REVIEW OF AXIAL HEAT CONDUCTION EFFECT IN PARALLEL FLOW MICROCHANNEL HEAT EXCHANGER

Bidyut Prava Jena[1], Binayak Mishra[2]
[1] *Mechanical Engineering, Gandhi Engineering College, Bhubaneswar, India*
[2] *Mechanical Engineering, Gandhi Engineering College, Bhubaneswar, India*

Abstract: *In this paper, a comprehensive review of available studies regarding axial heat conduction effect in parallel flow microchannels is presented and analyzed. Different articles are reviewed to identify the effect of axial heat conduction on the heat transfer. The numerical, analytical and experimental studies of axial heat conduction are reviewed. The effect of different dimensionless numbers on axial conduction is studied. Axial conduction with different channel geometries and flow regimes are studied. From the reviews it reveals that the other parameters that affect the axial heat conduction are hydraulic diameter of the channel, thermal conductivity ratio and Reynolds number. There is also emphasize on the effectiveness and optimum design consideration with axial conduction effect.*
Keywords: *Parallel Flow micro channel heat exchanger, Axial heat conduction, Dimensionless number.*

1. INTRODUCTION

Heat transfer in microchannel can suitably describe by the standard theories. The use of microchannels for removal heat is undertaking a great interest in various industrial fields such as bio-engineering, micro-heat exchanger, electronics. This type of cooling gives high performance of heat transfer. Heat transfer analysis in microchannel gives more attention due to its extensive application in micro heat exchanger. The high heat flux dissipation from microprocessor provides the focus on the studies on heat transfer in microchannel.

The performance of heat exchanger is dependent on the flow rate and properties of fluid. At micro-scale level when fluid flow inside a channel heat transfer takes place with many additional level such as electro-viscous effect, rarefaction, viscous dissipation and axial heat conduction. Rarefaction is important for small dimension (less then 5 µm at atmospheric condition) which is compared with the mean free path of a fluid, it is common for gas flow in microchannel. Electro-viscous effect are due to the interaction of ions in the fluid with Electric double Layer (EDL) near non-conductive wall [1].

When the fluid work against the viscous heating the effect of viscous dissipation is occurs. Effect of viscous dissipation can be important for flow with Reynolds number is greater than 100 [2]. The Reynolds number affects the velocity of fluid flow inside a channel at entrance and ending region of the channel.

The microchannel heat exchanger promising with its superior thermal performance. For conventional channel the thickness of separating wall comparatively small to the hydraulic diameter of the channel, therefor the effect of axial heat conduction may be neglected in conventional heat exchanger. But for microchannel heat exchanger thickness of separating wall comparatively large to the hydraulic diameter of the channel. The microchannel heat exchanger gives extremely high heat transfer area per unit volume over a conventional channel [3]. Mehendale et.al [4] classified the channel ranges from 1 to 100 µm as microchannels, 100 µm to 1 mm as meso-channels, 1 mm to 6 mm as compact passage, and greater than 6 mm as conventional channel.

Kandilkar and Grade [5] modified the channel dimension scheme which is based on the smallest channel dimension scheme as shown in Table 1

Table 1-Classification of channel proposed by Kandilkar and Grade.

CHANNEL	HYDRAULIC DIAMETER
Conventional channel	$D_h > 3$ mm
Minichannels	3 mm $\geq D_h \geq$ 200 μm
Microchannels	200 μm $\geq D_h \geq$ 10 μm
Transitional Microchannels	10μm $\geq D_h \geq$ 1μm
Transitional Nanochannels	1μm $\geq D_h \geq$ 0.1μm
Nanochannels	0.1μm $\geq D_h$

Kandilkar and Grade [6] also proposed the channel dimension on the basis of type of flow inside a channel for rarefaction effect of common gases at atmospheric pressure as shown on Table 2

Table 2- Channel dimension for different types of flow.

GAS	CONTINUUM FLOW	SLIP FLOW	TRANSITION FLOW	FREE MOLECULAR FLOW
Air	>67 μm	0.67 μm-67 μm	0.0067 μm -0.67 μm	<0.0067 μm
Helium	>194 μm	1.94 μm -194 μm	0.0194 μm -1.94 μm	<0.0194 μm
Hydrogen	>123 μm	1.23 μm -123 μm	0.0123 μm -1.23 μm	<0.0123 μm

The Knudsen number plays an important role to find out the type of flow inside a channel. It is defined as the ratio of mean free path to the characteristics dimension.

A. For $Kn < 10^{-3}$ the flow is continuum flow.
B. For $10^{-3} < Kn < 10^{-1}$ the flow is slip flow.
C. For $10^{-1} < Kn < 10$ the flow is transition flow.
D. For $Kn > 10$ the flow is free molecular flow.

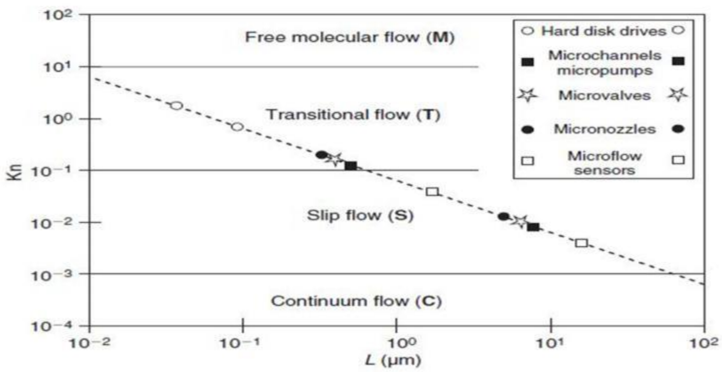


Fig.1. Flow regimes for usual microsystem (from Karniadakis and Beskok (2002))

In case of axial heat conduction the Knudsun number is small enough so that the fluid is consider as continuous media (No-slip) .Axial heat conduction has been accounted in the microscale heat transfer analysis using microchannel devices due to the relative scale between substrate thickness and hydraulic diameter of a channel.

Peclet number (Pe) is dimensionless parameter which is use to consider the effect from heat convection and heat conduction of a fluid. At the entrance of a channel region the axial heat conduction innovate the stronger heat transfer and higher temperature gradient of fluid.

In recent years, lots of researchers have been done experimentally and numerically study to estimate the effect on axial heat conduction in different geometry and also analys the effect of different dimensionless number.

2. EFFECT OF DIFFERENT DIMENSIONLESS NUMBER

The effectiveness of microchannel is may decrease due to the axial heat conduction effect. . If the Pe >> 1 the effect of axial heat conduction can be neglected but in experiments the effect of axial heat conduction cannot be neglected.

$$=$$

Where is the mean fluid velocity, is the hydraulic diameter of microchannel, and is thermal diffusivity of fluid. Maranzana et al. [7] found that when the fluid is in the low Reynolds condition regime the Nusselt number reduces and due to the axial heat conduction effect the efficiency of heat transfer also reduced. They proposed a dimensionless parameter named "axial heat conduction number (M)".

$$= ''$$

Rahimi and Mehryar [8] numerically investigated conjugate heat transfer in microtube. They shows that the thermal conductivity of the wall and reduction in local Nusselt number at entrance region due to the thickness of the microtube cause a axial heat conduction at the duct of the wall.

Stief et.al. [9] Numerically investigated the effect of solid thermal conductivity in microchannel heat exchanger. They investigate the reduction in thermal conductivity of separating wall material can improve the heat transfer efficiency of the heat exchanger. Vekatarathanam and Narayanan [10], Kroger [11], Al-bakhit and Fakheri [12] concluded that the effectiveness of heat exchanger is largely dependent on the wall of the heat exchanger and the thermal conductivity of the wall. Al-Bakhit and Fakheri [13] showed that if the Graetz number is depend on heat transfer length is the order of 0.03 so the assumption of constant overall heat transfer coefficient is not valid. Mushtaq. I. Hasan et.al. [14] concluded that axial heat conduction increase with increase in Reynolds nuber at the entrance region of the channel, and increase in hydraulic diameter of the channel reduction occurs in axial heat conduction flux.

3. EFFECT OF DIFFERENT GEOMETRY

Mori et al.[15] studied the effect of axial heat transfer on the convective heat transfer in circular microchannel and between parallel plates, they ignored the axial heat conduction effect in ending region under the first and second kind of boundary conditions.

Yin and bau [16] used a fully developed velocity field between infinite parallel plates and circular pipes to study the effect of axial heat conduction on the performance of microchannel heat exchanger. They found that at the entrance region axial heat conduction plays an important role.

Hussien Al- Bakhit and Ahmad Fakheri [13] numerically investigated the parallel flow microchannel heat exchanger with rectangular ducts and showed that for Graetz number below 0.03 the overall heat transfer coefficient is rapidly changed.

Al-Nimr et.al [17] numerically investigated the behaviors of laminar, 2 dimensional, fully developed ,slip flow inside an insulated parallel plate microchannel heat exchanger and showed that at the wall velocity slip and temperature jump increased with increase in Knudsen number.

Mushtaq. I. Hasan [18] made investigation in counter flow microchannel heat exchanger with different channel geometry and fluids.

Found that the existence of axial heat conduction leads to a reduction in the effectiveness of this heat exchanger.

Mushtaq. I. Hasan, et.al.[14] investigated on the study of the axial heat conduction in parallel flow microchannel heat exchanger, they found that some parameters affect the axial heat conduction in an isosceles right triangular microchannel heat exchanger. Jhih-Ren Lin et.al. [19] experimental study that axial heat conduction in different hydraulic channel of rectangular polydimethylsiloxane (PDMS) microchannel at Reynolds number of 15, and the hydraulic diameter varies from 40µm to 196µm with an aspect ratio of 0.1 and length 4cm. The experimental setup consist with heater which is use to provide heating in the fluid inside the microchannel with the power of 6.2 W, for uniform heating cooper plate is placed between microchannel and the heater, molecular based temperature sensor is applied to measure the temperature sensitive solution and temperature sensitive paint. To illuminate the luminescent molecules the excitation light is used at the top of the microchannel. The CCD camera is used to capture the luminescence as shown in figure (2).

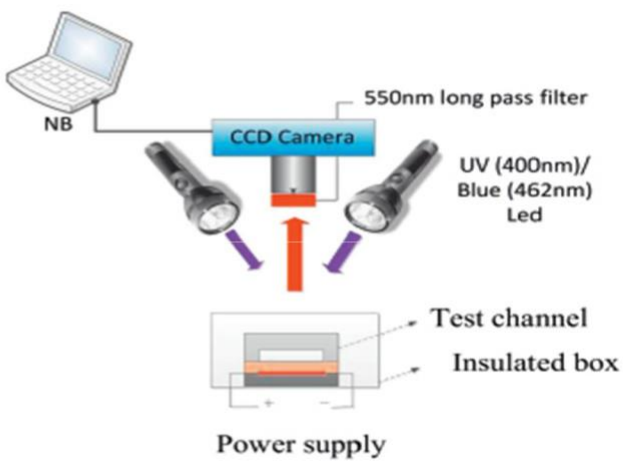
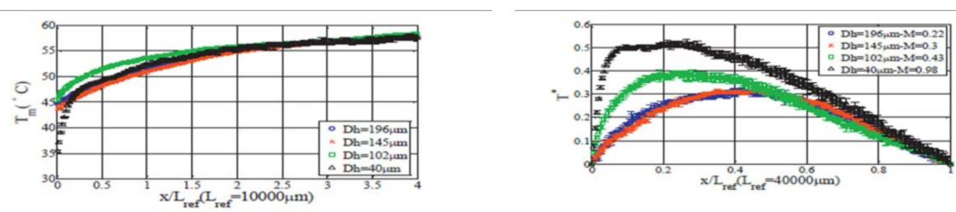


Fig.2. Experimental setup of molecule based temperature sensor measurement (Jhih-Ren Lin et.al.)



They concluded that the temperature gradient are increase and at the entrance region the axial heat conduction effect enhance the heat flux and also find out the axial heat conduction effect are increase as the hydraulic diameter of the channel are become smaller. The figure (3) shows the fluid temperature distribution along the channel and figure (4) shows the dimensionless temperature deviation from ideal linear temperature distribution.

Kevin D. Cole, Barbaros Cetin [20] study the convective heat transfer in parallel plate microchannel for low Pe number flow. They assumed the constant properties of fluid and the effect of axial heat conduction at the wall and in a fluid. They used the Greens function to analys the temperature in the fluid and the wall. They shows the importance of effect of axial heat conduction in microchannel with different criteria's such as.

A. Length over height ratio of the channel.
B. For small Peclet number.
C. Ratio of channel thickness to the channel height.
D. Thermal conductivity of the wall material is high relative to the thermal conductivity of a working fluid.

4. CONCLUSION

For the available literature we can conclude that, The parameters that affect the axial heat conduction are Hydraulic diameter of the channel, Thermal conductivity ratio, Reynolds number. As increase in temperature gradient the effect occurs in axial heat conduction flux. Many researcher investigate the effectiveness of the heat exchanger largely depend on wall thickness and thermal conductivity of a material. Some researcher paid attention in effect of axial heat conduction in microchannel heat exchanger for optimum design of microchannel.

REFERENCES

[1] B. Cetin, B.E. Travis, D. Li, Analysis of the electro-viscous effects on pressuredriven liquid flow in a two-section heterogeneous microchannel, Electrochimi. Acta 54 (2008) 660–664.
[2] G.L. Morini, Scaling effects for liquid flows in microchannels, Heat Transfer Eng. 27 (4) (2006) 64–73.
[3] H.E. Jeong, J.T. Jeong, Extended Graetz problem including streamwise conduction and viscous dissipation in microchannels, Int. J. Heat Mass Transfer 49 (2006) 2151–2157.
[4] Mehendale, S. S., Jacobi, A. M., and Shah, R. K., Fluid flow and heat transfer at micro- and meso-scales with applications to heat exchanger design,Appl. Mech. Rev., 53, 175–193.
[5] Kandlikar, S. G. and Steinke, M. E., 2003, Examples of microchannel mass transfer processes in biological systems, Proceedings of 1st International Conference on Minichannels and Microchannels, Rochester, NY,April 24–25, Paper ICMM2003-1124.ASME, pp. 933–943.
[6] Kandlikar,S.G.andGrande,W.J.,2003,Evolutionofmicrochannelflowpassages–thermohydraulic performance and fabrication technology, HeatTransfer Eng., 24(1), 3–17, 2003.

[7] G. Maranzana, I. Perry, D. Maillet, Mini- and micro-channels: influence of axial conduction in the walls, Int. J. Heat Mass Transfer 47 (17–18) (2004) 3993– 4004.

[8] M.Rahimi, R.Mehryar, Internationla journal of Thermal sciences 59 (2012) 87-94.

[9] Stief, T., Langer, O.U., Schubert, K., 1999. Numerical investigation of optimal heat conductivity in micro heat exchangers. Chemical Engineering Technology 22, 297–303.

[10] Vekatarathanam, G., Narayanan, S., 1999. Performance of counter flow heat exchanger with heat loss through the wall at the cold end. Cryogenics 39, 43–52.

[11] Kroeger, P.G.,1967. Performance deterioration in high effectiveness heat exchangers due to axial heat conduction effects. Advances in Cryogenic Engineering,

[12] Hussien Al-bakhit, Ahmad Fakheri, 2005. Entrance and wall conduction effects in parallel flow heat exchangers. In: Shah, R.K., Ishizuka, M., Rudy, T.M., Wadekar, V V. (Eds.), Proceedings of Fifth Internal Conference on Enhanced, Compact and Ultra-Compact Heat Exchangers: Science, Engineering and Technology. Engineering Conferences International, September 2005, Hoboken, NJ, USA.

[13] Al-bakhit, Hussien, Fakheri, Ahmad, 2006. Numerical simulation of heat transfer in simultaneously developing flows in parallel rectangular ducts. Applied Thermal Engineering 26, 596–603.

[14] Hasan, Mushtaq I., 2009. Numerical simulation of counter flow microchannel heat exchanger with different channel geometries and working fluids. PhD Thesis, Mechanical Engineering Department, Collage of Engineering, Basrah University, Iraq.

[15] S. Mori, T. Shinke, M. Sakakibara, A. Tanimoto 1976, Steady heat transfer to laminar flow between parallel plates with conduction in wall, Heat Tran. Jap. Res. 5 17e25.

[16] Yin, X., Bau, H.H., 1992. Axial Conduction Effect Performance of Micro Heat Exchangers, ASME Winter Annual Meeting, November 28–December 3, New Orleans, Louisiana, USA.

[17] Al-Nimr, M.A., Maqableh, M., Khadrawi, A.F., Ammourah, S.A., 2009. Fully developed thermal behaviors for parallel flow microchannel heat exchanger. International Communications in Heat and Mass Transfer 36, 385–390.

[18] Hasan , Mushtaq I., 2014. Study of the axial heat conduction in parallel flow microchannel heat exchanger. Journal of king saud university – Engineering sciences. 26, 122-131.

[19] Jhih-Ren Lin et.al. 2014. The study of axial heat conduction with various hydraulic diameters of microchannel. Procedia engineering 79, 273-278.

[20] Con, D.Kevin, C. Barbaros 2011. The effect of axial heat conduction in a liquid microchannel flow, International journal of heat and mass transfer 54, 2542-2549.