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

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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 microchip cooling. 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. Shanglong XU*, Yihao WU, Qiyu CAI, 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] The cross sections are, Circular, half circular, triangular, rectangular and trapezoidal [6]. Dichlorodifluoromethane (R-12) is used because its desired properties, R-12 is a fairly versatile refrigerant that is used for vast range of refrigeration and air conditioning functions even though in many air conditioning purposes it is now changed R22 as a refrigerant. Refrigerant R12 is used in home fridges and freezers, liquid chillers, dehumidifiers, ice makers, water coolers, water fountains and transport refrigeration. The huge vary of purposes of the refrigerant are due to its secure residences. For comparison water is also passed through same microchannel.

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.

$$\frac{\partial p_f}{\partial t} + \frac{\partial}{\partial x_i}(p_f u_i) + S = 0 \quad (1)$$

Momentum Equation

$$p_f \frac{\partial u}{\partial t} + \frac{\partial}{\partial x_i}(p_f \mu_f u_i) = \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_i}\left[\mu_f \frac{\partial u_i}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right] + F \quad (2)$$

Energy Equation

$$p_f c_p \frac{\partial T}{\partial t} + \frac{\partial}{\partial x_i}(p_f c_{pf} u_i T) = \frac{\partial p}{\partial x_i}\left(\frac{\partial T}{\partial x_i} k_f\right) + \mu_f\left[2\left(\frac{\partial u_i}{\partial x_j}\right)^2 + \left(\frac{\partial u_i}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right)^2\right] + \Phi \quad (3)$$

The mixed density is average by the volume fraction.

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$$p_f = p_f\alpha_j + p_v\alpha_v \quad (4)$$

Fully developed flow through channels, heat transfer Co-efficient can be written as

$$h = \frac{-k\frac{\partial T(H)}{\partial y}}{T_m - T_s} \quad (5)$$

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,

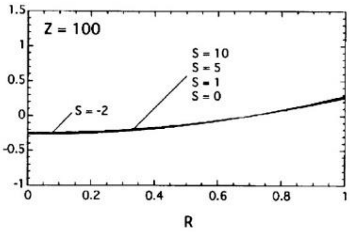

Figure 1a: Temperature plot of ZvS, (Z=100)

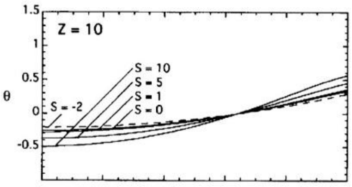

Figure 1b: Temperature plot of Z&S, (Z=10)

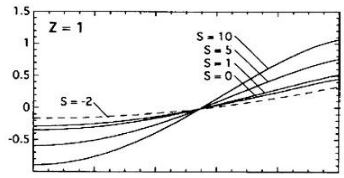

Figure 1c: Temperature plot of Z&S, (Z=1)

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,

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

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

$$Nu_{Lo} = \frac{h_{Lo} D_h}{k_L} \quad (7)$$

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.

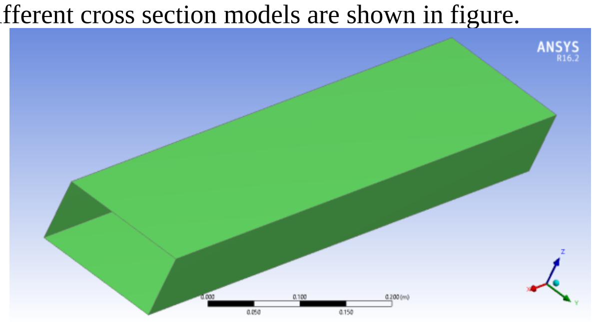

Figure2a: Rectengular Cross-section Geometry

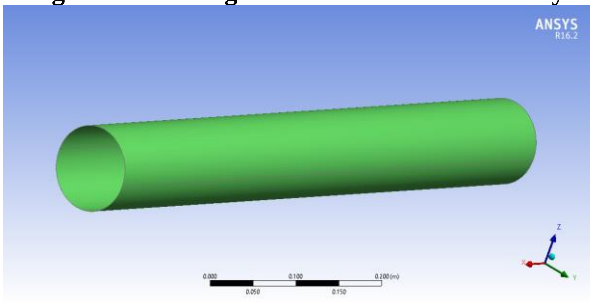

Figure 2b: Circular Cross-section Geometry

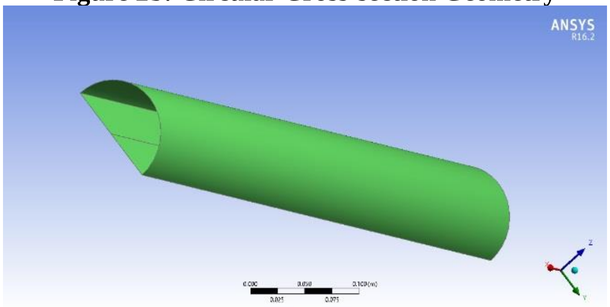

Figure 2c: Semi-circular Cross-section Geometry

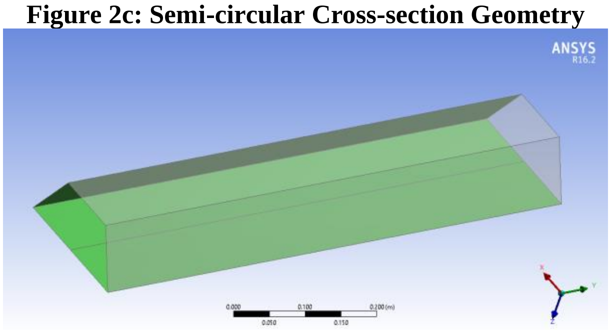

figure 2d:Trapezoidal Cross-section Geometry

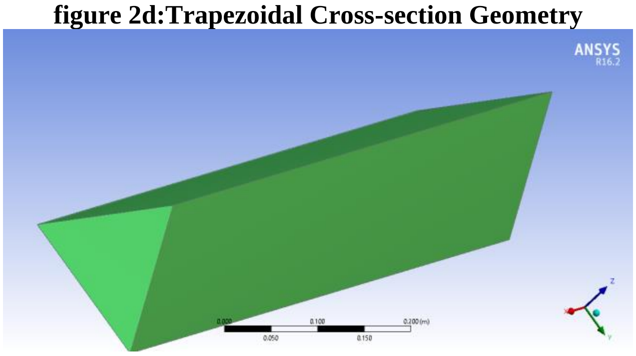

Figure 2e: Triangular Cross-section Geometry

Different cross section models are shown in figures. Their Dimensions are tabulated below.

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Table 1 Different cross section geometrical model with equivalent diameter and length

Geometry model	Equivallent diameter	Microchannel length()
circular	0.1 µm	0.8 µm
half circle	0.1 µm	0.8 µm
rectengle	0.1 µm	0.8 µm
triangular	0.1 µm	0.8 µm
trapezoidal	0.1 µm	0.8 µm

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

Geometry	Nodes	Elements
Circular	2496	1887
Half circle	1305	880
Rectangle	189	80
Triangular	380	228
Trapezoidal	240	114

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.

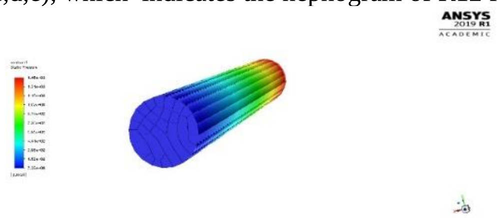

Figure 3a:Circular Temperaure Profile

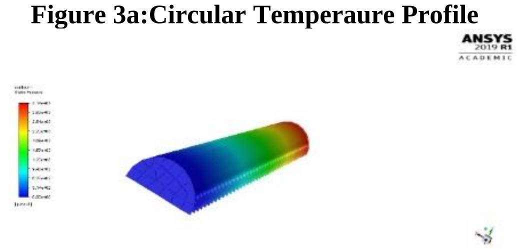

Figure 3b:Semi-circular Temperature Profile

Figure3c: Rectangular Temperature Profile

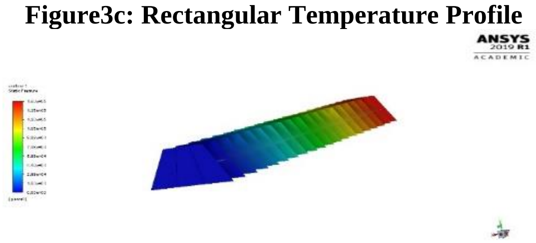

Figure3d: Trapezoidal Temperature Profile

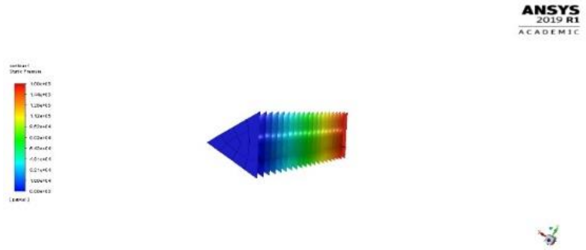

Figure 3e: Triangular Temperature Profile

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

Shape	Heat transfer Rate (W/cm2) water	Heat transfer Rate (W/cm2) R12
Circle	0.001175561	0.0002756156
Semi-circle	0.003420678	0.0001256904
Rectangle	0.00040108186	0.0001039971
Trapezoidal	0.00070111689	0.0001715533
Triangle	0.00114894527	0.00441217887

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 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.

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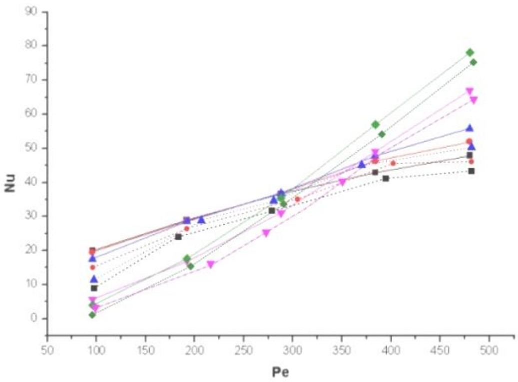

Fig 4 : Comparison of Nusselt and Peclet Number of Water & R12 through Different Cross Section

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.

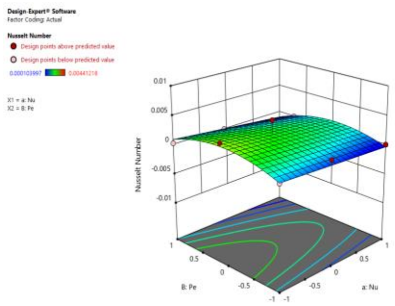

Fig 5: Response surface of Various Cross section microchannel with Coolants

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)

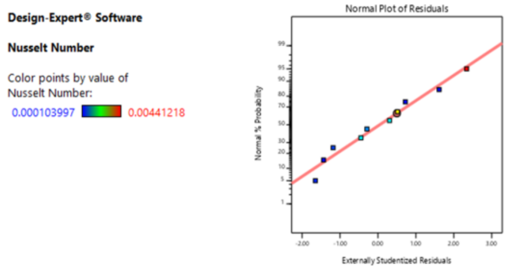

Fig 6 : Normal plot of the Residuals, Rising of Nusselt Number

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.

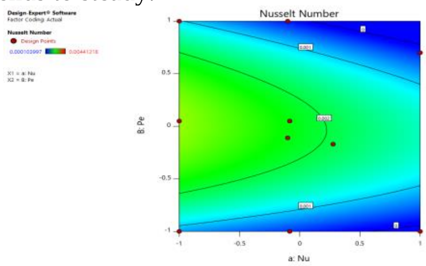

Fig 7 : Influence of Nusselt number in cross section contour

VI. TABLE SHOWS THE OPTIMUM RESULT OF THIS NUMERICAL INVESTIGATION FOR BEST SUITABLE MICROCHANNEL FOR THEIR RESPECTIVE COOLANT.

Coolant	Shape of best suitable microchannel
water	Semi-circular
R12	Triangular

VI. ACKNOWLEDGMENT

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REFERENCES

1. Dong Liu, Poh-Seng Lee, Suresh V. Garimella, International Journal of Heat and Mass Transfer, Prediction of the onset of nucleate boiling in microchannel flow, Elsevier publication 2005 pp- 5134-5149
2. Yutong Li, Jun Ren, Zhou Jing, Lu Jianping, Qing Ye, Zhijun Lv, 10th International Symposium on Heating , Ventilation and Air Conditioning,ISHVAC2017, The Existing Building Sustainable Retrofit in China-A Review and Case Study, Elsevier publication 2017 PP 3638-3645
3. ZHANG Hao, XU Tiantian, ZHANG Xinxin, WANG Yuxiang, WANG Yuancheng, LIU Xueting, Journal of Thermal Science Study on Local Reistance of non-Newtonian Power Law Fluid in Elbow Pipes 2016 PP 287-291
4. Shanglong XU, Yihao WU, Qiyu CAI, Lili YANG, and Yue LI, Optimization of the Thermal Performance of Multi-Layer THERMAL SCIENCE OPTIMIZATION OF THE THERMAL PERFORMANCE OF MULTI-LAYER SILICON MICROCHANNEL HEAT SINKS 2016 pp 2001-2013
5. J.D. Anderson.,2007. Computational fluid dynamics and its application. China Machine Press
6. B. Ji, X. Zhang, Y. Gu., 2015. Basic tutorials and case explanation of ANSYS ICEM CFD.
7. China Machine Press L.P. Yarin · A. Mosyak · G. Hetsroni.
8. Fluid Flow, Heat Transfer and Boiling in Micro-Channels
9. Satish G. Kandlikar, Satish G. Kandlikar, Dongqing Li, Stéphane Colin, Michael R. King. Heat transfer and fluid flow in minichannels and microchannels- © 2006 Elsevier Publication.

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