International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Study of Convective Heat Transfer through Micro Channels with Different Configurations

D. S. Ghodake†* and Rakesh Siddheshwar†

†Mechanical Engineering Department, JSPM's JSCOE, Hadapsar, Savitribai Phule Pune University, Pune, Maharashtra, India

Accepted 02 March 2016, Available online 15 March 2016, **Special Issue-4 (March 2016)**

Abstract

The micro channel heat sinks play a very important role in the functioning of the micro-electronic components. In this paper the focus is on the convective heat transfer performance of the micro channels with different geometric configurations. The heat transfer performance is a function of surface area available for the heat transfer and the heat transfer coefficient of the heat carrying medium. An experimental heat transfer analysis is carried out with different configurations of micro channels. Micro channels with four different configurations are fabricated using Photo Chemical Machining Process. The performance analysis is done in the Reynolds Number range of 15 to 50, with different inlet flow velocities and the experimental analysis emphasis the fact that the geometrical configuration of the channel has a considerable effect on the micro channel heat transfer performance and in turn on the performance of the micro-electronic components.

Keywords: *Convective Heat transfer, Convective Heat Transfer Coefficient, Micro- channel, Nusselts Number, Reynolds Number.*

1. Introduction

Size reduction is the buzzword in the modern electronic industry. But with the reduction in component size, different new problems like heat dissipation becomes critical and sometimes these devices fails due to overheating. Therefore it is very much important to dissipate the heat developed by such small equipments with faster rate or within very short span of time. The most promising solution for this problem is the introduction of micro or mini channels into the heat sinks. The main purpose of introducing micro- channel or mini channel is to increase the surface area which is exposed for heat transfer.

Numerous works have been reported relating to heat transfer as well as pressure drop with different geometrical configurations. However there still a lot of scope remaining for research on heat transfer & pressure drop in the micro- channel. The main objective of this paper is to study the convective heat transfer in micro- channel and also the effects of various parameters such as Reynolds number, inlet velocity of cooling fluid and rise in temperature of cold fluid. This paper mainly focuses on heat transfer through different configurations of micro- channels such as straight, square, triangular, circular and the comparison between them.

Naphon *et al*. (2009) studied the convective heat transfer & pressure drop in the micro- channel heat sink. Kayehpour *et al*. (1997) studied the effects of compressibility and rarefaction on the gas flows in micro-channels. Chen (1998) numerically analyzed the flow characteristics in micro-channels. Ambatirudi *et al*. (2000) analyzed the heat transfer in micro-channel heat sinks. Ng and Poh (2001) applied the CFD for analysis of liquid flow in the double layer micro-channel. Zhao and Lu (2002) presented the analytical and numerical study effect of porosity on the thermal performance a micro-channel heat sink. Xuan (2003) investigated the effect of the thermal and contact resistances of ceramic plate in thermoelectric micro-coolers. Hao and Tao (2004) applied a numerical model to analyze the phase-change flow in micro-channels. Bhowmil (2005) studied on the steady-state convective heat transfer of water from an in-line four electronic chips in a vertical rectangular channel. Zhang *et al*. (2005) reported the study of a single-phase heat transfer of micro-channel heat sink for electronic packages. Didarul (2007) investigated the heat transfer and fluid flow characteristics of finned surfaces. Zhen *et al*. (2007) compared the 3-D and 2-D DSMC heat transfer of flow-speed short micro-channel flows. Wang *et al*. (2008) numerically studied the gas flow and heat transfer in a micro-channel using DSMC with uniform heat flux boundary condition.

2. Experimental Apparatus

The experimental setup consists of mainly three parts which are heater assembly, temperature measuring unit, and different geometries of micro- channels.

*Corresponding author: **D. S. Ghodake**

A. Heater assembly

The heater assembly is as shown in fig.1. For the preparation of heater assembly, initially a wooden block is taken of dimension 130*70 mm as a base. On this wooden base asbestos sheet of 130*70 is placed as insulating material. Now on this asbestos sheet heating coil with Mica sheet is placed and finally over this surface Aluminum sheet of thickness 0.5mm is placed for uniform heating.

Fig.2.1 Heater Assembly

B. Temperature Measuring Unit

This unit is used for measuring inlet & outlet temperature of water to and from the micro channel heat sink. It consists of electronic components like LM35 (Integrated Circuit Temperature Sensor), Microcontroller Board, Potentiometer.

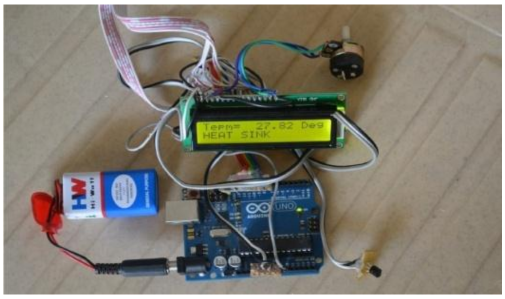

Fig.2.2 Temperature Measuring Unit

Different Geometries of Micro- Channels are used in this study. For the preparation of these different configurations of micro- channel, Copper is selected as raw material due to its higher heat transfer capability.

To study the heat transfer through micro- channels. Following types of micro channel Configurations are selected rectangular, Square, Triangular and Circular. For manufacturing of these configurations a non-conventional machining process such as Photo Chemical Machining is used. After preparation of different configurations of micro- channels they are placed on the heater element and to avoid leakage between the test plate & heater element Teflon coating is provided on the channel. An AC supply is power source for heaters. The rear side of heater is insulated with a thick Mica resistant sheet followed by acrylic sheet & wooden plate. The LM35 thermocouples are used to measure the temperate of inlet & outlet water to and from the micro- channel.

3. Design of Micro Channels

Design Process

A. Selection of Geometries

The following geometries are selected,

- Rectangular
- Square
- Triangular
- Circular

B. Designing of geometries

All geometries are designed by keeping surface area and depth of micro channel as constant.

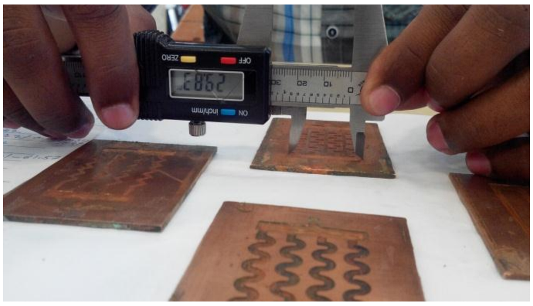

Fig.3.1 Design of Micro Channel

C. Preparation of AutoCAD Drawing

In order to design the different geometrical configurations micro channel heat sink very careful approach has to be adopted. By using AutoCAD 2015 CAD drawings are prepared for different configurations of micro channels.

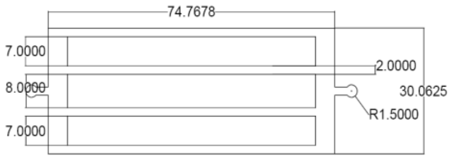

Fig.3.2 Rectangular Micro Channel

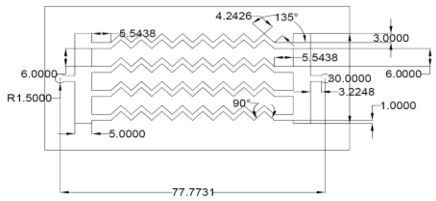

Fig.3.3 Triangular Pattern Micro Channel

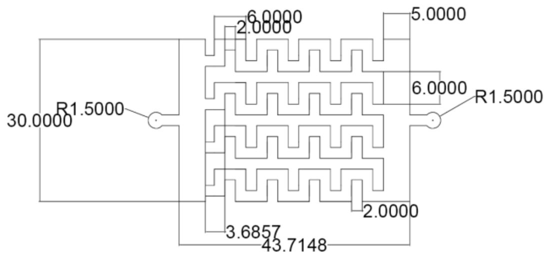

Fig.3.4 Square Pattern Micro Channel

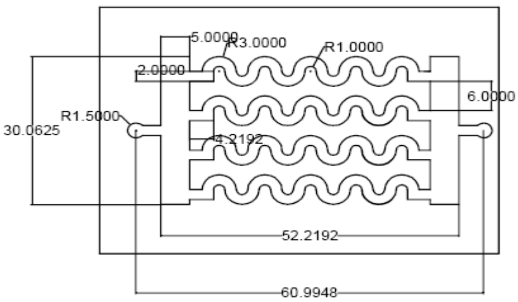

Fig.3.5 Circular Pattern Micro Channel

D. Selection of cold fluid

To find the heat transfer rate through different geometrical configurations of micro channels **water** is considered as **cooling fluid**.

E. Selection of Raw Material

The Copper is selected as a raw material by considering following properties,

- Melting temperature: 1084.62^{0}C
- Thermal conductivity: 401 W/m.K
- Electric resistivity: 16.78 nΩ.m(20^{0}C)
- Size: 50mm*70mm

Channel width: 2 mm
Channel height: 500 μm

4. Calculations

The Heat transferred to the cooling water in the test section, Q_w, is given by,

$$Q_w = m_w Cp_w\, [(T_{w,ave})_{out} - (T_{w,ave})_{in}] \quad (1)$$

Where,

m_w = Mass flow rate of water (Kg/Sec.)
Cp_w = Specific heat capacity of water(kJ/KgK)
$(T_{w,ave})_{out}$ & $(T_{w,ave})_{in}$ are the average outlet and inlet water temperatures respectively.

Heat added to the micro-channel is given by,

$$Q_{heater} = V * I \quad (2)$$

The average heat transfer rate, Q_{avg}, used in the calculation is determined from the heat transferred to the cooling water and the heat supplied to the heat source as follows:

$$Q_{avg} = [(Q_w + Q_{heater}) / 2] \quad (3)$$

The average heat transfer coefficient can be calculated from

$$Q_{avg} = h_m.\, A_m\, (\Delta T_{LMTD}) \quad (4)$$

Where,

$$\Delta T_{LMTD} = \frac{[Ts,avg-(Tw,avg)in] - [Ts,avg-(Tw,avg)out]}{\ln\frac{[Ts,avg-(Tw,avg)in]}{[Ts,avg-(Tw,avg)out]}} \quad (5)$$

Where,
$T_{s,avg}$ = average surface temperature (^{0}C)
A_m = surface area of the micro-channel (mm^2)

The average heat transfer coefficient is presented in terms of average Nusselts Number as given bellow,

$$Nu = \frac{hmDh}{K} \quad (6)$$

Where,
K = Thermal Conductivity of water (W/mK)
D_h = Hydraulic diameter of channel (mm)

The Reynolds number based on D_h of micro- channel is,

$$Re = u\, D_h / \nu \quad (7)$$

Where,

$$D_h = \frac{4\, Acs}{P}$$

Where,
u = Water velocity (m/s)
ν = Kinematic viscosity (m^2/s)
A_{cs} = Cross sectional area of micro- channel (mm^2)
P = Wetted perimeter (mm)

5. Results and Discussions

5.1 Analysis of Square Micro Channel

Table 5.1 Results of Square Micro Channel

Sr. No	h (Experimental)	h (Theoretical)	% Deviation
1.	823.4722	1204.058	31.60
2.	982.2247	1379.240	28.78
3.	1048.513	1516.991	30.88
4.	1144.463	1633.725	29.94

From Fig. 5.1 it is clear that the value of heat transfer coefficient goes on increasing with increase in the value of Reynolds Number. There is around 30 % deviation of experimental value of heat transfer coefficient from theoretical value.

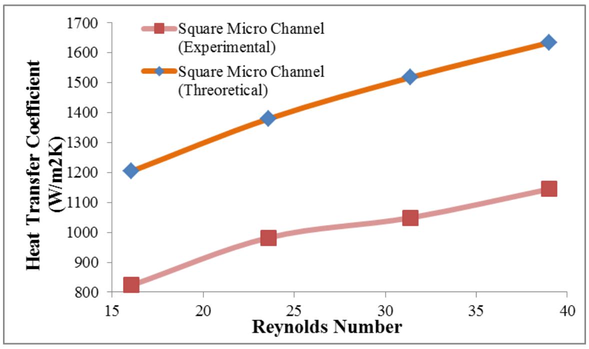

Fig.5.1 Variation of Heat Transfer Coefficient w. r. t. Reynolds Number

5.2 Analysis of Rectangular Micro Channel

Table 5.2 Results of Rectangular Micro Channel

Sr. No.	h (Experimental)	h (Theoretical)	% Deviation
1.	843.764829	1040.4330	18.902
2.	1041.16070	1193.16963	12.739
3.	1210.12729	1432.91467	15.547
4.	1510.45123	1545.55959	2.2715

From Fig.5.2 it is clear that the value of heat transfer coefficient goes on increasing with increase in the value of Reynolds Number. There is around 12 % deviation of experimental value of heat transfer coefficient from theoretical value.

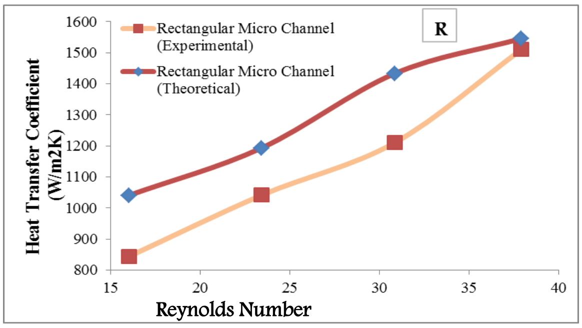

Fig. 5.2 Variation of Heat Transfer Coefficient w. r. t. Reynolds Number

5.3 Analysis of Triangular Micro Channel

Table 5.3 Results of Triangular Micro Channel

Sr. No.	h (Experimental)	h (Theoretical)	% Deviation
1.	1084.78137	1625.29	33.256371
2.	1235.98571	1858.00	33.477945
3.	1488.19582	2045.49	27.245112
4.	1748.91678	2202.65	20.599440

From Fig.5.3 it is clear that the value of heat transfer coefficient goes on increasing with increase in the value of Reynolds Number. There is around 28 % deviation of experimental value of heat transfer coefficient from theoretical value.

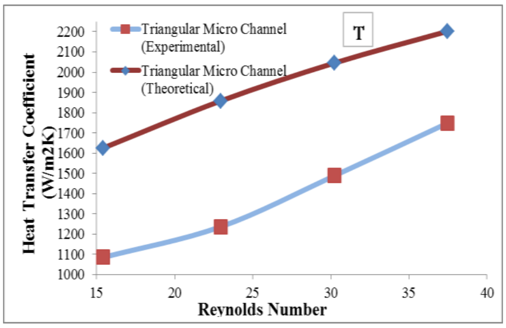

Fig.5.3 Variation of Heat Transfer Coefficient w. r. t. Reynolds Number

5.4 Analysis of Circular Micro Channel

Table 4.4 Results of Circular Micro Channel

Sr. No.	h (Experimental)	h (Theoretical)	% Deviation
1.	857.985545	1136.218331	24.487616
2.	1029.23657	1301.45404	20.916410
3.	1211.94639	1292.465245	6.2298660
4.	1380.67179	1414.991331	2.4254238

From Fig.5.4 it is clear that the value of heat transfer coefficient goes on increasing with increase in the value of Reynolds Number. There is around 14 % deviation of experimental value of heat transfer coefficient from theoretical value.

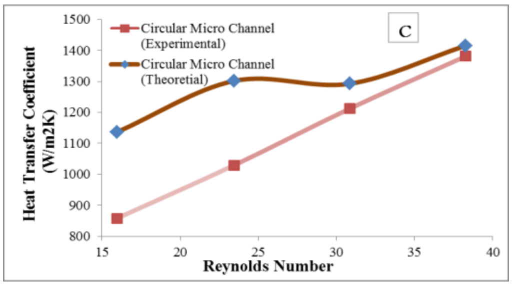

Fig.5.4 Variation of Heat Transfer Coefficient w. r. t. Reynolds Number

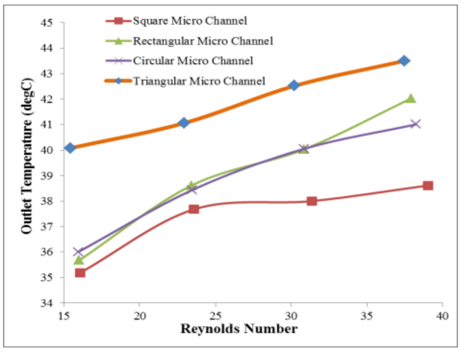

Fig.5.5 Outlet Temperature of Cooling Fluid Vs Reynolds Number

Fig.5.6 shows variation of experimental value of heat transfer coefficient with respect to Reynolds Number. Here also for triangular geometry the experimental value of heat transfer coefficient is higher as compared with remaining three geometries. For triangular geometry the value of heat transfer coefficient is 50 – 55 % more than square geometry, 15 – 20 % more than rectangular and 25 – 30 % more than circular geometry.

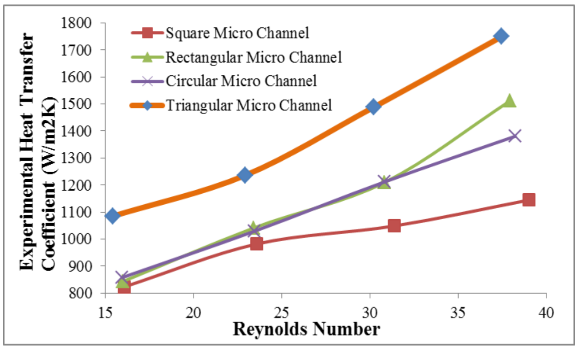

Fig.5.6 Experimental Heat Transfer Coefficient Vs Reynolds Number

Fig.5.7 shows variation of experimental value of heat transfer coefficient with respect to Reynolds Number. For triangular geometry the experimental value of Nusselts Number is higher as compared with rest three geometries. For triangular geometry the value of Nusselts Number is 40 – 45 % more than square geometry, 15 – 20 % more than rectangular and 25 – 30 % more than circular geometry.

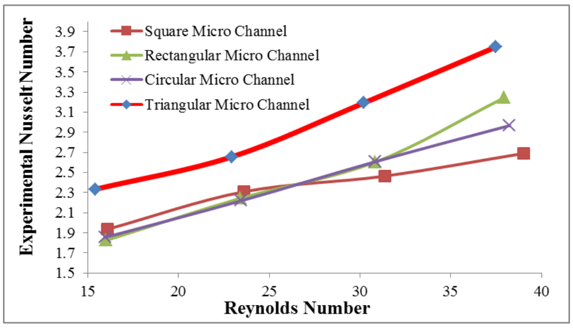

Fig.5.7 Experimental Nusselts Number Vs Reynolds Number

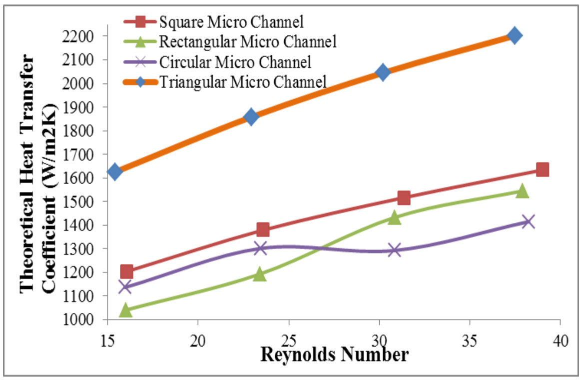

Fig.5.8 Theoretical Heat Transfer Coefficient Vs Reynolds Number

Fig. 4.8 shows the variation of theoretical value of heat transfer coefficient with respect to Reynolds Number. For triangular geometry the theoretical value of heat transfer coefficient is higher as compared with rest three geometries. For triangular geometry the value of heat transfer coefficient is 30 – 35 % more than square geometry, 40 – 45 % more than rectangular and 50 – 55 % more than circular geometry.

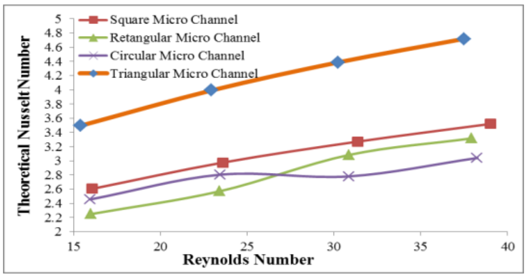

Fig.5.9 Theoretical Nusselts Number Vs Reynolds Number

Fig.5.9 shows the variation of theoretical value of Nusselts Number with respect to Reynolds Number. For triangular geometry the theoretical value of Nusselts Number is higher as compared with rest three geometries. For triangular geometry the value of Nusselts Number is 30 – 35 % more than square geometry, 40 – 45 % more than rectangular and 50 – 55 % more than circular geometry.

5.5 Deviation of Experimental Heat Transfer Coefficient from Theoretical Value

Table 5.5 Deviation of Experimental Heat Transfer Coefficient from Theoretical Value

Square Micro Channel		
h (W/m2K) (Experimental)	**h (W/m2K) (Theoretical)**	**% Deviation**
823.4722994	1204.05803	31.60858703
982.2247447	1379.240787	28.78511469
1048.513128	1516.991344	30.88206253
1144.463988	1633.725639	29.94760193
Rectangular Micro Channel		
h (W/m2K) (Experimental)	**h (W/m2K) (Theoretical)**	**% Deviation**
843.764829	1040.433005	18.90253148
1041.160706	1193.169632	12.73992577
1210.127293	1432.914675	15.54784705
1510.451233	1545.559599	2.271563355
Circular Micro Channel		
h (W/m2K) (Experimental)	**h (W/m2K) (Theoretical)**	**% Deviation**
857.9855451	1136.218331	24.48761634
1029.236571	1301.45404	20.91641044
1211.946391	1292.465245	6.229866056
1380.671793	1414.991331	2.425423877
Triangular Micro Channel		
h (W/m2K) (Experimental)	**h (W/m2K) (Theoretical)**	**% Deviation**
1084.781379	1625.295793	33.25637191
1235.985717	1858.008944	33.47794577
1488.195824	2045.49257	27.24511219
1748.916787	2202.650449	20.59944019

From above graphs it is clear that for every geometrical configuration

1. With increase in outlet temperature of water there is increase in Nusselts number in turn increase in heat transfer.
2. With decrease in surface temperature of heat sink there is increase in Nusselts number in turn increase in heat transfer.
3. With increase in heat transfer coefficient of water there is increase in Nusselts number in turn increase in heat transfer.
4. As temperature rise of cooling water in case of triangular micro channel is much higher as compared with rest three configurations.
5. The increase in heat transfer coefficient of cooling water in triangular micro channel is around 15 – 20% more than rectangular micro channel, 25 – 30% more than circular micro channel and 50 – 55% more than square micro channel. As the value of heat transfer coefficient is more in triangular micro channel therefore, it is concluded that the triangular geometrical configuration is best suited to have higher heat transfer through the micro channel.

Conclusions

Different geometrical configuration of copper micro channels is analyzed for their heat transfer performance in this work. The results show that the geometrical configuration of the micro channel affects the heat transfer performance of the micro channel heat sink to a considerable extent. Comparatively the triangular configuration resulted in giving better performance when compared to other types used in this experimentation.

Acknowledgements

I am thankful to my guide Prof. Rakesh Sidhheshwar for his guidance and being source of motivation to complete the work. I am also thankful to Prof. B. P. Ronge, Principal, SVERI's COE, Pandharpur, Prof. P. M. Pawar, Dean (R & D), SVERI's COE, Pandharpur, Prof. N. D. Misal, Principal, SVERI's COE (POLY), Pandharpur for providing all facilities without which this work would not have been possible. I am thankful to my Micro- fluidics LAB Team for their technical help and suggestions.

References

P. Naphon *et al*. (2009), Study on the convective heat transfer and pressure drop in the micro-channel heat sink", International Communications in Heat and Mass Transfer, 36, 39- 44.

H. P. Kayehpour *et al*, Effects of compressibility and rarefaction on gaseous flows in micro-channel", Numerical Heat Transfer, 32 (1997) 677–69.

C. S. Chen (1998), Numerical analysis of gas flow in Micro channels, Numerical Heat Transfer, 33, 749–762.

K. H. Ambatirudi *et al*. (2000), Analysis of conjugate heat transfer in micro channel heat sinks, Numerical Heat Transfer, 37, 711–731.

E. Y. K. Ng *et al*. (2001), CFD analysis of double- layer micro channel conjugate parallel liquid flows with electric double-layer effects, Numerical Heat Transfer, 40, 735–749.

C. Y. Zhao *et al*. (2002), Analysis of micro channel heat sink for electronics cooling, International Journal of Heat and Mass Transfer, 45, 4857–4869.

X. C. Xuan (2003), Investigation of thermal contact effect on thermoelectric coolers, Energy Conservation and Management, 44, 399–410.

Y. L. Hao *et al*. (2004), A numerical model for phase-change suspension flow in micro-Channels, Numerical Heat Transfer, 46, 55–77.

H. Bhowmil (2005), Convection heat transfer from discrete heat sourced in a liquid cooled rectangular channel, Applied Thermal Engineering, 25, 2532–2542.

H. Y. Zhang (2005), Single-phase liquid cooled micro channel heat sink for electronic packages, Applied Thermal Engineering, 25, 1472–1487.

I. M. Didarul (2007), Study on heat transfer and fluid flow characteristics with short rectangular plate fin of different pattern, Experimental Thermal and Fluid Science, 31, 367–379.

C. E. Zhen *et al*. (2007), Comparison of 3-D and 2-D DSMC heat transfer calculations of flow-speed short micro channel flows, Numerical Heat Transfer, 52, 239–250.

Q. W. Wang *et al*. (2008), Numerical investigation of rarefied diatomic gas flow and heat transfer in a micro channel using DSMC with uniform heat flux boundary condition—Part I: numerical method and Validation, Numerical Heat Transfer, 53, 160–173.

Q. W. Wang *et al*. (2008), Numerical investigation of rarefied diatomic gas flow and heat transfer in a micro channel using DSMC with uniform heat flux boundary condition—Part II: applications, Numerical Heat Transfer, 53, 174–187.

Nomenclature

A	Area (m2)
Cp	Specific Heat, (kJ/kgK)
Dh	Hydraulic Diameter, (m)
h	Heat Transfer Coefficient, (kW/m^2 K)
k	Thermal Conductivity, (W/mK)
m	Mass Flow Rate, (kg/s)
Nu	Nusselts Number
ΔP	Pressure Drop, (kPa)
Pr	Prandtl Number
P	Wet Perimeter, (m)
Q	Heat Transfer Rate, (W)
Re	Reynolds Number
T	Temperature, (°C)
u	Velocity, (m/s)
ρ	Density, (kg/m^3)
w	Water

Subscripts

avg	Average
in	Inlet
out	Outlet