Paper ID: TE-05

Numerical Study of Minichannel Heat Sink with PCM for Different Shapes and Geometry

Mahbub Islam Peyal[1], MD.Forhad Mazhar Bhuiyan[2], Kazi Ariful Islam[3], Tayamirul Islam[4]
[1,2,3,4]Department of Mechanical Engineering, Bangladesh Army University of Science and technology
E-mail:rozen.razz@gmail.com

A B S T R A C T

T*hermal control has become a critical factor in the design of electronic device because of the recent trends in the electronic industry towards increased miniaturization of components and device heat dissipation. So it is needed to control an adequate heat extraction, otherwise the device may fail or damaged. One of the most promising configurations for indirect liquid cooling of electronic systems is the use of mini channel heat sinks where a liquid is forced to flow through channels embedded in a solid matrix. Now a days researchers trying to develop many ways to enhance heat transfer by using many liquids (e.g. various Nano fluids, PCM etc). A phase change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature with lower thermal conductivity. In this study, numerical study has been conducted in various shapes of Minichannel Heat Sink with phase changing material (N-eicosane) as the coolant. Heat transfer and pressure drop characteristics of the different minichannels were calculated for the PCM. PCM fluid shows good heat transfer characteristics when PCM undergoes phase change. In the study, heat transfer performance of different minichannel were compared with others. We uses four shapes (Straight rectangular, Rectangular with roughness, Rectangular with bumps and Triangular) of minichannels. It states from the study using roughness in rectangular channel enhance heat transfer performance and triangular minichannel has 9.5 times higher heat transfer characteristics than rectangular mini channels.*

Keywords: PCM, Mini Channel, Heat Sink, Melting, Solidification, N-eicosane.

1. Introduction

Temperature is a key factor in operation of any electronic equipment. Because of advanced developments in circuit component and packaging technologies, recent trends in the electronic industry are towards increased miniaturization of components and device heat dissipation. Also, a great demand on the system performance and reliability has increased the needs for a better thermal management of electronic equipment.[1] The forced convection heat transfer with MCPCM slurries has been investigated theoretically by Charunyakorn et al. [2], Hu and Zhang [3], Roy and Avanic [4], Alisetti and Roy [5], Ho et al. [6], Xin et al. [7],Wang et al. [8] etc. Even with all recent interest on PCM slurry, the effects of several factors, such as fluid-particle conductivity and particle density, on the heat transfer enhancement mechanism seem not yet to be well understood. Nilson et al [9] studied minichannel using analytical and numerical solution for evaporating flow in rectangular minichannel for uniform width. The evaporating cooling capability of rectangular minichannels are presented in terms of flow on channels dimensions, also they investigated flow pattern within minichannel. Welin Qu et al[10] investigated friction factor correlation for water as working media for micro channels. Analyses of optimum heat transfer for rectangular aluminum micro channels are done with friction factor consideration. By analyzing microchannels for six friction factor correlations with own experimental data, they investigated new friction factor correlation. Proposed friction factor correlation is suggested by verifying available correlation for friction factor from literature. Derby et.al.[11] analyzed microchannel with zigzag, curvy, step microchannels and this various shape microchannels are compared with straight and wavy channels by numerical method. Hydraulic diameter 340mm with length of 10cm considered for analysis. For same cross-section of microchannel temperature and heat transfer coefficient of zigzag shape is least and greatest among various channel shape. Numerical prediction result shows that Zig-zag microchannel is best in thermal and hydraulic performance as compared to straight microchannel. P.Gunnasegaran et.al.[12] investigated effect of geometrical parameters on water flow and heat transfer characteristics in

NOMENCLATURE		
General Terms		
C_P	Specific heat	$J\ kg^{-1}K^{-1}$
k	Thermal conductivity	$W\ m^{-1}K^{-1}$
H	Heat transfer coefficient	W/m^2K
H	Channel height	*mm*
W	Channel width	*mm*
D_h	Hydraulic diameter	*m*
T	Temperature	*K*
ρ	Density	Kgm^{-3}
M	Dynamic viscosity	*Pa. s*
f	Finning factor	
q"	Heat flux	W/m^2
U	x component of velocity	*m/s*
V	y component of velocity	*m/s*
µ	Viscosity	*m*
V	Velocity	*m/s*
P	Pressure	N/m^2
c	PCM's volumetric concentration	
Z+	Non-dimensional axial distance	*m*
Lp	Latent heat of PCM particles	N/m^2
Re	Reynolds number	
Nu	Nusselt number	
SUBSCRIPTS		
p	property of the PCM particle	
f	property of the carrier fluid	
b	property of the bulk fluid	
c	cycle timed average	

microchannels numerically for Reynolds number range of 100–1000. Investigation is for three-dimensional steady, laminar flow and heat transfer governing equations solved by using finite volume method. Rectangular, trapezoidal, and triangular shape considered for analysis. Yamagishi et al. [13] analyzed with microencapsulated PCM slurries and observed heat transfer characteristics. C18H36 with water was used in their experiment and they found enhancement of heat transfer. Alvarado et al.[14] conducted some experiments with microencapsulated phase material (MPCM) in a circular tube and the flow condition was turbulent. They found MPCM fluid behaves as Newtonian fluid below 18% concentrations Chen et al.[15] conducted experiments with bromohexadecane as PCM and water as carrier fluid. They found enhancement in heat transfer using PCM compared to water. 30% less mean wall temperature was found and the heat transfer enhanced by 40% than water. Pressure drop in case of PCM was seen to be 67% lower comparing with water. Roy and Avanic [16] developed effective specific heat model to study numerically PCM fusion process accurately. They found good agreement with the experimental results and results achieved by applying effective specific heat model. Sabbah et al. [17] investigate the heat transfer characteristics of MPCM slurry flowing in a heated tube. Results indicate that MPCM can enhance the heat transfer coefficient by much as 50% due to the latent heat of fusion of the phase change material. One of the difficulties when numerically simulating MPCM slurries is the readiness and availability of reliable, effective, and computationally inexpensive numerical approaches that can account for tens and hundreds of thousands of almost neutrally buoyant PCM particles as small as 5l m. Moreover, the specific gravity of PCM particles is usually in the range of 0.8–0.9, which makes numerical simulation even more daring and difficult.

2. Problem Statement

2.1 Geometry:

Rectangular Minichannel's height was taken as 30 mm and the widths 30mm , wall thickness was neglected. Due to symmetry, one fourth of the flow domain was numerically investigated. Two adjacent sides were considered as no-slip walls and constant heat flux was applied, and the rest were considered as symmetric. Three different grid resolutions 10×20×600, 20×20×600 and 20×30×600 were used to ensure a grid-independent solution. Finally, rest of the simulations were performed with 20×30×600 Grid. In fig (b) roughness considered by given two fins. Fins dimension was 10mm x 10mm. In fig (c) three cylindrical bumps were given. For the triangular channel fig (d) we considered the height 45mm and width 45mm. All the figure has same length of 300mm.

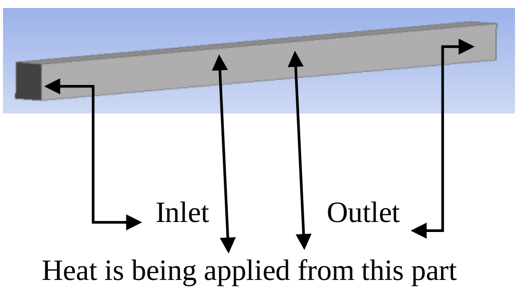

Figure 2.1: Straight Rectangular Mini-channel

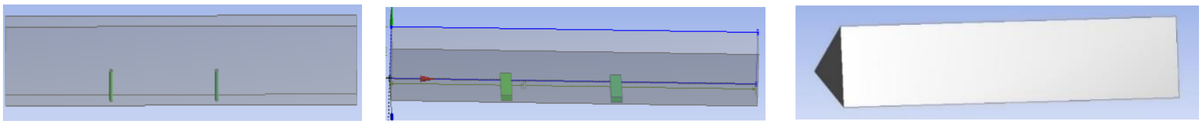

Figure 2.2: Rectangular Mini-Channel with roughness, Cylindrical Bumps & Triangular minichaneel

2.2 Governing Equations:

Computational fluid dynamics constitutes a new third approach in the philosophical study and development of the whole discipline of fluid dynamics. The advent of the high-speed digital computer combined with the development of accurate numerical algorithms for solving physical problems on these computers has revolutionized the way we practice fluid dynamics today. Computational fluid dynamics is today an equal partner with pure theory and pure experiment in the analysis and solution of fluid dynamics problems. There is no doubt that computational fluid dynamics will continue to play this role indefinitely. Applying the fundamental laws of mechanics to a fluid gives the governing equations for a fluid. The conservation of mass equation is,

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{V}) = 0 \qquad (1)$$

And the conservation of momentum equation is,

$$\rho \frac{\partial \vec{V}}{\partial t} + \rho(\vec{V}.V)\vec{V} = -\nabla p + \rho \vec{g} + \nabla.\tau_{ij} \qquad (2)$$

The most complete model we have of the flow of water is the Navier Stokes equations.

1. Conservation of mass: $$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} = 0 \qquad (3)$$

2. Conservation of momentum: $$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} = \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} \qquad (4)$$

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho v^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} = \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} \qquad (5)$$

2.3 PCM properties and flow pattern:

Viscosity: $$\frac{\mu_b}{\mu_f} = (1 - c - 1.16c^2)^{-2.5} \qquad (6)$$

Density: $$\rho b = c.\rho p + (1 - c).\rho f \qquad (7)$$

Thermal conductivity: $$K_b = K_f.\frac{2 + \frac{Kp}{K_f} + 2c.(\frac{Kp}{K_f} - 1)}{2 + \frac{Kp}{K_f} - c.(\frac{Kp}{K_f} - 1)} \qquad (8)$$

Table 1: Physical properties of water and PCM

Fluid	K (W/m k)	Viscosity (cP)	Density (kg/m3)	Cp (kJ/kg.K)
Water	0.613	0.855	997.0	4.180
PCM	0.150	Not applicable	946.5	1.970
Bulk	0.525	1.387	989.4	3.862

2.4 Equations for Mini-channel:

Hydraulic Diameter, $D_h = \frac{4\,hw}{2(h+w)}$

Reynolds Number, $Re = \frac{\rho V D_h}{\mu}$

Nusselt Number, $Nu = \frac{h\,D_h}{k_f}$

Heat transfer coefficient, $h = \frac{q}{T_w - T_i}$

Where, T_w = Wall Temperature T_i = Liquid inlet temperature= 300K

2.5 Boundary Condition:

Inlet: The channel inlet has been chosen to be velocity-inlet and the flow has been assumed to be fully developed flow. The velocity at the inlet has been varied according to the Reynolds number. The Reynolds number range was used in this investigation Re (150,300,700,900).

Outlet: The channel outlet has been chosen to be outflow. The flow rate weighting at outlet is 1. At inner wall surfaces no slip condition prevails i.e. u=v=0. For thermal boundary conditions, adiabatic boundary condition has been applied to all the boundaries of the solid region except at the heater surface i.e. the bottom surface. Heat flux at the bottom surface has been fixed 300000 W/m^2

2.6 Mesh Independence Test:

Grid generation is an important part of simulation, as it affects time, convergence, and results of the solution. Furthermore, regular gridding has better effects on the aforesaid parameters than irregular one dose. Three different mesh were generated for this model. The cells number were respectively 7500, 3960, 2324. For those meshes, velocity profile was plotted lengthwise of the channel. And mesh with 3960 was selected for further simulation.

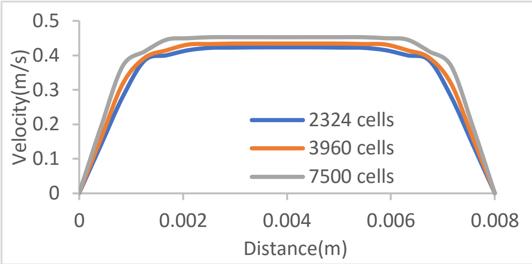

Figure 2.5: Mesh Independence Test

3. Results and Discussion

3.1 EFFECT OF STRAIGHT RECTANGULAR MINICHANEEL:

At the beginning of this study, flow inside a simple straight minichannel has been considered. A three dimensional model of simple straight rectangular channel generated in Gambit subjected to water flow has been used to obtain numerical solution. Since there is no roughness element in the minichannel, no boundary layer separation or flow separation occurs in the fluid flow.

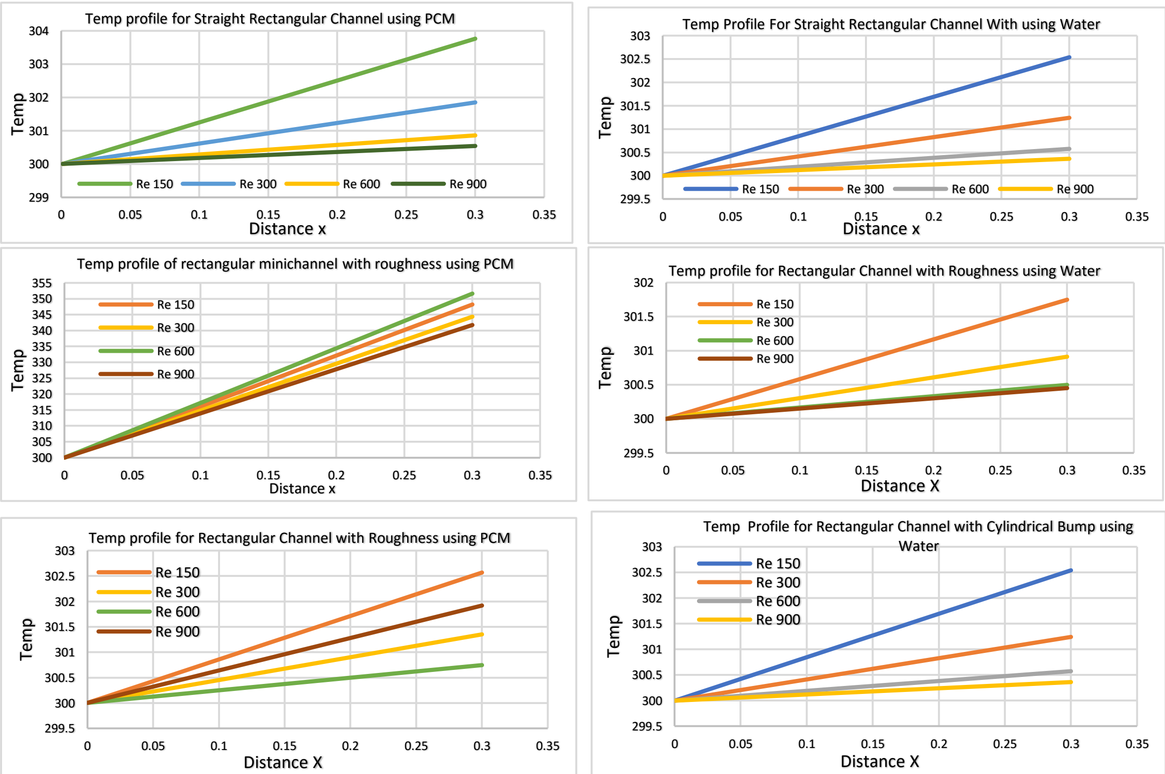

Fig 3.1: Temperature profile of Rectangular Minichannel with different (straight, roughness and cylindrical bump) using both PCM (left) and Water (right)

Figure 3.1 reveals that for the same value of heat flux with place upon Reynolds number, temperature at a particular section decreases. The fact that explains this phenomenon is that at higher Reynolds number means higher velocity of the working fluid. As a result mass flow rate inside the channel increases which in turn increases the energy transfer. Due to increase in energy transfer, the working fluid is able to take away more heat with it.

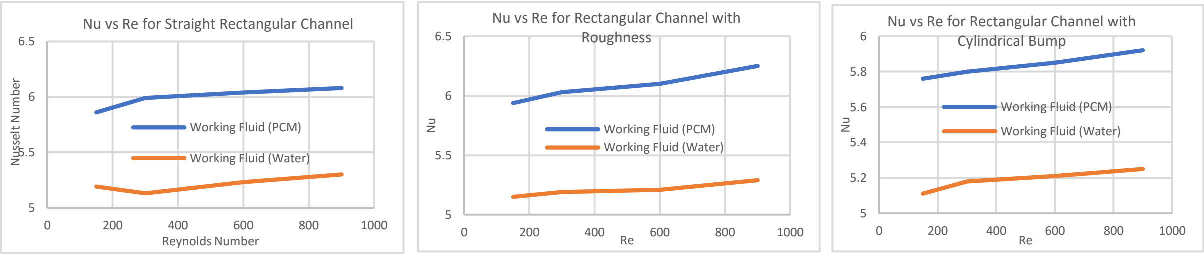

Figure 3.2 : Variation of Average Nusselt Number with Reynolds Number for both PCM and water as Working Fluid in Rectangular Minichannel (Straight, Roughness & Cylindrical bumps)

As a result, temperature of the sink decreases. The temperature profiles for various pressure differences more or less follow the same pattern.

3.4 COMPARISON OF EFECT BETWEEN DIFFERENT RECTANGULAR MINICHANNEL USING PCM:

We made a comparison between all rectangular shape minichannel. We found minichannel with roughness had quite better thermal performance than straight minichannel. It states from the results that increase number of roughness enhanced the thermal performance. In case of bumps it was found different. The nusselt number decreases with exclusion of bumps. So bumps are not suitable in case of enhance heat transfer performance.

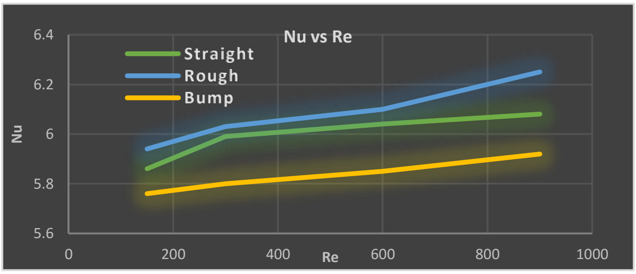

Figure 3.3: Nu vs Re for different geometry of rectangular minichannel

3.6: COMPARISON BETWEEN TRIANGULAR AND RECTANGULAR CHANEEL:

In fig 3.4 indicates Triangular shape minichannel has higher heat transfer performance than rectangular channel with the working fluid PCM. From the calculation it states that nusselt number increased by 9.5% in case of triangular channel. This is a significant enhancement in thermal performance The result clearly shows how the phase change process affects the Nusselt number of the fluid shown in Figs. 3.5 PCM shows increment in heat transfer during fusing process as PCM requires or release a good amount heat. During melting process, the temperature of fluid remains same and a large amount of heat is extracted. Figs. 3.5 shows that phase change process of PCM alternate with use of different shapes. It is observed from the present study that both wall and fluid temperature were higher for triangular minichannel. As temperature is in higher triangular shape this causes phase change effect becomes faster in triangular shape. In case of Nusselt number, it is noted that Nu is higher in entrance region of the channel as boundary layer thickness is very thin. With increase in boundary layer thickness, Nu decreases in PCM. Nu becomes constant at thermally and hydra-dynamically developed region. A fluctuation is observed in the Nusselt number curve for PCM in both shapes. This fluctuation in Nusselt number takes place during phase change process of PCM. Nu was found higher triangular minichannel than rectangular. Fluctuation in Nusselt number due to phase change of PCM started earlier in triangular shape. Nusselt number increases rapidly at the early stage of phase change process. At the end of the phase change process, Nusselt number reaches in minimum value. Firstly, phase change of PCM begins at wall and then gradually spreads in the cross section. While the melting process was taking place near the wall, the temperature of wall was nearly constant but the fluid temperature was increasing. As a result, the difference between the hot

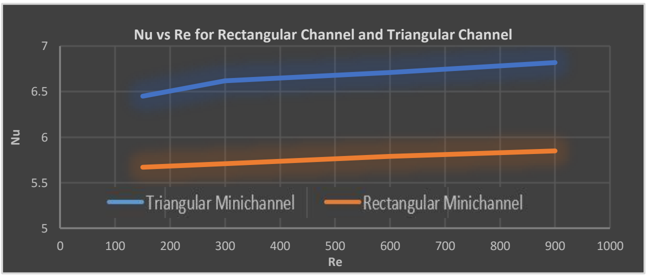

Figure 3.4: Nu vs Re for Rectangular and Triangular channel (Straight)

wall temperature and bulk fluid temperature reduces. Hence both the heat transfer coefficient and Nusselt number increase. At the last stage of melting process, phase change occurs at the centerline. At that time bulk temperature of fluid remains constant but wall temperature increases. As a result, temperature difference increases. Hence both heat transfer coefficient and Nusselt number decrease.

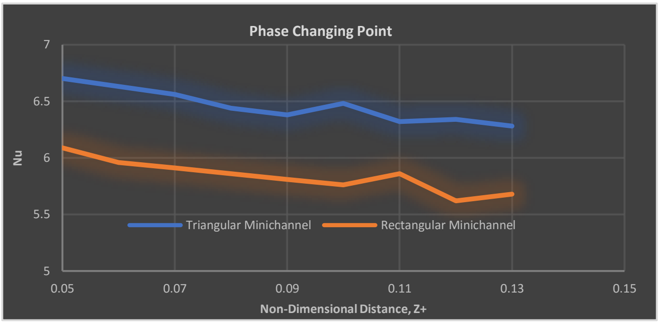

Figure 3.5: Phase changing point for both Rectangular and Triangular channel

4. CONCLUSIONS

Heat transfer performance of PCM fluid in minichannel of different Shapes and geometry was investigated in this study. The important observations that can be noted from the study are presented below:

- Nusselt number is seen to increase in case of PCM compared to water for both straight minichannel and minichannel with roughness.
- Nusselt number is increased in case of rectangular minichannel with roughness compared to straight minichannel
- Triangular minichannel has higher thermal performance than straight rectangular minichannel. Nusselt number is increased by 9.5% in case triangular minichannel than straight rectangular channel.
- Phase changes occurs earlier in triangular channel than in case of straight rectangular minichannel.

5. ACKNOWLEDGEMENT

First and foremost, thanks to most merciful, most gracious and the kindest almighty Allah for giving us with the ability to complete this work properly. Then we like to acknowledge our earnest gratefulness to our esteemed supervisor Dr. A. K. M. Monjur Morshed whose continuous supervision has enabled us to complete this whole work.

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