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An Experimental Investigation of Multiple Water and Air Jet Impingement Cooling

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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 0.25mm and 0.5mm diameter water and air jets arranged in 7X7 array with a pitch of 3mm. The distance between the nozzle and the test plate was maintained at 10 mm with the nozzle placed in both in horizontal and vertical position. Results show significant increase in heat transfer co-efficient about four times with multiple water jets as compared to multiple air jets.

Key words; Heat transfer enhancement, jet impingement cooling.

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.

Eric A. Browne, Gregory J. Michna. Michael K. Jensen and Yoav peles (1) Have conducted a experiment with two micro jet arrays of diameter 54μm and 112μm maintained at a spacing of 250μm. Jet-to- target plate was varied (H/d) between 1.8 and 3.7 and (S/d) pitch to diameter ratio was varied between 2.2 and 4.6. Two fluids deionized water and air were used. Reynolds number range for water is between 150 to3300 and for air it is 300 to 4900. Area averaged Nusselt number and area averaged heat transfer co-efficients of two arrays were reported with both fluids. The effect of the Mach number on the area averaged Nusselt number was found to be negligible.**Colin Gylnn, Anthony J Robinson, Darina B.Murray and Thomson L Lupton (2)** experimentally studied the heat transfer characteristics. The tests were carried out using a 1.22mm diameter jet with both water and air as fluid. Jet to target spacing (H/d) was varied from 2 to 5 and Reynolds number range of 5000 to 20000. Results were presented interms of local heat transfer co-efficients. It has been determined that (i) Lateral heat conduction effects are significant for the air jet measurements but are negligible for water jet results and (ii) The two fluids display hugely different heat transfer co-efficient profiles for the same non-dimensional flow condition.**M. Atlata and E. Specht (3)** have conducted experimental investigation of the convective heat transfer on a flat surface using multiple air jets. A thin metal sheet was heated electrically and cooled using an arrangement of nine jets inline on one side while the other side is black coated. The temperature distribution was measured using an IR camera. The jet Reynolds number was varied in the range of 1400 to 41400.The ratio of the distance between the nozzle and the metal sheet (H/d) was in the range of 1 to 10.The ratio of nozzle spacing to the jet diameter (S/d) was in the range of 2 to 10. The results show that the multiple jets enhance the local and average heat transfer in comparison with the single jet. The maximum heat transfer occurred at the spacing (S/d) = 6. The variation of (H/d) in the range of 2 to 4 seems to have negligible effect on the heat transfer. The relationship between average Nusselt number and the jet Reynolds number follow the relationship $Nu_{av}=0.104\ Re^{0.7}$ **Xianjin and Nader (4)** have investigated the effect of the spacing between the jets (S/d) and the distance between the nozzle and the heated plate (H/d) on the local heat transfer at the Reynolds number of 23,000. Tests were conducted using two circular air jets impinging on a flat plate. The ratios of (S/d) and (H/d) were varied in the range of 1.75 to 7.0 and 2 to 10 respectively. The investigations showed that the local Nusselt number at the centre of the two jets exceeds that at the jet stagnation point when (S/d) is below 3.5. With the values of (S/d) greater than 5.25 and (H/d) =2, the local heat transfer distribution in the region between the jets reaches the maximum values at the ratio of the distance from the stagnation point to the jet diameter (R/d) =0.3 and 1.3. **Dae Hee Lee, Jeonghoon Song and Myeong Chang Jo (5)** have investigated the effect of jet diameter on the heat transfer and fluid flow using a round turbulent air jet impinging on a flat plate surface. The flow at the nozzle exit has a fully developed velocity profile. The uniform heat flux boundary is created at the plate surface using gold film intrex, and liquid crystals were used to measure the plate surface temperature. The experiments were performed for the jet Reynolds number (Re) of 23,000, with the dimensionless distance between the nozzle and plate surface (L/d) ranging from 2 to14 and the nozzle diameter (d) ranging from 1.36 to 3.40 cm. The results show that the local Nusselt number increases with increase in jet diameter in the stagnation point region corresponding to $0 \leq (r/d) \leq 0.5$. This was attributed to the increase in the jet momentum and turbulence intensity level with the larger nozzle diameter, which results in the heat transfer augmentation. The effect of nozzle diameter on the local Nusselt number was found to be negligibly small in the wall jet region corresponding to(r/d) > 0.5.**M. Anwarullah, V. Vasudeva Rao and K.V. Sharma (6)** have performed experimental investigation to study the effect of various geometric parameters on the confined impinging jet flow field and heat transfer characteristics. The array of electronic resistors with three different nozzle cross-sections, viz. square, rectangular and circular each with different and equivalent diameter were used. The study involved the investigation of the effect of Reynolds number and the distance between the nozzle and test plate to jet diameter ratio (H/d) on Nusselt number. Measurements of surface temperatures of the resistors were made in the range of 6500 < Re< 12,500 and

2 < (H/d) < 10 and heat transfer coefficients were evaluated. Local and stagnation Nusselt numbers on the impinged resistor surface have been presented for all the nozzle configurations. The local heat transfer rate at a fixed radial location and the stagnation Nusselt number for different (r/d) ratios were correlated and compared with the data of the earlier investigators. **Huber and Viskanta (7, 8)** have investigated the effects of orifice-target distance separation (H/d) and Reynolds number on the heat transfer using an array of nine confined air jets. At large orifice target spacings (H/d), a single jet yielded higher heat transfer coefficients than jets in the array for a given Reynolds number and (H/d) ratio. For (H/d) values less than unity, the local Nusselt numbers for the jet arrays is nearly equal in magnitude to those for a single jet at the same Reynolds number. As the orifice target spacing (H/d) was decreased from 6 to 1, the local Nusselt number increased at all locations for the range of $(r/d) \leq 3$. In addition when (H/d) < 1, secondary peaks were observed at(r/d)≈0.5 and 1.6. The inner peak was attributed to a local thinning of a boundary layer, while the outer layer is said to be due to the transition to a turbulent wall jet.

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 parameters 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 and air jets. The test plate was selected to simulate the cooling requirement of a typical electronic device used for example, in telecommunication equipment or power electronics. Experiments were conducted with jets having diameter of 0.25mm and 0.5mm arranged with a pitch of 3mm.. Heat flux was varied in the range of 25 to 200 W/cm^2.The distance between the test plate and nozzle is 10mm. Tests were conducted by positioning the nozzle head in both horizontal and vertical positions.

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.

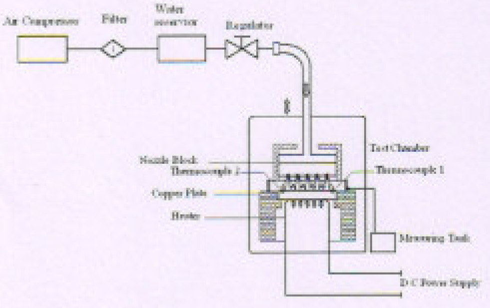

Fig .1(a)

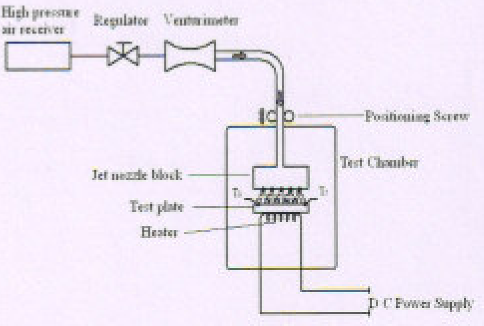

Fig 1(b)

Figure 1: Schematic diagram of the experimental set up (a) water jet impingement (b) Air jet impingemnet.

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 is selected because of its high thermal conductivity. The hot plate is of 20mm x 20mm size and thickness 1mm. The hot plate was mounted on the heating element. The heating element is a Nichrome wire of 16 gauge, 2 ohm, and wattage capacity of 1 kW. The power to the heater is controlled using the variable voltage transformer. Two thermocouples were mounted underneath the hot plate on the centre line and insulated with ceramic insulation. These thermocouples also provide indication of surface temperature uniformity on the plate. The complete heater assembly is mounted and insulated using a Teflon jacket. The leads from the thermocouples are connected to the control display system. The functions of the control and display system includes (a) To vary the heat input to the hot plate using the transformer (b) To display the hot plate surface temperatures, input voltage and current using digital temperature indicator, voltmeter and ammeter and (c)Limit the maximum surface temperature and automatically cut off the power supply when the hot plate temperature exceeds the set value.

The Jet nozzle head is made of stainless steel and it consists of the nozzle chamber and nozzle plate. The nozzle chamber is connected to the reservoir through a connecting tube. The nozzle plate is made of 3mm thick stainless steel plate. The nozzle plate is designed to cover the nozzle chamber making it a single leak proof unit. Two nozzle plates having 0.25mm and 0.5mm diameter holes were used. The holes 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 is maintained at 10mm . The test stand consists of a base tray, mounting plate, hot plate, movable nozzle plate and a top plate held together by vertical support rods. The nozzle head is attached to the nozzle plate which could be moved vertically. A calibrated screw thread assembly is provided along with a circular scale on the top plate. The nozzle plate can be fixed at the desired height by accurate positioning of the calibrated screw head. The hot plate surface is cleaned to remove residual adhesive stains and dust on the surface before starting the experiment. Compressed air is passed through the tube connecting the reservoir and the nozzle head to remove any dust particles which could block the nozzle. The filter is installed in the flow line prior to the auxiliary reservoir. The flow rate, power input and distance between nozzle exit and test hot plate were varied during the experiments. The hot plate is allowed to reach a steady state before acquisition of test data on flow rate, power dissipation and temperatures from thermocouples. Experiments were conducted by positioning the jets and the hot plate in both horizontal and vertical positions.

Results and Discussions

Fig 2 shows the variation of heat transfer co efficient with heat flux for different Reynolds number at Z=10mm and d=0.5mm for a vertical jet. It can be seen from the graph higher values of heat transfer coefficient are obtained with multiple water jet as compared to multiple air jet. Similar variations was observed with d=0.25mm and Z=10mm as shown in fig 3. In both the cases (Fig 2 and 3) the heat transfer coefficient has increased about four times with multiple water jet as compared to multiple air jet.

Fig 4 and 5 shows the variation of heat transfer coefficient with heat flux for different Reynolds number at Z=10mm ,d=0.5mm and d=0.25mm for horizontal jet respectively. Overall there is an increase in heat transfer coefficient with decrease in ΔT when multiple water jet is used. Fig 6 shows the variation of temperature difference with heat flux for different Reynolds number at Z=10 and d=0.5mm for vertical jet.

It is observed that ΔT values for water jets are in the range of 12^0C to 25^0C in the heat flux range of 25 to 200 W/cm^2. But ΔT values up to 70^0C has been noticed with air jet of diameter of 0.5mm. From fig 7 we can notice that the ΔT values in the range of 4^0C to 14^0C as jet diameter reduced to 0.25mm.Fig 8 and 9 shows the jet in horizontal position. From figs 6 to9 We can observe that the significant effect of Reynolds number and jet diameter on heat transfer coefficient. The effect of positioning of the jet, horizontal and vertical is more with d=0,5mm . Overall higher values of ΔT have been obtained with multiple air jet.

Fig 10 to 13 shows the heat transfer results obtained using d=0.5mm and d=0.25mm with different Reynolds number, Z=10 mm and horizontal and vertical positioning of the jet. Similar qualitative variation of heat transfer coefficient with heat flux has been noticed in all cases; The effect of Reynolds number, 'Z' and horizontal and vertical positioning of the nozzle are not significant. It is evident that higher values of heat transfer coefficient are obtained with a 0.25mm diameter jet as compared to 0.50mm jet. Thus the smaller diameter jets are more effective in increasing the heat transfer at a given Reynolds number.

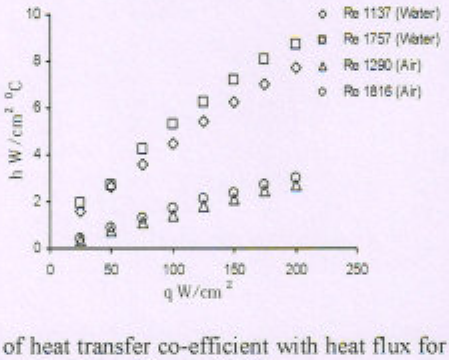

Figure 2: Variation of heat transfer co-efficient with heat flux for different Reynolds number at Z=10mm and d=0.5mm for vertical jet

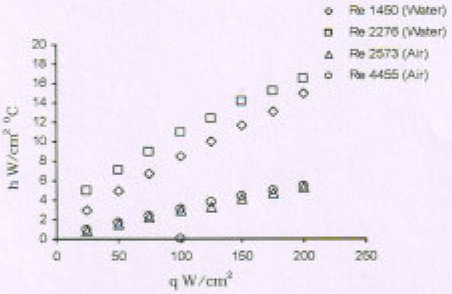

Figure 3: Variation of heat transfer co-efficient with heat flux for different Reynolds number at Z=10mm and d=0.25mm for vertical jet

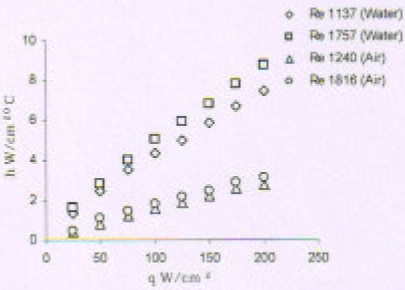

Figure 4: Variation of heat transfer co-efficient with heat flux for different Reynolds number at Z=10mm and d=0.5mm for horizontal jet

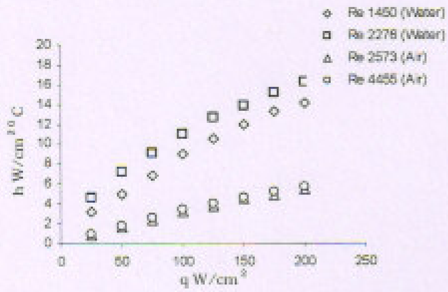

Figure 5: Variation of heat transfer co-efficient with heat flux for different Reynolds number at Z=10mm and d=0.25mm for horizontal jet

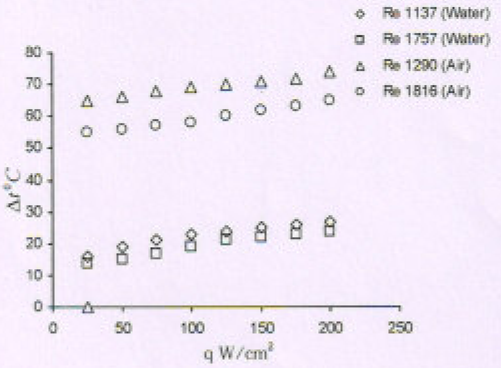

Figure 6: Variation of temperature difference with heat flux for different Reynolds number at Z=10 and d=0.5mm for vertical jet

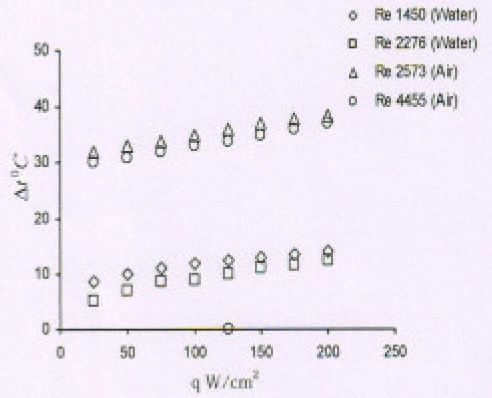

Figure 7: Variation of temperature difference with heat flux for different Reynolds number at Z=10 and d=0.25mm for vertical jet

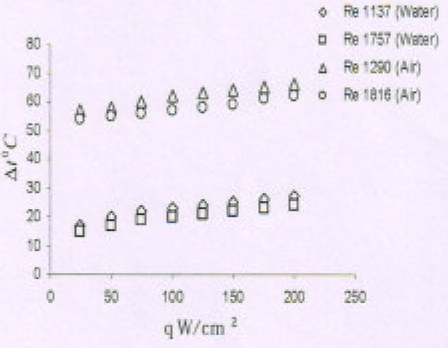

Figure 8: Variation of temperature difference with heat flux for different Reynolds number at Z=10 and d=0.5mm for horizontal jet

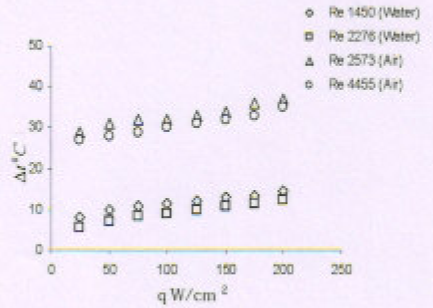

Figure 9: Variation of temperature difference with heat flux for different Reynolds number at Z=10 and d=0.25mm for horizontal jet

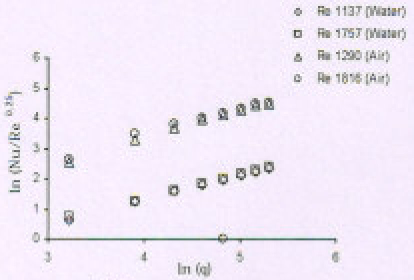

Figure 10: Variation of ($Nu/Re^{0.25}$) with heat flux for various Reynolds numbers at Z=10mm and d=0.50mm for Vertical jets.

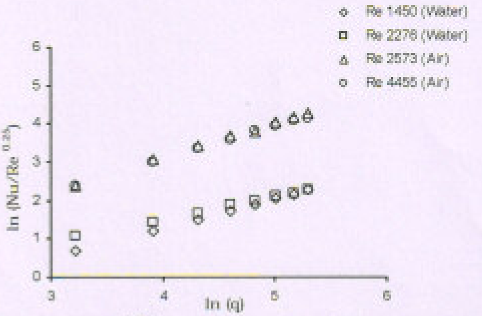

Figure 11: Variation of ($Nu/Re^{0.25}$) with heat flux for various Reynolds numbers at Z=10mm and d=0.25mm for Vertical jets

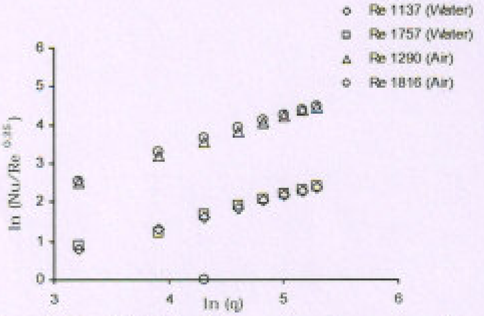

Figure 12: Variation of ($Nu/Re^{0.25}$) with heat flux for various Reynolds numbers at Z=10mm and d=0.50mm for horizontal jets

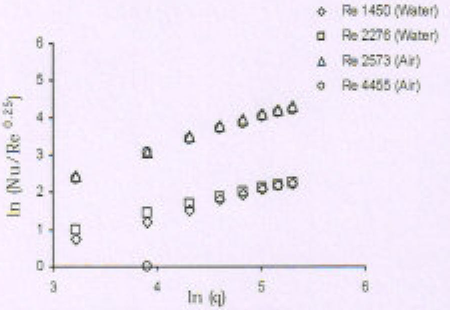

Figure 13: Variation of ($Nu/Re^{0.25}$) with heat flux for various Reynolds numbers at Z=10mm and d=0.25mm for horizontal jets

Conclusion

Experiments were conducted to study the enhancement of heat transfer using impingement of multiple water and air 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 and jets of 0.25mm and 0.5mm diameter. Tests were conducted by varying the heat flux, flow rate, distance between the heated test plate and the nozzle exit and by keeping the nozzle in both horizontal and vertical positions.

It is observed that the heat transfer co-efficient is a strong function of heat flux. Reynolds number plays an important role. The effects of distance between the test plate and the nozzle exit and the horizontal or vertical positioning of the nozzle can be noticed at the lower values of heat flux. The effects of all these parameters decrease when the jet diameter is increased from 0.25mm to 0.5mm. Results show a significant increase in heat transfer co-efficient about four times with multiple water jets as compared to multiple air jets.

Nomenclature

A	Hot plate surface area (cm^2)
d	Nozzle diameter (mm)
h	Heat transfer coefficient (W/cm^{2}c) ($q / (T_c - T_w)$)
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/v)
T_b	Bulk fluid temperature (^{0}C)
T_c	Chip surface temperature (^{0}C)
T_w	Inlet water temperature (^{0}C)
V	Jet velocity (m/s)
v	Kinematic viscosity (Ns/m^2)
z	Nozzle height from chip surface (mm)
ΔT	$(T_c - T_w)$ (^{0} C)

References

[1] Eric A. Browne, Gregory J. micha, Michael k. Jensoen, yoav peles. " Experimental Investigation of Single Phase Microjet Array Heat Transfer" Journal of Heat Transfer, Vol 132, (2010).

[2] Colin Gylnn, Anthony J Robinson, Darina B. Murray and Thomson I Lupton. " Microscale Heat Transfer of Confined Miniature Jets" 4th International Conference on Nanochannels, Microchannels and Minichannels June 19-21, (2006), Limerick ,Ireland.

[3] M. Attalla, E. Specht, "Heat Transfer Characteristics of In-line Arrays of Free Impinging Jets", Heat Mass Transfer 2009 45, pp 537-543,

[4] Xiaojun Y, Nader S, "Measurements of Local Heat Transfer Co-efficient from a Plate to a Pair of Circular Air Impinging Jets". Experimental Heat Transfer 1996, Vol 9 : pp 29-47.

[5] Dae Hee Lee, Jeonghoon Song, Myeong Chang Jo, "The Effect of Nozzle diameter on Impinging Jet Heat Transfer and Fluid flow", ASME.Journal of Heat transfer August 2004, Vol. 126, pp 554-557.

[6] M. Anwarullah, V. Vasudeva Rao & K.V. Sharma, "An Experimental Investigation on the Influence of the Shape of the Nozzle for Flow Field and Heat Transfer Characteristics between Electronic Equipment Surface and Confined Impinging Air Jet, International Journal of Dynamics of Fluids, 2009, ISSN 0973-1784, Vol. 5, No. 2m pp. 129-138.

[7] Huber, A.M. and Viskanta, R., "Convective Heat Transfer to a Confined Impinging Array of Air Jets with Spent Air Exits", ASME Journal. Heat Transfer. 1994, Vol. 116 pp. 570-576.

[8] Huber, A.M. and Viskanta, R., "Effect of Jet-Jet Spacing on Convective Heat Transfer to Confined, Impinging Arrays of Axisymmetric Air Jets," International Journal of. Heat Mass Transfer, 1994, Vol. 37, pp. 2859-2869.

[9] 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).

[10] Lin Z.H., Chou Y.J., and Hung, Y.H.. Heat transfer behaviors of a confined slot jet impingement, International Journal of Heat and M ass Transfer, Vol.40, (1997) pp. 1095-1107.

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