Numerical analysis of two phase flow heat transfer in rectangular micro channel heat sink

Ahmed Jassim Shkarah
Mechanical Engineering
Universiti Teknikal Malaysia Melaka
E-mail: shkarah@student.utem.edu.my

Dr. Mohd Yussof bin Sulaiman
Mechanical Engineering
Universiti Teknikal Malaysia Melaka

Prof.Md Razali bin Ayob
Mechanical Engineering
Universiti Teknikal Malaysia Melaka

Abstract

A 3D-conjugate numerical investigation was conducted to predict heat transfer characteristics in a rectangular cross-sectional micro-channel employing simultaneously developing Tow-phase flows. The sole purpose for analyzing two phase flow heat transfer in rectangular micro channel is to pin point what are the different factors affecting this phenomenon. Different methods and techniques have been undertaken to analyze the equations arising constituting the flow of heat from gas phase to liquid phase and vice versa. Different models of micro channels have been identified and analyzed. How the geometry of micro channels affects their activity i.e. of circular and non-circular geometry has also been reviewed. To the study the results average Nusselt no plotted against the Reynolds no has been taken into consideration to study average heat exchange in microchannels against applied heat flux. High heat fluxes up to 140 W/cm2 were applied to investigate micro-channel thermal characteristics

Keywords: Tow Phase flow , Micro channel , VOF

Nomenclature :

H : channel height, μm

Cp : specific heat, kJ/kg K

Dh : hydraulic diameter, μm

K : thermal conductivity, W/m K

L : channel length, mm

Nu : Nusselt number (Nu = hDh/k)

Nuave : Average Nusselt number

q ¨ : heat flux, W/m2

Re : channel Reynolds Number (Re = ρuDh/μ)

T : temperature, K

U : velocity, m/s

W : channel width, μm

X : x-coordinate, mm

Y : y-coordinate, mm

Z : z-coordinate (axial distance), mm

Greek symbols

α : channel aspect ratio (α = b/w)

ρ : density, kg/m3

μ : dynamic viscosity, Ns/m2

Subscripts

Avg : average

1. INTRODUCTION

The significance of micro-channels substantially grew because of their high-level heat exchange coefficient and diminishing size. Micro-channels submit amplify heat transferring surface and bigger surface area to volume ratio facilitating a higher heat exchange per unit of volume than the channels of usual sizes. Heat exchange in micro channels attracted much limelight due to their impending in many practical applications like lowering temperature of powerful microelectronics, biomechanical and aerospace applications as well. The geological requirements of the channel are remarkably influential on convection heat exchange features leading to the outline of an efficiently micro create important parameters like the shape of the channel, diameter of hydraulic, channel quantity, material of channel, the working fluid and it's flow rate along with few other distinctive parameters. This is to be taken into account extracting the accurate possible values of these parameters to ensure the system is effective and cost efficient. The growth in development of micron sized devices is increasing the depth of understanding the thermal as well as hydrodynamic features of flow occurring in micron sized tubes and micron sized channels. The setbacks are taken into account that is associated with conducting experiments in the micro-channel specifically for micro geometries. This is another reason why it is suitable to develop dependable numeric models that demonstrate the flow and also the heat in the micro channels. These numeric models provide significant description of combined effect of the drop in pressure and thermally sensitive performance. So, these models can be used for optimizing the fluidic micro systems without the fabrication of apparatus and the experimental data. The ever increasing development in the production of micro-channel systems, specifically in the field of the MEMS i.e. the Micro Electro Mechanical Systems, have resulted in the creation of exclusive and distinctive devices of mechanical importance as well as electromechanical importance, only on a thin layer of silicone. These MEMS are generically explained as units having a distinctively minute length of 1 mm and just 1µm. They are heat exchanging units, micro-channel reactors, micro-channel sensors, micro-channel pumps that are used for printers, blood analyzing units, laser diode, environmental testing and so on. (Tuckerman 2001, Mudawar 2000) The two phase flow constituted in micro-channels sink is essential for analyzing its utility to science and technology like micromechanical, electromechanical systems, electronic cooling process, chemical engineering, genetics, bio engineering and many more (Hetsroni, G., et al 2003) .Various arenas of the two-phase flow and exchange of heat in micro channel heat sink has been studied, (Qu, W. and I. Mudawar 2004) , (Lee, J. and I. Mudawar 2008) , (Imke, U.2004),(Chang, K.H. and C. Pan 2007) . Lee has efficiently studied the heat exchange characteristics of the Two-phase flow of micro channel heat sink and published a letter (Lee, J. and I. Mudawar 2008) .The use of R134a as a flowing fluid under controlled heat flux was used (q''=15.9 - 93.8 W/cm^2) with vapor of quality$x_e = 0.26 - .087$). With this, new and improved heat exchange coefficient correlation that depicts excellent prophecies for both water as well as R134a. Hedge also (Hegde, P., et al2005) analyzed the heat exchange and 2 phase flow in the micro channels. The FEM i.e. the Finite Element Method was effectively used to solve the equations involving energy balance. Water was taken into account as coolant and calculations were carried out at a mass flux fixed of $255\ Kg/m^2$keeping the inlet of coolant temperature fixed at 608C$^{\circ}$. The observations by Mornii, (Morini, G.L.2005) ,were done to analyze the convection that was forced through the micro channels. The viscous indulgence effect was established as a conventional "scaling effect" for studying the flow in micro-channels.

2. Problem statement :

The real life model analyzed is depicted in the figure 1 which shows the two-Phase flow in micro-channels heat sink. Heat is distributed to the silicon substrate which is highly conductive having known heat conductivity arising from a heating point situated at the base of heat sink; later on it is removed using a fluid that flows through numerous micro channels as shown in the Fig no 1. Going by the proportion, we can pick a cell unit which contains the micro channel which is sketched on the models made by Tuckerman , and Pease for analysis.

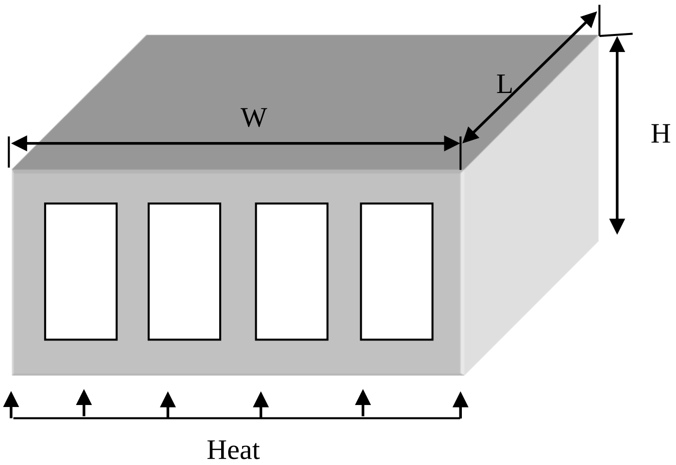

Fig 1 : micro-cahnnel heat sink

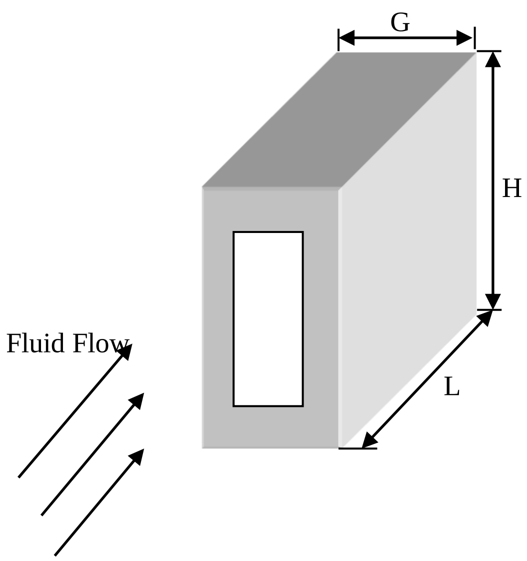

Fig :2 Computional domain of micro channel heat sink

Heat exchange in one cell unit is an issue which collaborates heat transmission in solid and convective exchange of heat to coolant.

3. Applications of Microchannels :

The functions of the Microchanels are essential due to its capacity to eliminate a fair quantity of heat from a less volume. This capacity makes it ideal for specific applications which require dense and elevated heat energy elimination like processes of biomedical importance, metrological processes, telecommunications, cooling the heat flux density in microelectronics, industries of automotives, barriers in nuclear reactor, processing fuels, industries of chemicals and aerospace. (Roy, S.K. and B.L 1996) ,(Okabe, T., et al 2003) Fluids that lower the temperature play an essential role in applications and it’s thermo-physical properties is accounted as vital parameters affecting the cooling properties (Shakir, A.M 2011). Microchannel heat transferring unit is one of the most vital function of micro channel. Equally important are the micro channel hat sinks which are used in the Micro Electro Mechanical System i.e. MEMS, in unconventional military avionics, in electric vehicles and power devices (Klein, D., G. Hetsroni, and A. Mosyak 2005) . One of the most vital functions of micro channel is in the fuel running automobiles that are based on microchannel technology (Wegeng, R.S., et al 2001) . Micro channels play a key role in advancing technologies which progress the existing ones for cooling. Essentially used in electronics cooling and also in micro heat transferring system due to their simplicity in manufacturing (Muzychka, Y.S 2007) .

4. Micro channel geometry :

There is a vast geometry of microchannels which are directly dependent on the functions of microchannels. It is divided to two categories, circular micro channel type and non circular micro channel type (Vasiliev, L.L 2008) . The non circular geometry types of micro channels are squares (Salimpour, M.R.2011) , triangles, trapezoidal (Bahrami, M., M et al 2007) .

5. Two-phase flow in Microchannels:

Issam and Weil (Qu, W. and I. Mudawar 2003) have proved that two-phase flow in micro channel have an advantage of having distinctive feature of lower thermal resistance, tightly packed dimensions in small coolant and lower flow rate parameters. They have also experimentally investigated the features of flow in micro channel heat sink containing 21 parallel channels of dimensions 231 x 713 µm of cross section. Using deionized water, tests were conducted over mass velocity ranging from 135-402 kg/m2, temperature of inlet ranging 30-60 C and 1.17 bar outlet pressure. They also discovered the laminar flow to turbulent flow transition regime at approximately Re=1000. It was also demonstrated that heat exchange and flow features were influenced by geometric features. It was also discovered that there was an apt channel size if the width to height ratio is ½ or 2, at this point maximum heat exchange occurs. Zhao and Bi (Zhao, T.S. and Q.C. Bi 2001) conducted experiments to analyze 2-phase flow designs in upward flow of air in triangle channels that are equilateral and having 2.886,1.443 and 0.886 hydraulic diameters. The impressions of the flow designs were captured by high speed analyzer of motion combining it with transitory drop of pressure measurements. The flow designs which included isolated bubble flow pattern, slug flow pattern, chum flow pattern and annular flow patter. These patterns were observed in two large triangular channels. These observations made were similar to the ones that generally came across in conventional size tubes placed vertically. It was remarkable to discover a new pattern of fall called the capillary bubbly pattern of flow. It was classified as smallest channel adding to typical flow designs excluding the design of bubbly flow. Additionally, the slug-chum flow of pattern and chum- angular flow transition lines shift to right when the hydraulic diameter decreases. Also, when the former flow pattern transition models were available for gas-liquid flow in upward Two-phase flow contained in conventional size tubes were not useful to predict transition in flow. Attributed to their 2nd paper, the investigation for studying the velocity of gas, void fraction and drop in pressure was conducted in the same experimental way.

6. Governing equations :

Consider a gas-liquid 2-phase flow in a particular micro channel of rectangular shape. The VOF i.e. Volume of Fluid principle is applied to facilitate the gas-liquid 2-phase flow in microchannels. This technique was developed by Nicholas and Hirt (Hirt, C.W. and B.D. Nichols 1981). In this particular method, two or more phases are forbidden to interpenetrate into each other. The summation of fractions of volume in all phases consisting in every control volume is assigned to unity. The VOF is probably one of the easiest techniques compared to other two-phase flow models. This technique has considerable accuracy is less computationally intense when compared to Eulerian model), it is also easier to use and can also solve intricate free flowing surfaces. The phases, the gas as well as liquid are considered as uncompressible in this study. The technique is designed to solve the single momentum of equation overall in the domain, while the velocity field resulted is shared in all the phases. The equation shown below depends on volume fraction of all the phases in the 1 and q. Continuity, energy equation and Navier strokes are used in two-phase flow:

Continuity equation

$$\frac{\partial u_j}{\partial x} + \frac{\partial v_j}{\partial x} + \frac{\partial w_j}{\partial x} = 0 \qquad (1)$$

Equations of momentum:

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

$$u_j \frac{\partial u_j}{\partial x} + v_j \frac{\partial v_j}{\partial y} + w_j \frac{\partial w_j}{\partial z} = -\frac{1}{\rho_j} \frac{\partial P}{\partial x} + \frac{\mu_j}{\rho_j}\left(\frac{\partial^2 v_j}{\partial x^2} + \frac{\partial^2 v_j}{\partial y^2} + \frac{\partial^2 v_j}{\partial z^2}\right) \quad (3)$$

$$u_j \frac{\partial u_j}{\partial x} + v_j \frac{\partial v_j}{\partial y} + w_j \frac{\partial w_j}{\partial z} = -\frac{1}{\rho_j} \frac{\partial P}{\partial x} + \frac{\mu_j}{\rho_j}\left(\frac{\partial^2 w_j}{\partial x^2} + \frac{\partial^2 w_j}{\partial y^2} + \frac{\partial^2 w_j}{\partial z^2}\right) \quad (4)$$

$$\mu = \frac{\alpha_L \rho_L \mu_L + \alpha_G \rho_G \mu_G}{\alpha_L \rho_L + \alpha_G \rho_G} \quad (5)$$

The equation for volume by tracking interfaces between phases (Brackbill Brackbill, J.U., D.B. Kothe, and C. Zemach 1992) .

$$\frac{\partial}{\partial \mathrm{t}}(\alpha_L \rho_L) + \vec{\nabla}\left(\alpha_L \rho_L \overrightarrow{V_L}\right) - (\dot{m}_{GL} - \dot{m}_{LG}) \quad (6)$$

The term for gas to liquid phase transfer is $\dot{m}_{GL}$ and the term for liquid to gas phase transfer is $\dot{m}_{LG}$. The transfer between the liquid and gas phases have not been taken into account. The equation of volume fraction, Eq (6) is kept unsolved in the primary phase. It will be computed on the basis of following constraint, $\alpha_L + \alpha_G = 1$ (7)

An equation of single energy will be resolved with the help of the domain and the result will be shared by the phases on the basis of following equation.

The equation above was resolved using the finite volume technique which is deployed in the fluid flow solver i.e. Ansys fluent 14, a systematic rectangular grid was deployed for simulations. For every dissertation, the QUICK scheme of third order was used. A condition of pressure boundary was utilized at the channel outlet whose value was equivalent to the atmospheric pressure. The volume fraction summation in the volume fraction of all phases is set as unity. The VOF method is the easiest methods used. This technique has considerable accuracy is less computationally intense when compared to Eulerian model), it is also easier to use and can also solve intricate free flowing surfaces. The phases, the gas as well as liquid are considered as uncompressible in this study. The technique is designed to solve the single momentum of equation overall in the domain, while the velocity field resulted is shared in all the phases. The equation shown below depends on volume fraction of all the phases in the ρ and μ.

7. Results and discussions:

A plot of average Nusselt no values against Reynolds no (500-200) for applied heat flux between 45-140 W/cm^2, is displayed in Fig 3. When compared with the results of Lee (Lee, P.-S., S.V. Garimella, and D. Liu 2005) , there is a considerable increase in the average Nusselt no. therefore the heat transfer coefficient is observed for an increase in applied heat flux. This agrees with the generic statement in published contents mentioning that heat transfer coefficient values increase with the magnitude reduction when heat flux that is applied increases (Webb, R.L., et al. 2002) .

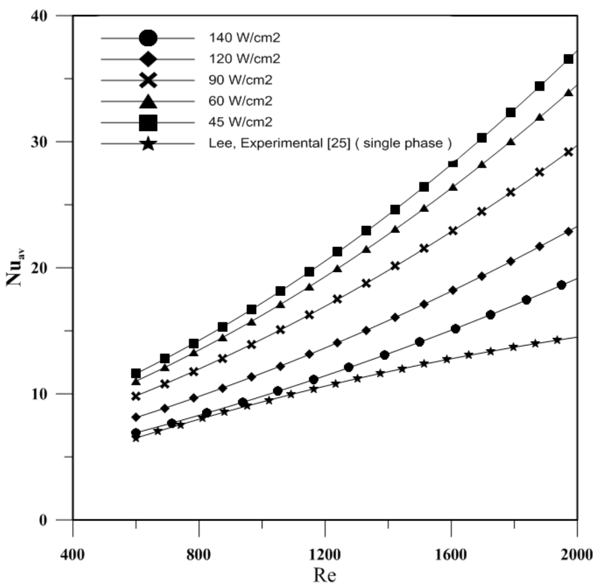

Fig .3. variation of nusult number against Re in the base of micro-channel

The difference of the surface temperature and the base of microchannel may get affected by variables like heat flux, velocity of heat, inclination of microchannel and the situation od flow entrance. The distribution of temperature at the base of microchannel only for selected runs is depicted in Fig 2.

Fig (4) depicts the effect of (Re) number difference on the base of microchannel's surface for heat flux (45 W/cm2). Apparently the increasing values of (Re) decreases the temperature of base of microchannel surface when the heat flux is maintained constant. It is essential to say that heat flux actually increases the temperature of base of microchannel surface due to the free convection in the more dominating aspect of heat transfer.

Fig (5) depicts the difference of temperature of surface across the base microchannel at different values of heat flux and for Re=600. It also reveals that base microchannel temperature increase at entrance and reaches a maximum value. After that, the surface of inner tube decreases for higher heat flux.

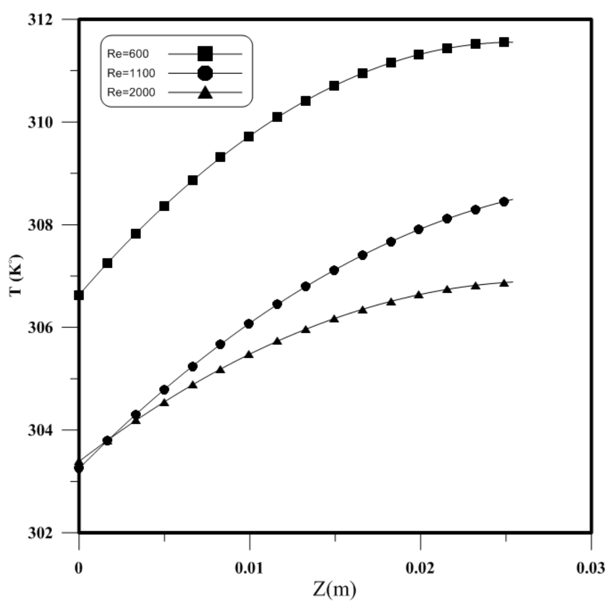

Fig .4. Variation of Temperature against Z axis in the base of micro-channel
(For difference Re)

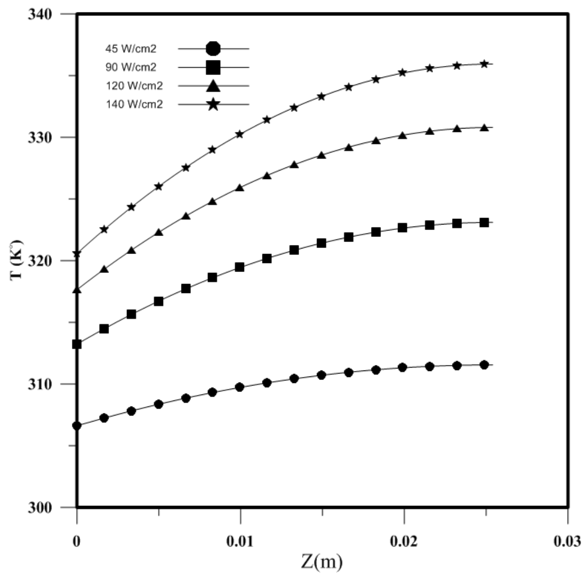

Fig .5. variation of nusult number against Re in the base of micro-channel
(For difference Heat transfer)

8-CONCLUSION :

As we come to an end of this topic revolving around the Numerical analysis of two phase flow heat transfer in rectangular micro channel heat sink, we have concluded numerous findings.
We have observed how the size of microchannels plays a key role in heat transfer leading to many applications of it. We have also studied how the geometry of microchannels i.e. circular and non-circular geometries can play a very important role in its functionality and applications.
We have studied the various experimental investigations conducted on microchannels and the derivations of equations from them. Different flow models or patterns like isolated bubble flow pattern, slug flow pattern, chum flow pattern and annular flow pattern, were concluded which could depict the factors affecting heat exchange.
We have also resolved governing equations regarding the heat flow from gas phase to liquid phase and vice versa.It is used in the arenas of powerful microelectronics, biomechanical and aerospace as well.
They are of enormous importance in the following processes like biomedical processes, metrological processes, telecommunications, cooling the heat flux density in microelectronics, industries of automotives, barriers in nuclear reactor, processing fuels, industries of chemicals and aerospace. And especially in the field of the MEMS i.e. the Micro Electro Mechanical Systems, have resulted in the creation of exclusive and distinctive devices of mechanical importance as well as electromechanical importance, only on a thin layer of silicone.

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