EXPERIMENTAL ANALYSIS OF HEAT TRANSFER AND FLUID FLOW IN MICRO-CHANNEL HEAT SINK

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ABSTRACT

In this paper heat transfer in single phase through micro-channels was studied. The validation of classical correlations of conventional channels to micro-channels is explored. It is found that classical approach is in good agreement with the experimental results of heat transfer in micro-channels. The material used for micro-channel heat sink (MCHS) is copper, experiments were conducted using water as cooling agent in this study. Micro-channels are made with the help of EDM machine on the upper surface of MCHS. Variation of heat transfer rates, effect of friction factor, effect of pressure drop and variation in temperature distribution is investigated in this study. It is observed in the study that with decrease in velocity flow friction also decreases.

KEYWORDS

micro-channel; electronics cooling; friction factor

1. INTRODUCTION

Micro-channel heat exchangers are extensively used in various applications and industries for saving energy and resources. Investigation of micro-channels is based on the single phase internal flow correlation for convective heat transfer:

$$h = N_u \frac{k}{D_h} \quad (1)$$

Nusselt number remains a constant for internal flow. Above mentioned correlation is investigated by Tuckerman and Pease [1]. Their results encouraged and motivated others to investigate heat transfer in micro-channels. Due to miniaturizations of the electronic components and due to space considerations and demand for high speeds, the cooling of electronic components has become a tough challenge. So we need compact heat exchangers which can cool these components at faster rates and may be small in their size so, micro channel type compact heat exchangers offer advantages due to higher heat transfer coefficients. The large surface to volume ratios helps in enhanced heat transfer rates in micro-channels.

Micro-channels are the heat sinks which can transfer large amount of heat and can be fabricated by different techniques [2]. Micro-channels were used first time by Tuckerman and Pease [1]. They used water as a coolant under laminar conditions through micro-channels. They used micro-channels for electronics cooling and able to achieve heat fluxes as high as 790 W/cm² with the chip temperature maintained below 110°C. Various other authors investigated heat transfer in micro-channels [3-7].

X.F. Peng et al. [8] concluded that for flow in micro-channels, the low values of the inner diameter limit the significance of the mixed convection. Chein-Yuh Yang et. al.[9] investigated that at lower values of Re (Reynolds No.) the temperature variation increases along length and

DOI: 10.14810/ijmech.2016.5302

heat losses are higher in the downstream. As the value of Re increases thermal resistance and friction factor decreases but pressure drop, heat transfer coefficient and pumping power increases [10].

Surface roughness plays an important role in the micro-channel performances [11], since at micro level it is nearly impossible to obtain smooth surface. Large roughness of the micro-channel causes high friction factor [12-13]. The convective heat transfer rate can be enhanced by varying boundary conditions, geometry, or by enhancement of thermal conductivity of the fluid [14]. Nowadays nano particles are used for the enhancement of heat transfer rates but they also rises presuree drop [15-19].

The controlling factors for the enhanced heat transfer in micro-channels are velocity of working fluid ,type of heat transfer i.e. single phase or vapor phase, type of material used for heat exchanger ,pressure drop and friction factor.

In present study investigations are made on the above mentioned factors and presented in the form of figures or graphs. It is observed that the conventional heat transfer relations and equations are also applicable to microchannels. Various literatures [1, 20-23] also validate the same.

2. EXPERIMENTAL SETUP AND PROCEDURES

Water as a working or cooling fluid is taken from a reservoir with the help of a pump, which provides steady and smooth flow over wide range of flow rates. Flow rate from 0.3 L/min. to 3.5 L/min are used in this investigation. The fluid enters into the copper micro-channel test section, which is heated by using cartilage heating system. Hot fluid then exits from the test section and passes through the heat exchanger which is used for lowering the temperature of working fluid i.e. water. After that working fluid goes to reservoir. Closed loop cooling system is used in the experimental set-up.

The equivalent hydraulic diameter was calculated using the following expression:

$$D_h = 4A/P \quad (2)$$

Figure 1 Flow Diagram Experimental Setup

Thermocouples were used to measure the temperatures of micro-channel walls (shown in Figure 2). Data acquisition system as shown in Figure 3 is used to read the temperatures and provides temperature distribution across the length of micro-channels. Heat gain by the coolant is provided by the following equation:

$$q = \rho c_p Q (T_{m,o} - T_{m,i}) \quad (3)$$

where Q is volumetric flow rate, $(T_{m,o}$ and $T_{m,i})$ inlet and outlet fluid temperatures.

The actual picture of micro-channel heat sink is shown in Figure 4. The heat transfer coefficient is determined from the following relation:

$$h = q / [NA(T_w - T_m)] \quad (4)$$

The desired flow rates are obtained with the help of needle valve used in the circuit. After the stabilization of flow, heat is supplied to the MCHS through cartridge heaters provided in the bottom of MCHS. The temperature measurements from all the sensors were stored using data acquisition system during the experimentations. Following correlations given in Table 1 are used for investigations.

Figure 2 Position of Thermocouples in Micro Channel

Figure 3 Data Acquisition System Heat Sink

3. RESULTS AND DISCUSSION

The heat transfer correlations used for laminar flows in channels are shown in Table 1 these correlations have been widely used in the literature for comparison against experimental results for micro-channels. The correlations presented in the table are according to different flow and boundary conditions.

Figure 4 Actual Microchannel Heat Sink with Adapters

Table 1 Convection Correlations for Flow in a Micro Channel Heat Sink

conditions	Correlations
Laminar fully developed	$\frac{64}{Re}$
Laminar fully developed, uniform heat flux $Pr \geq 0.6$	$Nu = 4.36$
Laminar fully developed, uniform T_s , $Pr \geq 0.6$	$Nu = 3.66$
Laminar, thermal entry length, uniform T_s	$\overline{Nu} = 3.66 + \frac{0.0668(D/L) Re Pr}{1 + 0.04[(D/L) Re Pr]^{2/3}}$

The changes in pressure drop with respect to velocity i.e. Reynolds no. is shown in Figure 5. It was observed that with increase in velocity the pressure drop also increases. But it is also observed that effect of heat flux on pressure drop is negligible.

Figure 5 Reynolds Number Versus Pressure Drop at Different Heat Fluxes

The variation of experimental fanning friction factor with Reynolds number varying from 350 to 2200 is shown in Figure 6 for micro-channels having hydraulic diameter 0.61 mm and depth 2.5 mm. It was observed that fanning friction decreases up to certain limit with increases in Reynolds no. and after that it increases. The shape of the graph was observed as 'S' in shape.

Figure 6 Reynolds Number Versus Fanning Friction Factor .

It has been from the Figure 7 that there is negligible effect of heat flux on fanning friction. As seen from figure that the fanning friction line remains straight with variation in heat flux values.

Figure 7 Heat Flux Verses Fanning Friction at Different Reynolds Numbers

It was observed that with increase in mass flow rate, the heat transfer rate also increases, which is given by the relation

$$q'' = mc_p \Delta T \quad (8)$$

So with large mass flow rates rise in temperature of micro-channel walls becomes low i.e. cooling will be better.

Same trends were observed for other heat fluxes, as shown in Figures 8 (a),(b), (c) and (d).As flow rate was increased from 0.5 LPM to 2.5 LPM, it was observed that the heat removal rate also increases rapidly.It is also seen from the figure that with increases in flow rate of microchannels will be able to resist the increase in temperature.

(a)

(b)

Figure 8 Temperature distributions along the length of micro channel heat sink (MCHS) in non-dimensional form at different flow rates (a) 17.77 W/cm^2 , (b) 35.55 W/cm^2 , (c) 53.33 W/cm^2 , (d) 71.11 W/cm^2 and (e) 88.88 W/cm^2

5. CONCLUSION

Experimental analysis was made for the fluid flow and heat transfer with micro-channels. The conclusions made throughout the study are discussed in this section. When mass flow rate decreases, friction factor also decreases due to decrease in velocity of flowing fluid. The pressure drop increases with increase in velocity of fluid, thereby increases heat flux removal rate. Initially fanning friction factor decreases as there is increase in mass flow rate. But after certain value of mass flow rate it starts increasing. The heat transfer rate from MCHS increases with increase in mass flow rate. And in turn pressure loss is converted into heat which is carried by the water which was used as cooling agent. So it is observed that conventional mathematical correlations or equations used for conventional channels can be used for micro-channels.

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