Numerical Prediction of Heat Transfer of Commercial R12 Coolant Through Different Cross-Section Microchannels of Same Hydraulic Diameter

Gourab Chakraborty, Shubhankar Sarkar, Pritam Chatterjee, Soupam Samanta Arunabha Chanda

Abstract: Microchannels are the next step for current heat exchangers and probably the most effective cooling technique for recent miniaturized electronic components. Five different shapes of pipes (rectangular, circular, triangular, semi-circular & trapezoidal) of same hydraulic diameter are taken into consideration for this numerical investigation. One industrial coolant namely R12 is passed through the above-mentioned channels. This numerical investigation seeks to find out which section shape is the best suitable one for two phase heat transfer phenomenon. The present work is validated with the experimental work of Liu, Lee & Garimela where water is used as a coolant and passed through a rectangular channel and the numerical simulation is carried out with the help of commercial Ansys software. The current investigation aims to link the applicability of commercial coolants in the field of microchipping. This study will help electronics cooling industries by pinpointing the enhanced heat transfer phenomenon through microchannel where microchannel geometry and coolant both play a crucial role apart from the material itself.

Keywords: Microchannel, CFD, Coolant performance, Heat transfer, Hydraulic diameter.

I. INTRODUCTION

Microchannel industry is rapidly growing, and lot of varieties of microchannel are available in the market. This variety are observed due to their respective properties, eg: Shapes, temperature withstand capacity and materials. This work is purely based on the work Liu, Lee & Garimella[1] where they investigated the onset nucleate boiling under various flow conditions. The microchannel is dimension of 275 μm width and 636 μm depth. The work of Zhang, Kang & Xu[2]. Where they studied the heat transfer of non-Newtonian power law fluid in pipe in different cross section is another pillar for this numerical investigation.

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Shanglong XU*, Yihao WU, Qiuy CAl, Lili YANG, and Yue LI[4] have done optimization of silicon microchannel with multi-layer thermal perfomence. H. Zhang,T. Xu[3], this work is done with elbow pipes for non-Newtonian fluids. In this work, simulation process is used to determine the heat transfer and heat flux values of cross section microchannel [5]

Thus, the thermal conduction along flow direction and radial direction and viscous dissipation are considered in this model. The mixed density is average by the volume fraction.

Momentum Equation

$$\frac{d\rho f}{dt} + \frac{\partial}{\partial x_i} (\rho f u_i) + S = 0$$

(1)

Energy Equation

$$\frac{d}{dt} \left[ \frac{c_p}{\rho f} \frac{\partial (\rho f u_i^2)}{\partial x_i} \right] + \frac{\partial}{\partial x_i} \left[ \frac{c_p}{\rho f} \frac{\partial (\rho f u_i \theta)}{\partial x_i} \right] = \frac{\partial}{\partial x_i} \left[ \frac{\partial (\rho f u_i \theta)}{\partial x_i} \right] + F$$

(2)

$$\frac{\partial}{\partial x_i} \left[ \frac{c_p}{\rho f} \frac{\partial (\rho f u_i \theta)}{\partial x_i} \right] = \frac{\partial}{\partial x_i} \left[ \frac{\partial (\rho f u_i \theta)}{\partial x_i} \right] + F$$

(3)

I. MATHEMATICAL MODEL

A 3D compressible laminar flow model is designed as the flow is flowing through continuum, Where the Knudsen number is less than 10^{-3}. Knudsen number is defined as the ratio of the mean flow path of fluid molecules to the characteristics dimension. Here the flow is continuum, the Naviers Stroke equation and no sleep boundary condition indicated the conjugated effect of wall conduction. Fluid axial conduction can be derived simultaneously by developing laminar flow [7] and heat transfer in Microchannels. [8]. Thus, the thermal conduction along flow direction and radial direction and viscous dissipation are considered in this model.
\[ p_f = p_f \alpha_j + p_v \alpha_v \]  
(4)

Fully developed flow through channels, heat transfer coefficient can be written as

\[ h = \frac{\theta_f}{T_w - T_s} \]  
(5)

This approach has the advantage of preventing the need to calculate pressure and eliminating the coupling between Continuity and Momentum equations. Axial condition in the fluid on heat transfer of microchannel, assuming the energy dissipation is negligible.

### II. NORMALIZED TEMPERATURE PROFILE

If we plot the value obtain by the temperature, the temperature profile is shown in figure.

**Figure 1a:** Temperature plot of ZvS, (Z=100)

**Figure 1b:** Temperature plot of Z&S, (Z=10)

**Figure 1c:** Temperature plot of Z&S, (Z=1)

Here the microchannel are depended into two dimensionless group where as velocity profile is depended in single parameter. The shape of the velocity profile changes to parabolic corresponding to Poiseuille flow (Z<1) where Z & S are the function of normalized temperature profile. low Peclet numbers, axial conduction may be important, it increases the Nusselt number. While interreacting with microchannel we have simplified the velocity solutions obtain the instantaneous mean fluid velocity,

\[ \beta = \frac{\mu}{k} \left[ \frac{U_s}{H(1+2Kn)} \right] \]  
(6)

with the all liquid flow in the laminar region the corresponding all liquid flow Nusselt number is given

\[ Nu_{LO} = \frac{h_{LO} D_R}{k_L} \]  
(7)

Where the constant is dependent on the channel geometry and the wall thermal boundary condition.

### III. GEOMETRICAL MODEL

Different cross section models are shown in figure.

**Figure 2a:** Rectangular Cross-section Geometry

**Figure 2b:** Circular Cross-section Geometry

**Figure 2c:** Semi-circular Cross-section Geometry

**Figure 2d:** Trapezoidal Cross-section Geometry

**Figure 2e:** Triangular Cross-section Geometry

Different cross section models are shown in figures. Their Dimensions are tabulated below.
Table 1 Different cross section geometrical model with equivalent diameter and length

<table>
<thead>
<tr>
<th>Geometry model</th>
<th>Equivalent diameter</th>
<th>Microchannel length()</th>
</tr>
</thead>
<tbody>
<tr>
<td>circular</td>
<td>0.1 μm</td>
<td>0.8 μm</td>
</tr>
<tr>
<td>half circle</td>
<td>0.1 μm</td>
<td>0.8 μm</td>
</tr>
<tr>
<td>rectangle</td>
<td>0.1 μm</td>
<td>0.8 μm</td>
</tr>
<tr>
<td>triangular</td>
<td>0.1 μm</td>
<td>0.8 μm</td>
</tr>
<tr>
<td>trapezoidal</td>
<td>0.1 μm</td>
<td>0.8 μm</td>
</tr>
</tbody>
</table>

Table 2. Mesh properties of different cross section geometrical model with equivalent diameter

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Nodes</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular</td>
<td>2496</td>
<td>1887</td>
</tr>
<tr>
<td>Half circle</td>
<td>1305</td>
<td>880</td>
</tr>
<tr>
<td>Rectangle</td>
<td>189</td>
<td>80</td>
</tr>
<tr>
<td>Triangular</td>
<td>380</td>
<td>228</td>
</tr>
<tr>
<td>Trapezoidal</td>
<td>240</td>
<td>114</td>
</tr>
</tbody>
</table>

The Influence Of Section Shape & Nephogram Of Coolants

The analysis of different microchannel with various geometrical configuration for different coolants are performed. It has been found that peak temperature is obtained on parallel flow condition through microchannel. On the basis of simulation result obtained by analyzing the various shape of microchannel though different microchannel is observed and their profile is shown in the Figure 3(a,b,c,d,e), which indicates the nephogram of R12 fluid.

Figure 3a: Circular Temperature Profile

Figure 3b: Semi-circular Temperature Profile

Figure 3c: Rectangular Temperature Profile

Figure 3d: Trapezoidal Temperature Profile

Figure 3e: Triangular Temperature Profile

Microchannel flow characteristics of capillaries are very much different to characteristics of larger microchannel flow. In circular microchannel the condition of flow is leading to annular flow, which is commonly accepted approach in the microchannel flow. Where in the rectangular microchannel the flow is in transition from slug flow to annular flow. Similarly, triangular flow also has same flow behavior of rectangular microchannel, the flow is also in transition phase from slug to annular flow. According to the turbulence point of view of microchannel the bubbly flow regime has much higher superficial velocities, which implies the bubbly flow regime could be generated in very short distance over the microchannel, which will lead to frictional pressure drop.

Table 3: Comparison of Boiling Heat transfer Rate of Water & R12 Coolants of various shapes

<table>
<thead>
<tr>
<th>Shape</th>
<th>Heat transfer Rate (W/cm²) water</th>
<th>Heat transfer Rate (W/cm²) R12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circle</td>
<td>0.001175561</td>
<td>0.0002756156</td>
</tr>
<tr>
<td>Semi-circle</td>
<td>0.003420678</td>
<td>0.0001256904</td>
</tr>
<tr>
<td>Rectangle</td>
<td>0.00040108186</td>
<td>0.0001039971</td>
</tr>
<tr>
<td>Trapezoidal</td>
<td>0.00070111689</td>
<td>0.0001715533</td>
</tr>
<tr>
<td>Triangle</td>
<td>0.00114894527</td>
<td>0.00441217887</td>
</tr>
</tbody>
</table>

IV. EFFECT OF DIMENSIONLESS NUMBERS

Nusselt number is ratio of convective to conductive heat transfer. Where convection is combination of advection of fluid and diffusion. Nusselt nu has major importance on any flow regime. Where peclet no is ratio of advective transport rate to the diffusive transport rate. The general characteristics of microchannel fluid flow can be determined for given heat transfer between working fluid and the wall. According to governing equation correlation is introduced in the microchannel fluid flow.

Knudsen number is influencing the rarefaction on the fluid. Along with the compressibility of the liquid is change due to shape of microchannel. Basically, all continuum assumption is hard to implied.
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on the microchannel fluid flow because of its rarefaction properties. As density gets less due to Knudsen number effect heat flux values get increases in the microchannel.

![Graph](image)

**Fig 4 : Comparison of Nusselt and Peclet Number of Water & R12 through Different Cross Section**

The minimum heat transfer with rectangular geometry is 0.0001039971 (for R12). Semi circular geometry is preferable over the rectangular geometry, with better heat transfer (0.0001256904 for R12 fluid). The microchannel heat sink is more effective with Higher heat transfer. Remaining shapes are also taken in account for Heat transfer simulation resulting the computational result is triangular microchannel is most preferable surpassing the circular microchannel & trapezoidal microchannel. Similar observation shows for H2O, the preference of order is; Semi-circular, circular, trapezoidal, triangular & rectangular. Thus lower heat transfer from both cases is Rectangular microchannel is least preferable for microchannel cooling & optimization.

Here two fluids are considered in various shapes of microchannel. The various heat transfer rate is observed from various geometry in the microchannel it has been found the computational result stay in well agreement with the theoretical results.

**V. CONCLUSION:**

Temperature distribution profile of the pipe with various cross section can be described as wall temperature highest and core direction relatively lesser than wall. At the entrance section of the geometry temperature relies upon on the cross section.

![Graph](image)

**Fig 5: Response surface of Various Cross section microchannel with Coolants**

Variation in Nusselt number (Nu) in all respective cross section is much more identical. Result has also shown Nu increases with the rise of Peclet Number (Pe)

![Graph](image)

**Fig 6 : Normal plot of the Residuals, Rising of Nusselt Number**

In our Investigation, we came to conclusion that Nusselt number decreases respective of increasing nature of microchannel length irrespective of their cross section and finally it tends to steady.

**Fig 7 : Influence of Nusselt number in cross section contour**

<table>
<thead>
<tr>
<th>Coolant</th>
<th>Shape of best suitable microchannel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Semi-circular</td>
</tr>
<tr>
<td>R12</td>
<td>Triangular</td>
</tr>
</tbody>
</table>

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**REFERENCES**

8. Fluid Flow, Heat Transfer and Boiling in Micro-Channels

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Author has completed his post graduate study from National Institute of Technical Teachers’ Training & Research (NITTTR), Kolkata in the year 2011. Soon after his post-graduation he joined Brainware Group of Institutions, Barasat as the capacity of Assistant Professor. The author is keen in continuing his research work on the topic of Microchannel fluid flow and heat transfer. The topic has its own variety in the field of MEMS applications as well as aerospace and other different industries.

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Author currently final year student of Brainware Group Of Institutions, the department of Mechanical engineering. Author has completed his secondary education from the school of Ushumpur Adarsha Uchcha Vidyalaya with 77% marks from the board of West Bengal Board Secondary Education & also completed higher secondary education from that same institutions with 68% marks from the board of West Bengal Council Of Higher Secondary Education. The research interest of the author includes Numerical Simulation of Thermo-Fluid behavior in different domain. The author is currently supervised by Mr. Gourab Chakraborty, assistant professor, Brainware Group Of Institutions & also Member of Institutions of Engineers (India) on the topic of Micro-Fluidic flow behavior. Author is currently occupied with the algorithm of mathematical modeling in Micro-fluidic Heat transfer & it’s related other industrial applications. The author again extends his thankful regards to his supervisor for assigning the insightful topic.

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