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Study of Fluid Flow and Heat Transfer Through Mini-Channel Heat Sink

Hemant Kumar[1] and S.S.Sehgal[2]
[1]*University College of Engineering, Punjabi University, Patiala, Punjab -147 002, India*
[2]*Department of Mechanical Engineering, Chandigarh University, Mohali, Punjab – 140 307, India*
Email: htdhiman@gmail.com

***Abstract* - Mini/Micro-channel type compact heat exchangers have attracted much attention during the last decade. The reason is mainly the possibilities of reducing the size, weight and cost of the heat exchangers compared to current designs. Also, new applications, where objects of small size need to be cooled, as electronics and micro-electro-mechanical devices, require heat exchangers with miniature channels. For the application of mini channel heat exchangers, it is necessary to have accurate design tools for predicting heat transfer and pressure drop. The present paper aims to set up an experimental set-up to study the fluid flow and single phase heat transfer through mini-channel heat sink. The present set-up add to the knowledge of the fundamentals of single phase heat transfer and pressure drop in narrow channels, thereby aiding in the development of this new, interesting technology with the possibility of decreasing the size of electronics through better cooling, and of increasing the energy efficiency of thermal processes and thermodynamic cycles through enhanced heat transfer.**

***Keywords* - Mini Channel, Heat Sink, Fluid Flow, Single Phase, Pressure drop, Heat transfer.**

I. Introduction

Miniaturization in the field of electronics packaging, coupled with faster circuits dissipating higher power has resulted in an increase in the heat flux for microelectronic devices.

Thermal management of electronic devices is one of the important aspects of electronics packaging.

Air has been the fluid of choice in such cooling applications. With the rapid advances in microelectronics technology, the volume occupied by the devices has reduced considerably. But with increasing demand for faster and more efficient processors, the number of circuits and the power dissipation per unit volume has also increased. The combined effect of this has lead to an increase in the heat flux that needs to be removed from the chip surfaces.

Direct cooling of chips offers a practical solution to the heat dissipation problem. In such systems, water (with possible addition of antifreeze to allow cold weather shipments) is circulated in micro/mini channels fabricated on the chip substrate. Cooling of small components by small-scale cooling methods can meet the future needs. Many theoretical and experimental studies have been reported in the past decade. The experimental results for circular micro/mini pipes agree well with the theoretical predictions for conventional ducts.

In electronic components the cooling method mostly used is air cooling. Air as a cooling medium is an easy approach for small components. The set up for such purpose is economically suitable, small, easily assessable and available as well as compact.

But the only disadvantage or drawback of this method is its effectiveness when compared with liquid cooling.

The liquid cooling may be more expensive as compared to the air cooling but its effectiveness is supposed to be more as comparable to its cost. So its cost is compensated when compared with its effectiveness.

Minichannels are fluid flow channels with small hydraulic diameters. Following the classification by Kandlikar and Grande (2003), and later modifications suggested by Kandlikar *et al.* (2004), channels with a minimum cross-sectional dimension between 200μm and 3mm are classified as minichannels and between 1μm and 200μm are classified as microchannels.

II. History

Since the development of the first electronic computers in the 1940s, the development of faster and denser circuit technologies and packages has been accompanied by increasing heat fluxes at the chip and package levels. Over the years, significant advances have been made in the application of air cooling techniques to manage increased heat fluxes. Although air cooling continues to be the most widely used method for cooling electronic packages, it has long been recognized that significantly higher heat fluxes can be accommodated through the use of liquid cooling. Application of liquid cooling for microelectronics may be categorized as either indirect or direct.

In an investigation on the application of conventional refrigeration system to cool IBM's S/390 mainframe, Schmidt showed that the chip temperatures can be maintained below that of comparable air-cooled systems, but well above cryogenic temperatures. The development of a Kleemenko cooler, which provides 80 watts of refrigeration for the CPU at 96 oC, is perhaps one of the significant advances in cooling of computers. The method of cooling technique used depends upon the amount of heat flux to be removed, as shown in Fig.1.

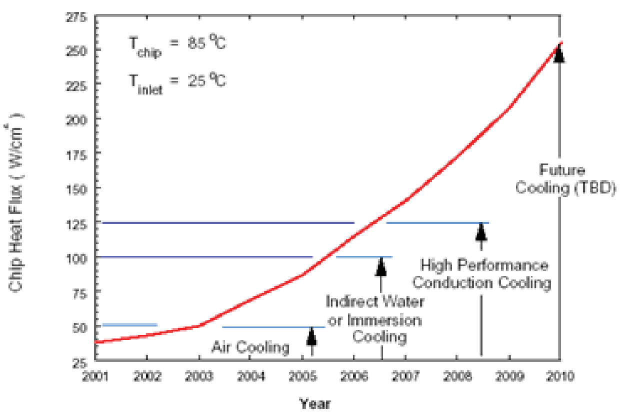

Fig.1 Cooling technologies versus heat flux

Minichannels are found in many biological systems providing very high heat and mass transfer rates in organs such as the brain, lung, liver and kidney. Many high flux cooling applications are effectively utilizing their high heat transfer capabilities for these channels. Small channel diameters are at the heart of all biological systems. Fluid flow and mass transfer in the human body, for example, utilize the high heat and mass transfer coefficients associated with minichannels. Following nature's lead, many heat transfer devices are utilizing minichannels in emerging novel applications, such as high heat flux cooling of lasers and digital microprocessors.

The potential of minichannels in high heat flux removal application was first brought to our attention by the pioneering work of Tuckerman and Pease (1981). The experimental investigations that followed in the next ten years focused on obtaining the single-phase heat transfer and pressure drop characteristics in these channels. A wide array of disparaging results were reported, with frictional pressure drop being very different (higher as well as lower compared to conventional channels), and early transition to turbulence, in some cases as early as Reynolds Number of 300-400.

The need for smaller, faster and lighter products has put considerable demands on the thermal management of microelectronics.

III. Methodology

Distilled Water from a holding tank (reservoir) is driven through the flow loop using pump and provided smooth and steady flow over wide range of flow rates. A ball valve downstream of the flow meter allows fine adjustments of the flow rate from 0.4L/min. to 1L/min., which corresponds to a Reynolds number, range 385-1851. The fluid then enters into mini channel test section through inlet plenum. Heated water exits the test section and the holding tank again.

IV. Results

A. Variation of Temperature difference at inlet and outlet of channel with Reynolds Number

Fig.2.shows the variation of temperature difference at inlet and outlet of minichannel heat sink with Reynolds number at different heat loads for water. It was observed that with the increase of the Reynolds number, temperature difference is decreasing for constant heat flow.

For a mixture of Ethylene Glycol/water (50:50 v/v), the temperature difference is more, which is an important parameter for electronic cooling. As the concentration of Ethylene Glycol in water decreases the temperature difference also decreases which is expected because of the thermo – hydraulic properties of water and Ethylene Glycol.

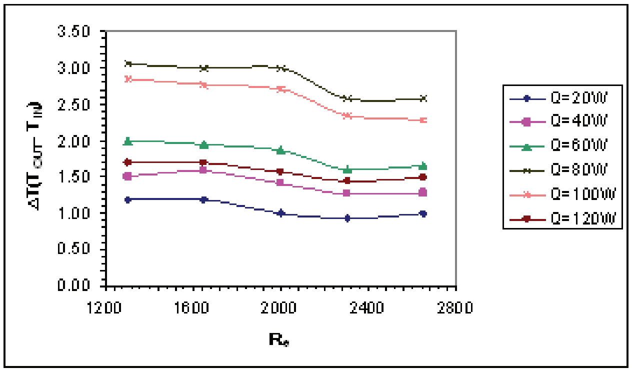

Fig.2 Reynolds number versus temperature difference (T_{out} $-T_{in}$) atdifferent heat loads for water

B.Variation of Fanning Friction factor with Reynolds Number

Fig. 3 shows the variation of experimental fanning friction factor for Reynolds number varying from 1300 to 2650 for water for a minichannel having hydraulic diameter 5mm. It was observed that with the increase in the mass flow rate, fanning friction factor also increases for a constant value of heat flow.

This increase is due to decrease in dynamic viscosity of the water with increase in temperature, which leads to more fanning friction factor. The increase in slope of the curves is due to the decrease in viscosity with increase in temperature and with increase in velocity of flow and mass flow rate. The Similar trends were also observed for a mixture of Ethylene Glycol/water (50:50 v/v) Fig 4.

Fig3 shows, with the increase of heat flow the fanning friction factor increases, because of the decrease in the density of the fluid with temperature increase. The value of fanning friction factor increases with the increase in concentration of water for a particular value of Reynolds number and heat flow as shown in fig 3.

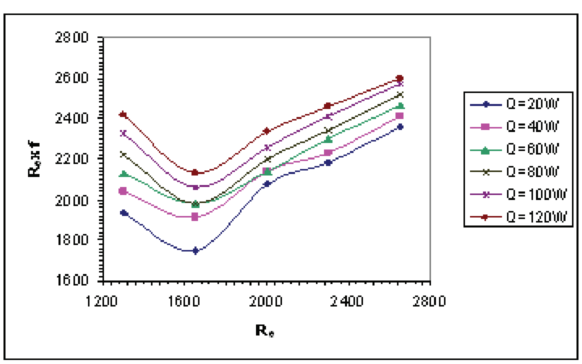

Fig.3. Reynolds number versus fanning friction factor at different heat loads for water

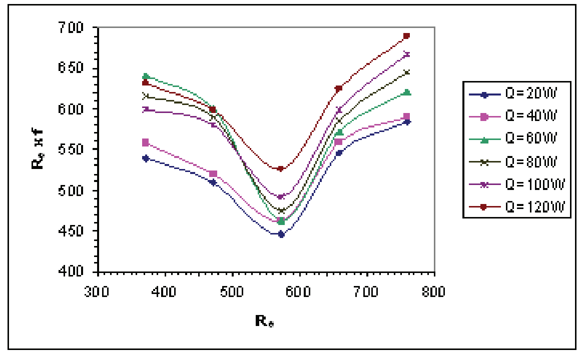

Fig.4. Reynolds number versus fanning friction factor at different heat loads for Ethylene Glycol/water (50:50 v/v).

V. Conclusion

a. When mass flow rate decreases, friction factor increases due to decrease in velocity of flowing fluid.

b. The pressure drop increases with increase in velocity of fluid, thereby increasing heat flux removal rate.

c. The heat removal rate from mini channel heat sink increases with increase in mass flow rate, as with increase in mass flow rate pressure drop also increases, so that pressure loss is converted into heat which is carried by the water which was used as coolant in the flow loop.

Similar trends were also observed in conventional channels, which lead to the conclusion, that even below 5 mm hydraulic diameter, conventional heat transfer equations and methodologies hold well.

VI. Future Scope

- All the process may be repeated for two phase fluid flow and variation in friction factor, temperature drop across the mini channel heat sink, friction factor and pressure drop may be studied.
- Effects of hydraulic diameter may be studied in future. Whole experimentation may be repeated for varying hydraulic diameter of mini channels and their effects on temperature drop and pressure drop are to be studied.
- Effects of dimensions on heat transfer rate, i.e. width and depth may be studied using, different micro/mini channel heat sinks having different dimensions.
- The effect of different kind of materials of mini channel heat sink on heat transfer rate can be studied.

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