STUDY OF HEAT TRANSFER CHARECTERSTICS BY MULTIPLE LIQUID JETS

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ABSTRACT

The problem of cooling of electronic components has become a subject of special interest in recent years due to the increasing capacity and rapidly decreasing size of electronic components. Direct contact cooling using multiple jet impingement is considered as the most effective method. The heat transfer problem is complex and better understanding of jet impingement method is essential for proper application of this method for electronic cooling. Investigations were carried out using electrically heated test plate. Heat flux in the range of 25 to 200W/cm^2, which is a typical requirement for cooling high power electronic components was dissipated using 0.5mm diameter water jets arranged in 7X7 array with a pitch of 3mm. Temperature difference between the test plate and water was within 30^{0}C. Tests were performed in the flow rate range of 22 to 40 ml/min, resulting in the Reynolds number range of 1100 t0 1750. Results show significant increase in heat transfer co-efficient or Nusselt number with increase in heat flux. The effect of flow rate or Reynolds number on heat transfer coefficient is found to be negligible.

INTRODUCTION

With the advances in electronics and communication technology, smaller and more powerful components are being introduced in the market. The demand for high performance electronics has increased; several applications require electronic components to be faster, smaller, able to

handle higher amount of power and more reliable. Small size and high power unfortunately lead to higher heat fluxes that need to be removed from the components to avoid high temperatures and failure. The requirements of high power dissipation and miniaturization demand cooling rates which cannot be obtained using traditional cooling methods such as forced convection, boiling and evaporation. Several methods have been developed to meet the present day demands of high cooling rates. Direct contact cooling using multiple jet impingement is considered as the most effective solution. The multiple jet impingement heat transfer problem is complex and systematic study to assess its effectiveness for cooling electronic components is essential.

Impinging jets for direct liquid cooling of microelectronic components has been investigated by many researchers. *Matteo Fabbri, Shanjuan Jiang, Vijay K. Dhir* [2] conducted a study of cooling using both jets and sprays. Authors have investigated the performances of both sprays and micro jets and the comparison of results has been presented. The following conclusions were made: (a)Micro-jet arrays can have the same or better performance compared to jet sprays with similar flow rate, but with lower pumping power (b)For the same pumping power and wall- to-liquid temperature difference of 76^0 C, the jets could remove heat fluxes as high as 240W/cm^2, while the spray could remove only 93 W/cm^2 (c) In practice, there is always a combination of jet diameter and jet spacing that can yield the same heat transfer coefficients as that of the spray, but at much lower pumping energy costs and (d) A highly populated micro jet arrays were much more preferable than the arrays with few and large jets, because they needed a much lower flow rate to obtain the same heat removal rate.

Womac et al [4] performed experiments with 2x2 and 3x3 jet arrays using water and FC77as cooling fluids. The impinging surface made of copper was a 12.7x12.7 mm^2. Tests were conducted with jet diameters of 0.513 and 1.02 mm and pitches of 5.08 and 10.16 mm. It was found that for a given flow rate, the heat transfer improved with the increase in jet velocity. It was also observed that the reduction in heat transfer that occurs with lowering the flow rate becomes more pronounced at very low flow rates and authors have attributed this effect to the bulk heating of the fluid.

Wang et al. [5] used micro-jet heat sinks to cool VLSI chips. Micro-jet heat sinks can improve temperature uniformity in the presence of chip hot spots. Experimental comparison of micro-jet and micro-channel performance showed that micro-jets have improved thermal uniformity. The results suggested that micro-jet arrays are the preferred micro heat sinks for effective device cooling

Yang Shang, Andrew A. O. Tay Xue Hong [7] investigated heat transfer from single phase and two phase boiling free jet impingement. Experiments were carried out using a free jet impinging on the surfaces of 2mm and 3mm thick film resistor. Effect of jet velocity and sub-cooling were studied. It was found that higher velocities resulted in higher heat transfer coefficients and jet diameter had very little effect in single phase heat transfer. However, higher velocities and larger jet diameters resulted in higher heat transfer co-efficient in boiling heat transfer.

The problem of cooling by jet impingement is complex because of several parameters affecting the heat transfer process. Systematic study of the effect of various factors on the heat transfer phenomena is essential to understand the cooling process. Parametric investigation of cooling of a 2X2 cm^2 heated copper plate has been carried out using a 7X7 array of multiple water jets. The

jets have diameter of 0.5mm and pitch of 3mm. Tests were conducted in the flow rate range of 22 to 34 ml/min. Heat flux and the distance between test plate and nozzle were varied in the range of 25 to 200 W/cm2 and 10 to 20mm respectively.

NOMENCLATURE

A Hot plate surface area (cm^2)

d Nozzle diameter (mm)

h Heat transfer coefficient (W/cm^2c) ($q / (T_c - T_w)$)

Nu Nusselt number (hd/k)

P Total heat transfer (W)

q Heat flux (W/cm^2) (P/A)

Q Total flow rate (ml/min)

R_e Reynolds number (Vd/?)

T_b Bulk fluid temperature (^0C)

T_c Chip surface temperature (^0C)

T_w Inlet water temperature (^0C)

V Jet velocity (m/s)

? Kinematic viscosity (Ns/m^2)

z Nozzle height from chip surface (mm)

? T $(T_c - T_w)$ (^{0} C)

EXPERIMENTAL APPARATUS AND TEST PROCEDURE

The test apparatus is shown schematically as shown in Fig. 1. The apparatus is designed and fabricated to carry out tests using different types of nozzles. The arrangement consists of air compressor, fluid delivery system, heater assembly, jet nozzle head and the test stand. The fluid delivery system consists of a water reservoir, auxiliary reservoir, flow control valves, pressure gauge, filter and piping systems. The auxiliary reservoir acts as a buffer and smooth out flow fluctuations to provide steady flow at the nozzle.

It also serves to achieve fine control over the flow rate. Safety valve is provided to prevent excess pressure build-up in the system.

The heater assembly consists of hot plate, heating element, thermocouples, variable voltage transformer and a control - display system. The hot plate represents the surface of a typical electronic component and is made of Copper. Copper was selected because of its high thermal conductivity. The hot plate is of 20mm x 20mm size and thickness 1mm.

The Jet nozzle head is made of stainless steel and it consists of the nozzle chamber and nozzle plate. The nozzle chamber was connected to the reservoir through a connecting tube. The nozzle plate is made of 3mm thick stainless steel plate.

The nozzle plate was designed to cover the nozzle chamber making it a single leak proof unit. The nozzle plate had 49 holes, each of 0.5 mm diameter, which are laser drilled and arranged in a square array of 7X7 with a pitch distance of 3mm between the holes. The distance between the nozzle plate and the hot plate surface can be varied in the range of 10 to20mm. Experiments were conducted by positioning the jets and the hot plate in both horizontal and vertical positions**.**

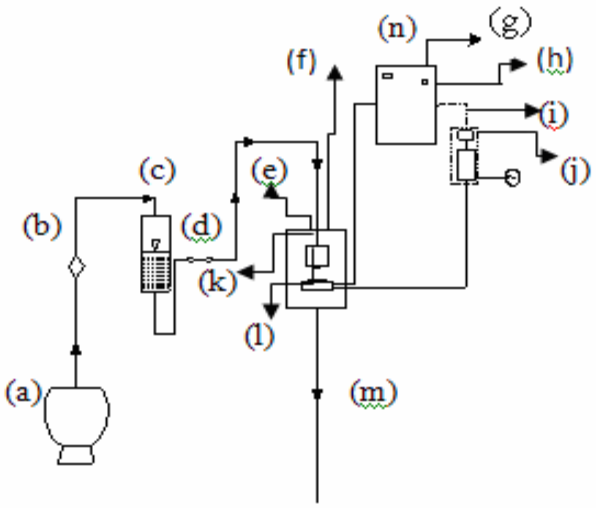

Fig.1 Schematic diagram of the experimental set up

(a) Compressor (b) Filter (c)Auxiliary Reservoir (d)Flow control valve (e)Test stand
(f) Nozzle head (g) Control unit (h) Dimmer stat (I) Variable voltage Transformer
(j) AC power supply (k) Copper chip (l) Heater block (m) Drain out (n) Display unit

RESULTS AND DISCUSSIONS

The heat transfer enhancement using impingement of multiple water jets is complex because of several parameters affecting the heat transfer process.

Fig.[2] shows the variation of heat transfer co-efficient (h) with heat flux for various flow rates, when the nozzle is placed in vertical position. It is observed that (h) increases significantly with heat flux at all flow rates. Similar trends in the variation of (h) with heat flux have been observed with different values of (Z) for both horizontal and vertical positioning of the jets and the test plate. The heat transfer results have been plotted in the non-dimensional form, ln ($Nu/Re^{0.25}$) versus ln(q) in Figs. [3-6] by varying the parameters independently. The effect of (Z) and the horizontal or vertical positioning of the jet and the test plate seems to be less important as compared to the effect of heat flux.

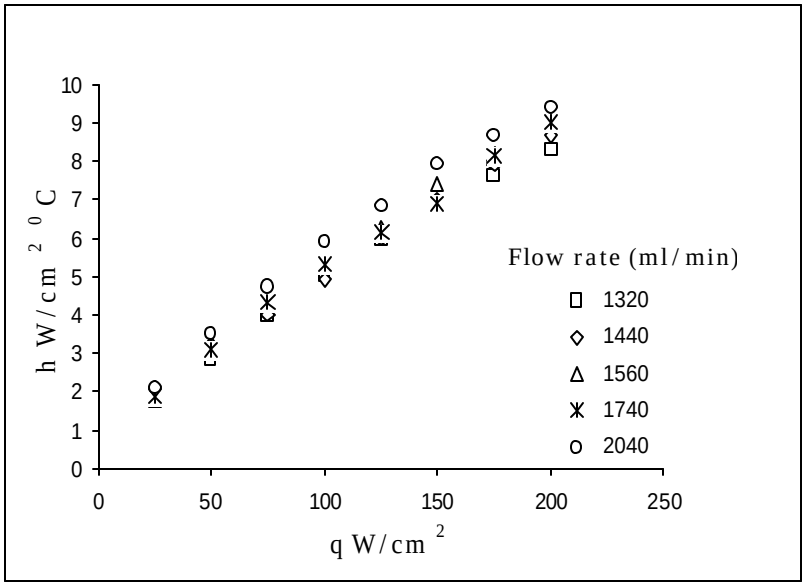

Fig .2 Variation of heat transfer co-efficient with heat flux. Z=20mm, Vertical Position

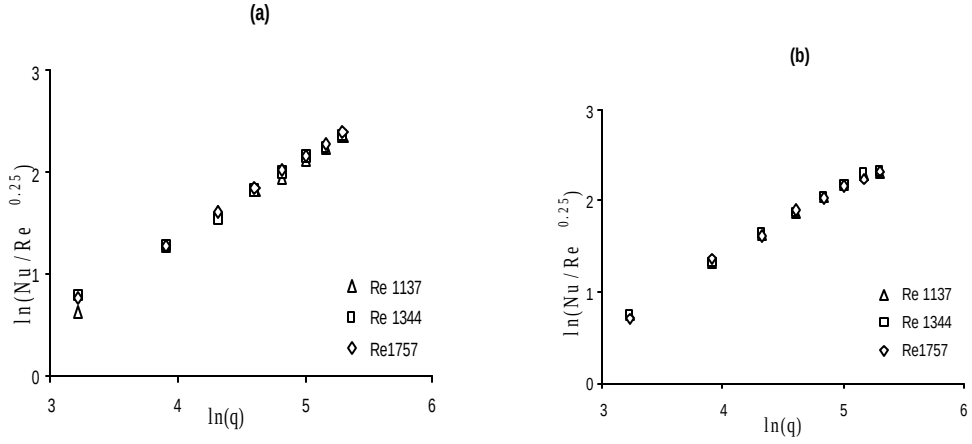

Fig.3. Variation of $Nu/Re^{0.25}$ with heat flux for various Reynolds numbers, horizontal position
(a) Z=10mm (b) Z=20mm

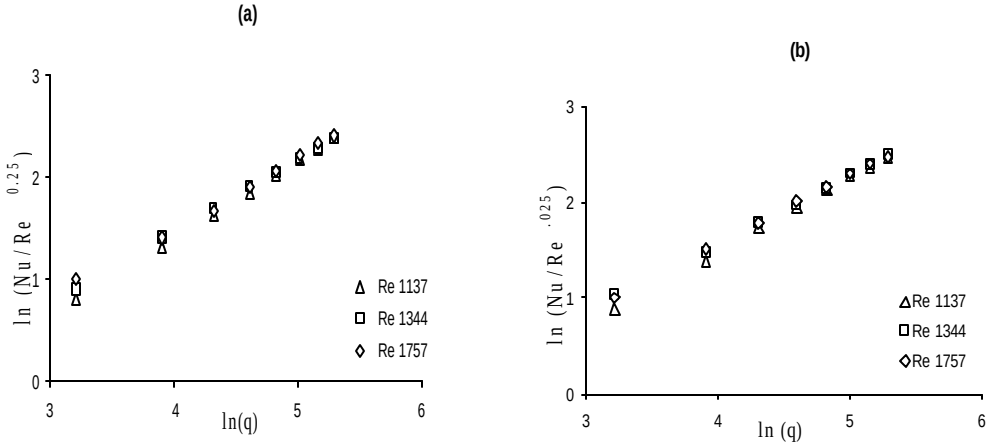

Fig.4 Variation of $Nu/Re^{0.25}$ with heat flux for various Reynolds numbers, Vertical position (a) Z=10mm (b) Z=20mm

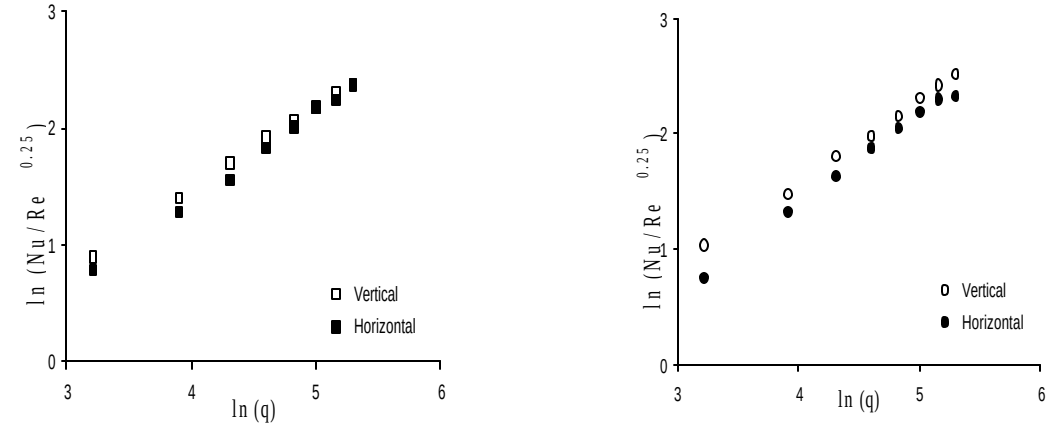

Fig. 5 Variation of $Nu/Re^{0.25}$ with heat flux , Re=1344, Jet in vertical and horizontal position (a) Z=10mm (b) Z=20mm

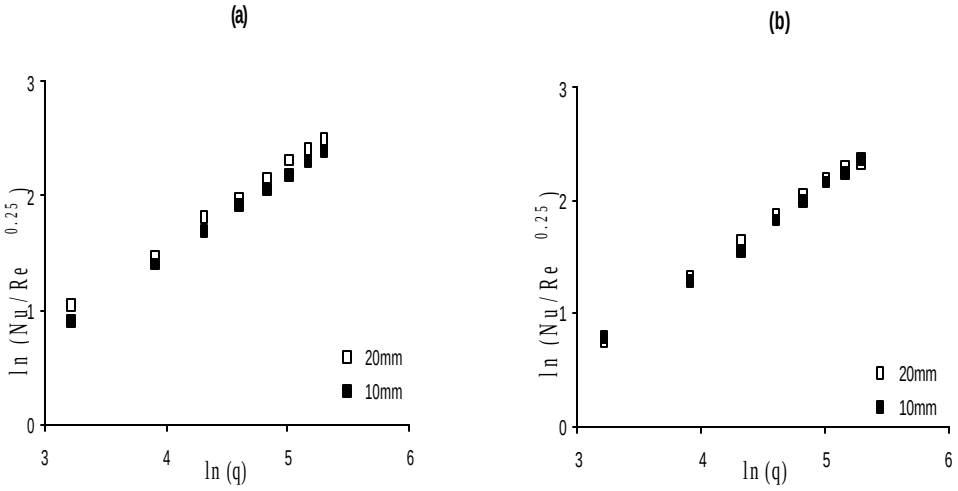

Fig. 6 Variation of $Nu/Re^{0.25}$ with heat flux, Re=1344 (a) Z=10and 20mm vertical position (b) Z= 10 and 20mm horizontal position

CONCLUSION

Experiments were conducted to study the enhancement of heat transfer using impingement of multiple water jets on an electrically heated test plate. Heat flux in the range of 25 to 200W/cm^2, which is typical for high power electronic components was dissipated using multiple water jets of 0.5mm diameter. The temperature difference between the test plate and water is within 30^0C.Tests were conducted by varying the heat flux, flow rate, distance between the heated test plate and the nozzle exit and by keeping the jets and the test plate in both horizontal and vertical positions. It is observed that the heat transfer co-efficient is a strong function of heat flux. The effect of Reynolds number is not significant in the range of testing. The effect of (i) the distance between the heated test plate and the nozzle exit and (ii) horizontal or vertical positioning of the jets and the test plates is found to be negligible.

REFERENCES

[1] Elison, B.and Webb, B.W. "Local heat transfer to impinging liquid jets in the initially laminar, transitional, and turbulent regimes." International Journal of Heat and Mass transfer, 37, no 8, (1994), pp.1207-1216.

[2] Matteo Fabbri, Shanjuan Jiang, Vijay K. Dhir; Comparative Study of Spray and Multiple Micro Jets Cooling for High Power Density Electronic Applications;
ASME Intenational Mechanical Engineering Congress and Exposition Washingtn, D.C., (Nov 2003)

[3] Jiji.L.J and Dagan.Z; Experimental Investigation of Single-Phase Multi Jet Impingement Cooling of an Array of Micro Electronic Heat Sources; Proceedings of the International Symposium on Cooling Technology for Electronic Equipment, W. Aung, ed., Hemisphere Publishing Corporation, Washington.D.C., (1987), pp. 333–351).

[4] Womac.D. J, Incropera.F. P and Ramadhyani.S; Correlating Equations for Impingement Cooling of Small Heat Sources With Multiple Circular Liquid Jets; ASME J. Heat Transfer, 116, (1994), pp. 482–486.

[5] Wang.E.N, Zhang.L, Jiang.L, Koo.J.M, Goodson.K. E, Kenny.T.W, Maveety.J. G, Sanchez.E.A; Micro-machined Jet Arrays for Liquid Impingement Cooling of VLSI Chips, Solid-State Sensor, Actuator and Microsystems Workshop; Hilton Head Island, South Carolina, 2002., June 2-6,

[6] Matteo Fabbri, Shanjuan Jiang, Vijay K. Dhir; "Experimental investigation of single – phase micro jets impingement cooling for electronic applications" ASME Summer Heat Transfer Conference July 21-23, Las Vegas, Nevada, USA,(2003).

[7] Yang Cheng, Andrew A.O. Tay, Xue Hong " An experimental study of liquid jet impingement cooling of electronic components with and without boiling" International symposium on electronic materials and packaging (2001).

[8] Fundamentals of liquid cooling; A presentation in Thermal Management of Electronics, San José State University, Mechanical Engineering Department.

[9] 3M specialty fluids ;http://3m.com/market/industrial/fluid/library (2006).

[10] P.Ing, C.Sperry, R.Philstrom, P.Claybaker, J.Webster and R.Cree; Supercomputer Cooling System; in Proc 43rd electronic Components Technology Conf, (1993), pp.218 -237

[11] Avram Bar – Cohen, Mehmet Arik and Michael Ohadi; Direct Liquid Cooling of High Flux Micro and Nano Electronic Components; Proceedings of IEEE, vol.94, No.8, (2006).

[12] Matteo Fabbri, Vijay K. Dhir; "Optimized heat transfer for high power electronic cooling using arrays of microjets" Transactions of the ASME Vol. 127, (2005).