as air-cooling, heat pipes, vapour chambers, jet impingement, and thermoelectric cool- ing [4–9] seem to have reached their practical limits creating the need for new cooling techniques. For power dissipation by heat fluxes above 1 MW/m2, liquid immersion and liquid cooling using microchannel cooling device are the most suitable [10]. However, direct integration of microchannels on the heat-generating substrate prevents any thermal contact resistance which makes them favourable over other solutions available in the same heat flux range. High heat transfer phenomenon in microchannels is attributed to their reduced boundary layer thickness and increased heat transfer area to volume ratio. In addition, temperature gradients in the substrate are considerably reduced. Furthermore, very high heat transfer coefficients of the order of 103 W/m2K or more are possible owing to significantly smaller hydraulic diameter in case of microchannels.

II. ANALYSIS

Computational Model. Figure 1 shows double-layer microchannel heat sink along with the coordinate system. Counter and parallel arrangements are depicted using arrows along the flow direction. The three-dimensional computational domain is illustrated in Figure 2. Owing to symmetry conditions, only half of the double layer microchannel has been included in the computational domain. Origin of the coordinate system is assumed to be at the center of the base of the upper heat sink. The cross section of the geometry used in this analysis is the same as that

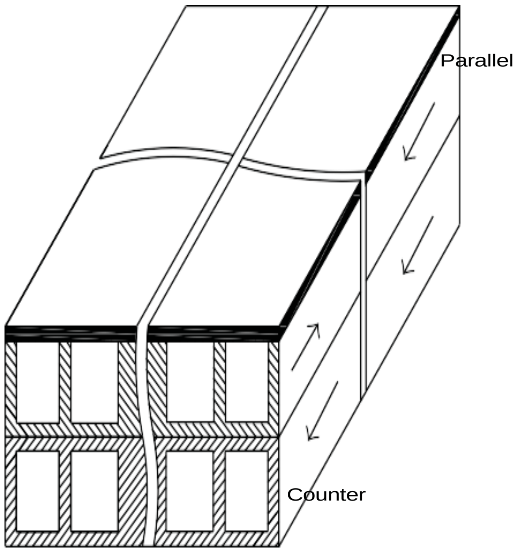

Fig 1 Schematic of Double Layer Microchannel

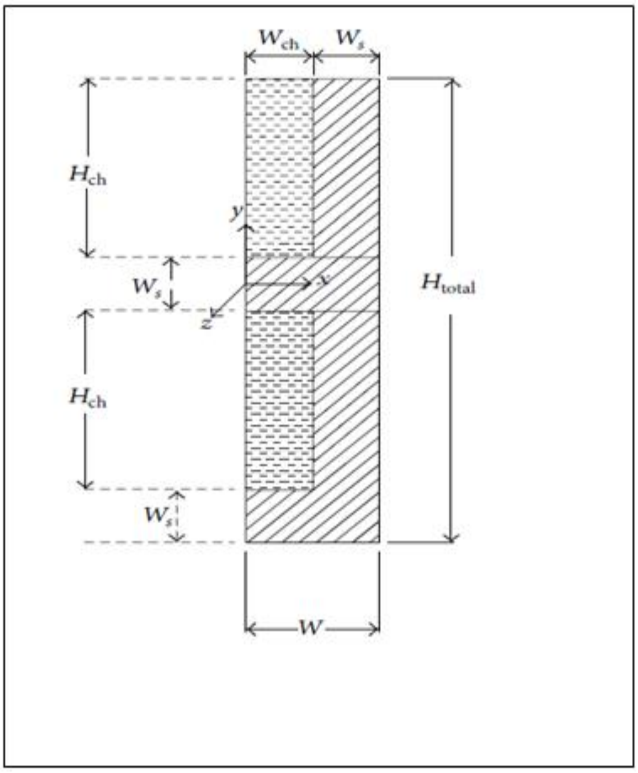

Fig 2 Three-Dimensional Computationalmodel used in Analysis

- Width of solid domain (Ws)=0.8 mm
- Width of fluid domain (Wf)=0.4 mm,0.4mm Depth of solid
- domain =1.2mm
- Depth of fluid domain =0.4mm,0.4mm
- Length=50 mm
- Total vertical height=2mm
- Total horigental length=1.2mm
- Hydraulic diameter=0.4 mm
- Here fluid is water whose conducity is 0.6 W/mK and solid is
- Aluminium whose conducity is 237W/mK

➢ *The Analysis is Based on the Following Assumptions:*

- Steady state flow
- Incompressible fluid.
- Laminar flow.
- Constant properties of both fluids and solid.
- Effects of viscous dissipation are negligible.

➢ *Governing Equations:*

Continuity equation:
$\nabla \cdot \vec{V} = 0$ (1)

Momentum equations:
$\rho\, [\partial \vec{V} / \partial t + (\nabla \cdot \vec{V})\vec{\ }] = -\nabla p + \mu \nabla^2 \vec{V}$ (2)

Energy equation:
$\rho f c f\, [\partial T / \partial t + \vec{V} \cdot \nabla T] = \nabla \cdot kf$ (3)

Energy equation for the solid,
$ks \nabla^2 Ts = 0$ (4)

➢ *Boundry Condition:*

- Heat flux=5.83*10^{11}
- Re no =50, Inlet velocity=0.1253m/s
- Re no =100,Inlet velocity=0.25m/s
- Re no=200,Inlett velocity=0.50m/s
- Outlet pressure=0
- Heat generated through bottom surface
- Solid = Aluminium
- Fluid = water
- Both channel water is flow

III. RESULTS AND DISCUSSION

➢ *Straight Microchannel With Double Flow:*

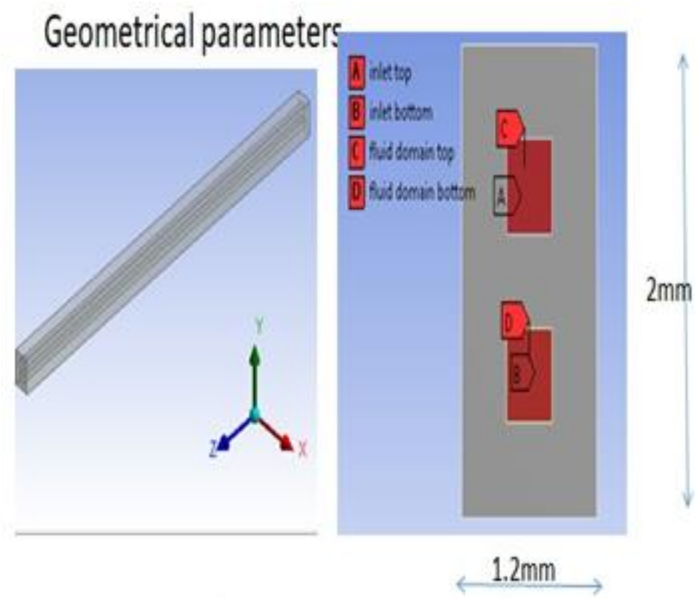

Fig 3 Geometrical Parameters

➢ *Parallel Flow:*

- *In this Case Both Fluid Moves in Same Direction*

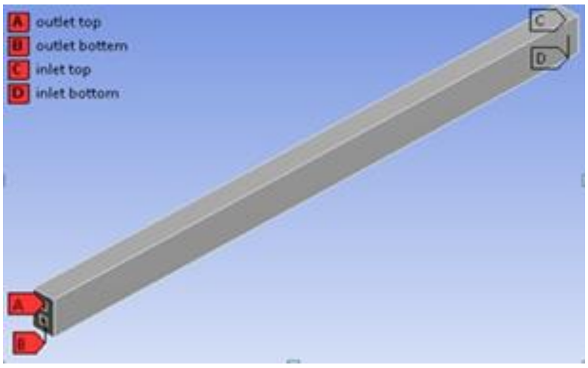

Fig 4 Geometry

Length	Grid size Size 1	Size 2	Size 3
1	12×52×75	24×66×100	30 ×104 ×150
2	12×52×75	24×66×150	30 ×104 ×200
3	12×52×100	24×66×250	30 ×104 ×400

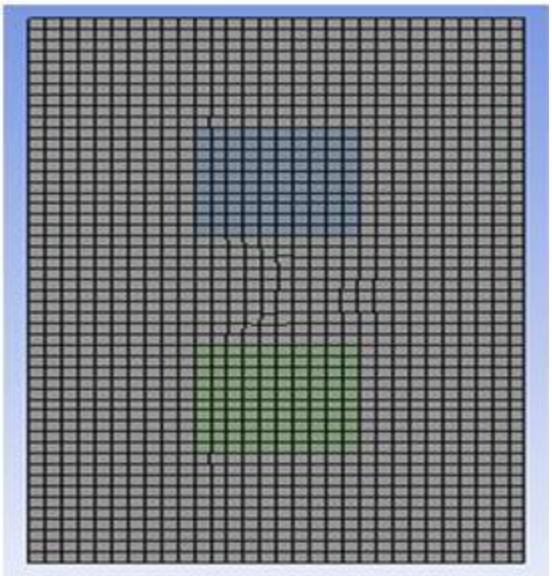

Fig 5 Mesh

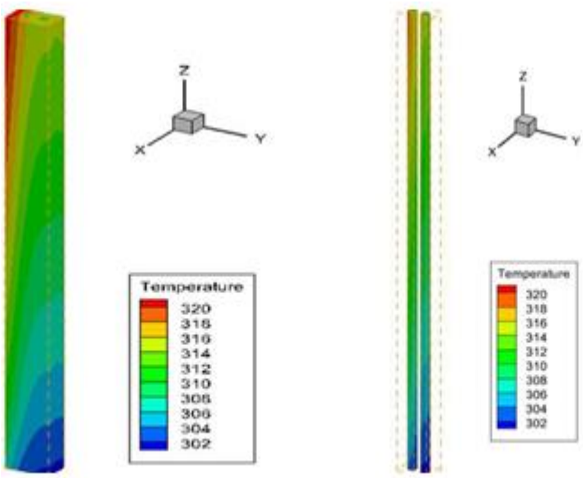

Fig 6 Temperature Contours

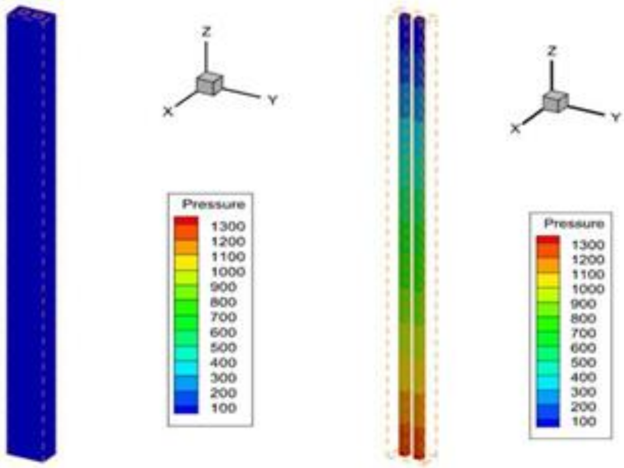

Fig 7 Pressure Contours

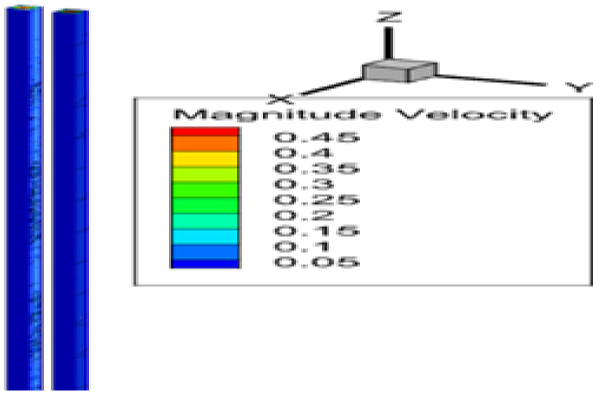

Fig 8 Velocity Contours

- Non Dimensional Parameter

$$\phi = \frac{\overline{q'_z}}{\overline{q'}}, \quad \delta_{sf} = \frac{\delta_s}{\delta_f}, \quad z^* = \frac{z}{\mathrm{Re}\,\mathrm{Pr}\,D_h}, \quad \mathrm{Nu}_z = \frac{h_z D_h}{k_f},$$

$$\Theta = \frac{T - T_i}{T_o - T_i}, \quad \Theta_f = \frac{T_f|_z - T_{fi}}{T_{fo} - T_{fi}}, \quad \Theta_w = \frac{T_w|_z - T_{fi}}{T_{fo} - T_{fi}}$$

➢ *Axial Variation of following*

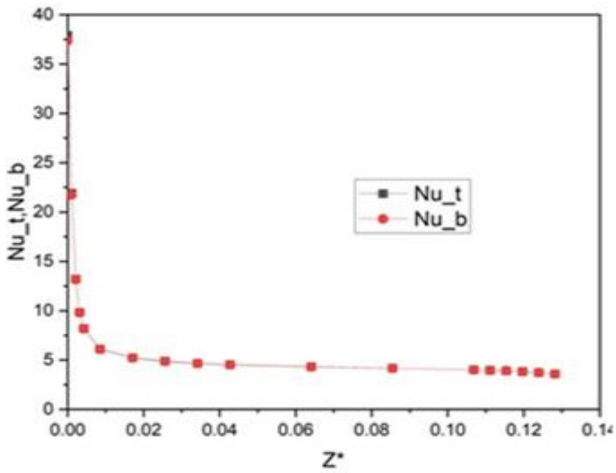

Fig 9 Graph between Nu no and Z*

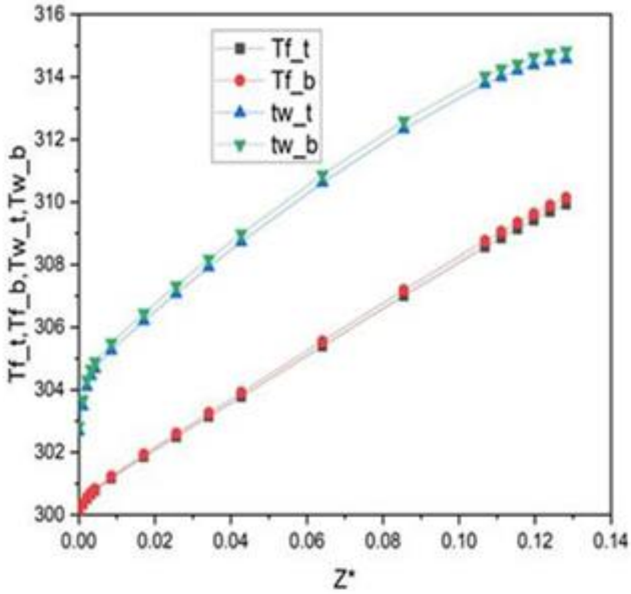

Fig 10 Graph between Temp of Fluid, Wall and Z*

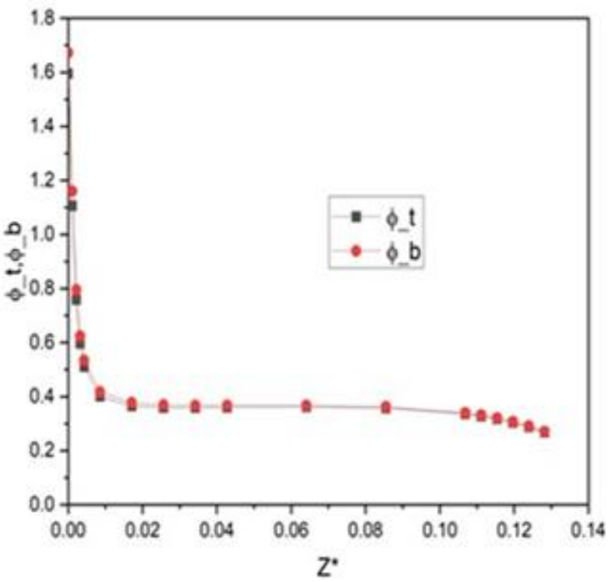

Fig 11 Graph between Phi and Z*

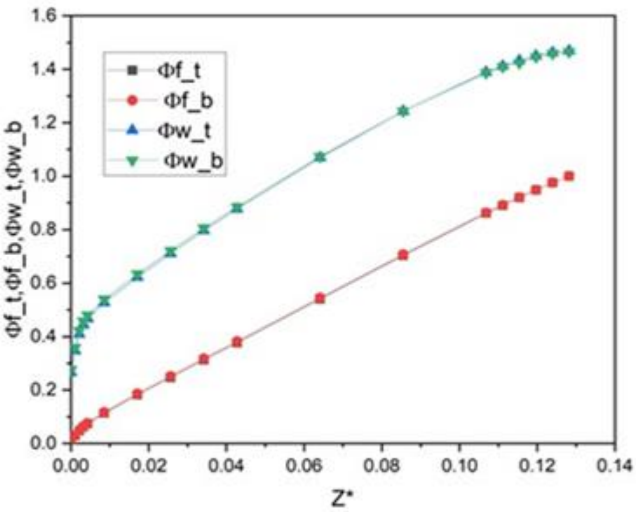

Fig 12 Graph between Theta and Z*

➢ *Counter Flow:*

- *In this Case Fluid in Both the Channel Moves in Opposite Direction*

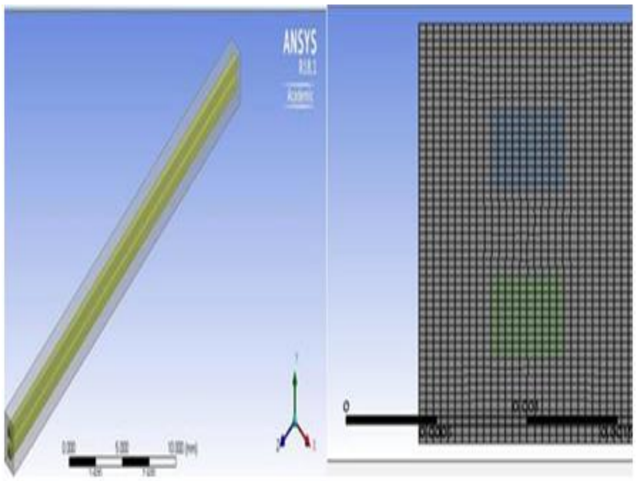

Fig 13 Geometry, Mesh

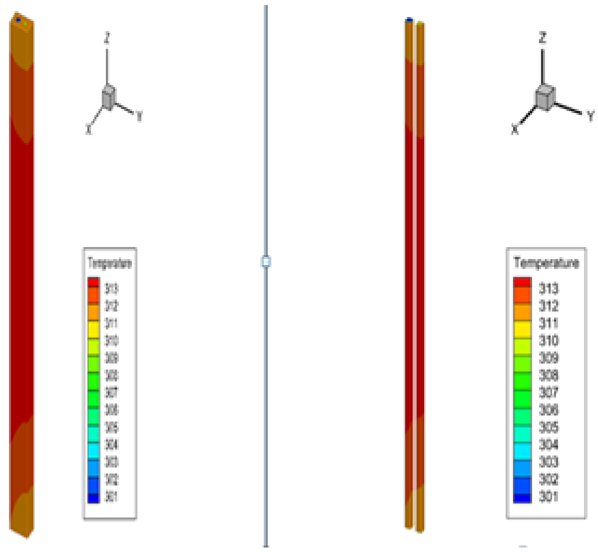

Fig 14 Temperature Contours

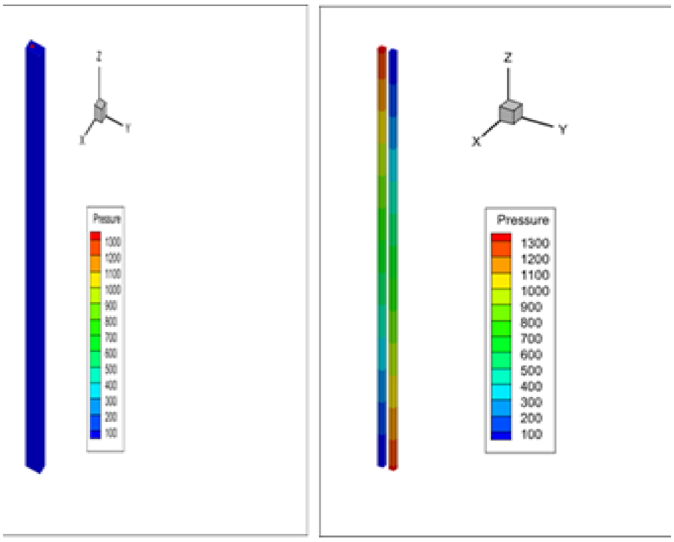

Fig 15 Pressure Contours

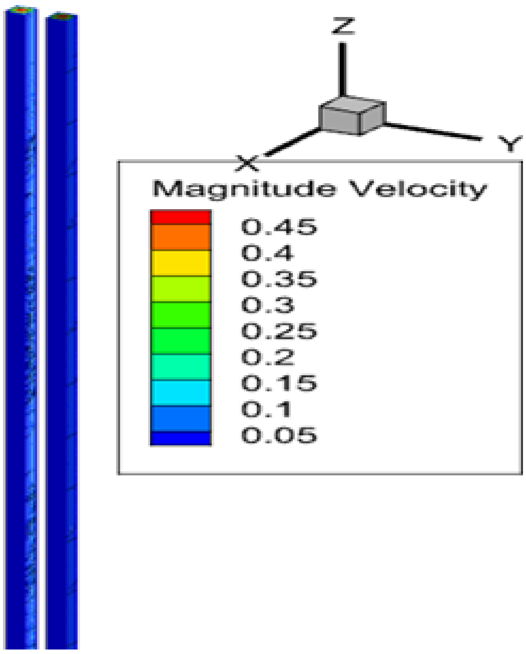

Fig 16 Velocity contours

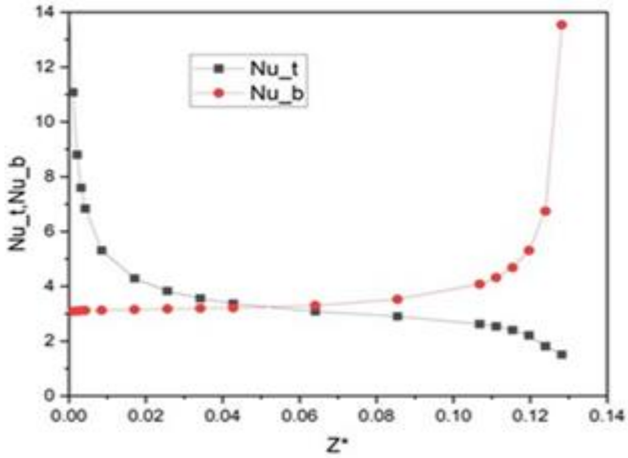

Fig 17 Graph between Nu no and Z*

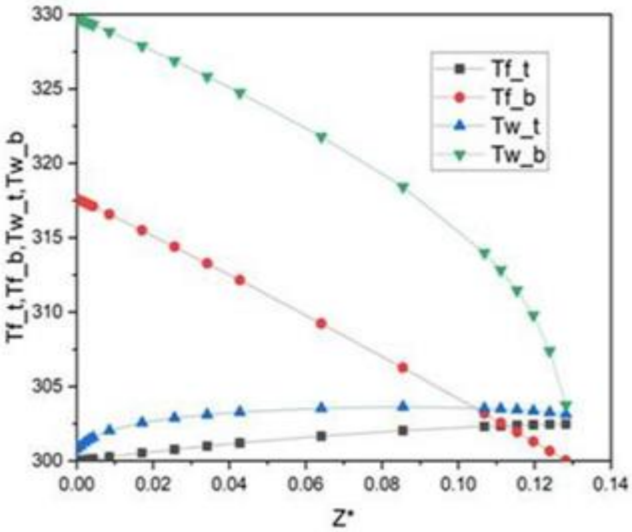

Fig 18 Graph between Temp of Fluid, Wall and Z*

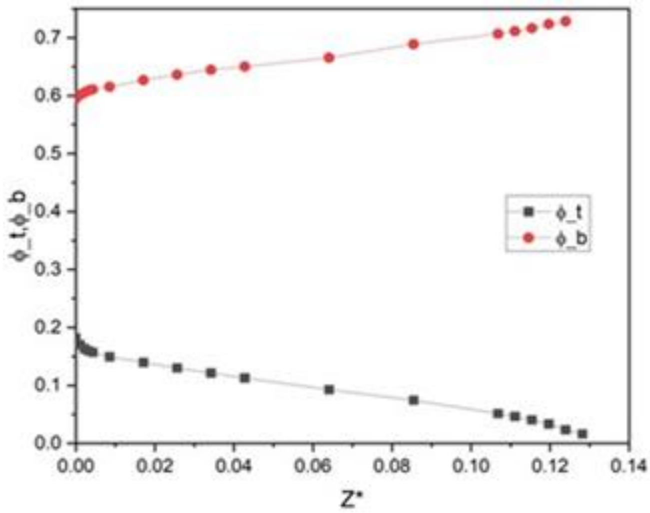

Fig 19 Graph between Phi and Z*

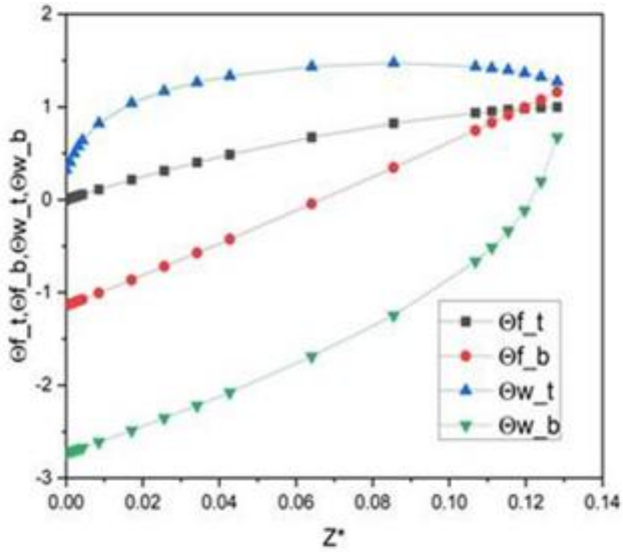

Fig 20 Graph between Theta and Z*

IV. CONCLUSION

The performance of water in water type of configuration is found to be dependent on microchannel length. For longer channels, 5000 μm in this study, parallel configuration is suitable at low flow rate. Poor performance of counter configuration is due to increase in fluid temperature above base temperature.

These observations indicate a significant effect of specific heat of the fluid on its cooling capacity.With pumping power as input criteria, use of liquid was found to be worthy only beyond a critical pumping power. Moreover, critical pumping power was found to increase with length of the double layer microchannel. This suggests the use of liquid for small double layermicrochannel. For longer length, large pumping power may result in transition from laminar to turbulent region, which needs further investigation. The results indicate that fluid density is also an important parameter in fluid selection under given conditions of the double layer microchannel. In terms of temperature uniformity, water out performed liquid in all the cases considered.

➢ *Nomenclature*

- a: Cross-sectional area
- CF: Counter flow
- DUC: Hydraulic diameter of upper channel
- DLC: Hydraulic diameter of lower channel
- h: Heat transfer coefficient (Wm−2 K−1)
- Hch: Channel height
- Htotal: Computational domain height
- HM: Middle line of lower channel
- LC: Lower channel
- LM: Middle line of lower channel
- P: Pressure (Nm−2)
- PF: Parallel flow
- PP: Pumping power
- Pr: Prandtl number
- F: Flow rate in a channel (m3 s−1)
- q: Heat flux applied at base (Wm−2)
- $q$pos: Positive heat flux at solid wall (Wm−2)
- $V$1: Total positive heat flux at wall $V$1
- Re: Reynolds number
- Rth: Thermal resistance (KW−1 m2)
- S: Perimeter of a channel
- T: Temperature (K)
- Tf,in: Inlet fluid temperature
- UC: Upper channel
- UM: Middle line of upper channel along
- $\vec{V}$ Velocity vector(ms−1)
- $V$1: Vertical wall of solid region
- K : Thermal conductivity (Wm−1 K−1)
- α: Thermaldiffusivity
- δ: Boundary layer thickness
- ρ: Density (kgm−3)
- μ: Dynamicviscosity(Nsm−2)

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