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PARAMETRIC STUDY OF HEAT TRANSFER ENHANCEMENT USING IMPINGEMENT OF MULTIPLE AIR 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 the 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 air jets arranged in 7X7 array with a pitch of 3mm. Tests were performed in the Reynolds number range of 1200 to 4500. Results show significant increase in heat transfer co-efficient with increase in heat flux. Jet Reynolds number plays an important role. Overall, the heat transfer results can be correlated using the relationship $Nu = Aq^m Re^n$ where the constants,A,m and n depend upon the jet diameter and the horizontal or vertical positioning of the jet nozzle. The agreement of the present results with the data obtained from similar studies in the literature is satisfactory.

Keywords: Multiple air jet cooling, Heat transfer enhancement, Effect of jet nozzle position

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.

M. Atlata and E. Specht (1) 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 (2) 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 (3) 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 d" (r/d) d" 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 (4) 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 (5,6) 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) d" 3. In addition when (H/d) < 1, secondary peaks were observed at(r/d)H"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.Jung-Yang San, Yi-MIng Tsou and Zheng-Chieh Chen (7) have experimentally investigated the heat transfer with impingement of circular air jets confined in a channel. The impingement plate was supplied with a constant surface heat flux. Five jets, including one at the center and four neighbouring jets arranged in a staggered array were used. The jet Reynolds number (Re) was in the range 5000-15,000; the jet height to diameter ratio (H/d) was in the range 1.0-4.0; the jet spacing to jet diameter ratio (S/d) was in the range 4.0-8.0; the jet width to jet diameter ratio (W/d) was in the range6.25-18.75. Tests were conducted with the jet plate length to jet diameter ratios (L/d) of 31.7 and 83.3. For the center jet at a given Reynolds number, the stagnation Nusselt number was found to linearly increase with the jet Reynolds number of the four neighboring jets. For all the five jets with the same Reynolds number, the correlation shows that the stagnation Nusselt number at the center jet is proportional to the $Re^{0.7}(W/d)^{-0.49}$. A weak dependence of the stagnation Nusselt number on H/d, S/d and L/d was observed.Tzer-Ming Jeng and Sheng-Chung Tzeng (8) have numerically investigated the heat transfer of a sintered porous block under a confined slot air jet. The width of the jet nozzle (W) is 5 mm; the ratio of the porous block length to the jet nozzle width (L/W) is 12. The ratio of the porous block height to the jet nozzle width (H/W) and the Reynolds number (Re) were varied. The results reveal that the cooling performances with the sintered porous block were better compared with an aluminum foam block. The Nusselt number increased as the (H/W) ratio is reduced. The effect of Reynolds number on the heat transfer was negligible in the range, Re d" 1000 Yahya Erkan Akansu, Mustafa Sarioglu, Kemal Kuvvet and Tahir Yavuz (9) have carried out an experimental study to determine the effects of inclination of an impinging two dimensional slot air jet on the heat transfer from a flat plate. Local Nusselt numbers and surface pressure distributions were measured for various values of inclination angle, jet-to-plate spacing and Reynolds number. The results showed that the angle of inclination is an important parameter in determining the heat transfer. As the inclination angle increases, the location of the maximum heat transfer shifts towards the uphill side of the plate and the value of the maximum Nusselt number gradually increases at lower jet-to-plate spacing.Vadiraj Katti and S.V. Prabhu (10) have performed an experiments to study the effect of jet-to-plate spacing (H/d) and Reynolds number on the local heat transfer distribution on a smooth and flat surface with a normally impinging submerged circular air jet. A single jet from a straight circular nozzle of length-to-diameter ratio (l/d) of 83 was tested. Reynolds number based on the nozzle exit condition was varied between 12,000 to 28,000 and jet-to-plate spacing (H/d) was varied between 0.5 and 8. The local heat transfer characteristics were estimated using thermal images obtained by infrared thermal imaging technique. Measurements of the static wall pressure distribution due to the impingement jet at different jet-to-plate spacing were made. The local heat transfer distributions were analyzed based on the theoretical predictions and experimental results of the fluid flow characteristics in the various regions of jet impingement. The heat transfer from the stagnation point is analyzed from the static wall pressure distribution. Semi-analytical solutions for heat transfer in the stagnation region were obtained assuming an axi - symmetric laminar boundary layer with favorable pressure gradient. The heat transfer in the wall jet region is determined considering fluid flow over a flat plate of constant heat flux. Heat transfer in the transition region were explained from the reported fluid dynamic behavior in this region. Correlations for the local Nusselt numbers in different regions were obtained and compared with experimental results.

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 air jets. The test plate was selected to simulate the cooling requirement of a typical electronic device. The jets have diameters of 0.25mm and 0.5mm and the pitch distance between the jets is 3mm. Tests were conducted in the Reynolds number range of 1200 to 4500. Heat flux was varied in the range of 25 to 200 W/cm^2.The distance between the test plate and the nozzle was maintained at10mm and 20mm. Tests were conducted by positioning the nozzle head in both horizontal and vertical positions. Heat transfer results were analyzed and compared with the data obtained from similar experiments in the literature.

NOMENCLATURE

A	Test plate surface area (cm^2)
d	Jet nozzle diameter (mm)
h	Heat transfer coefficient (W/cm^{2}C) ($q / (T_c - T_w)$)
k	Thermal conductivity(W/mK)
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	Test surface temperature (^{0}C)
T_a	Inlet air temperature (^{0}C)
V	Jet velocity (m/s)
v	Kinematic viscosity (Ns/m^2)
Z	Nozzle height from chip surface (mm)
ΔT	Difference in temoerature between the test surface and air at inlet ($T_c - T_a$) (^{0} C)

EXPERIMENTAL APPARATUS AND TEST PROCEDURE

The experimental arrangement is shown schematically in Fig. 1. The apparatus is designed and fabricated to carry out tests using different types of jet nozzles. The setup consists of an air compressor and the test chamber. The test plate is made of copper and is heated using the heater. The test chamber consists of the test plate, jet nozzle block and the heating element. The variable voltage transformer, control system and display system are provided to control power supply to the heater. The test plate represents the surface of a typical electronic component and is made of Copper. Copper is selected because of its high thermal conductivity. The test plate is of 20mm x 20mm size and thickness 1mm. The heating element is a Nichrome wire of 16 gauge, 2 ohm, and wattage capacity of 1 kW. Two thermocouples are embedded on the test plate on the centre line. These thermocouples also provide indication of the surface temperature uniformity on the plate. The complete test assembly is mounted and insulated using a Teflon jacket. The leads from the thermocouples are connected to the control and display system. The functions of the control and display system includes (a) To vary the heat input to the test plate using the transformer (b) To display the test 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 test plate temperature exceeds the set value. The air flow rate from the receiver is varied using the regulator. The air flow rate is measured using the venturimeter and the water manometer.

The jet nozzle block is made of stainless steel and it consists of the nozzle chamber and jet nozzle plate. The jet nozzle plate is made of 3mm thick stainless steel plate. The jet nozzle plate is designed to cover the nozzle chamber making it a single leak proof unit. Two jet 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 jet nozzle plate and the test plate surface is maintained at 10mm and 20mm. The test chamber includes a base tray, mounting plate, test plate and positioning screw held together by vertical support rods. The nozzle block is attached to the jet nozzle plate which could be moved vertically. A calibrated positioning screw 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 test plate surface is cleaned to remove residual adhesive stains and dust on the surface before starting the experiment. The air flow rate, power input and distance between nozzle exit and test plate were varied during the experiments. The test plate is allowed to reach a steady state before the acquisition of test data on air flow rate, power dissipation and test plate temperatures. Experiments were conducted by positioning the jets and the test plate in both horizontal and vertical positions. The values of test parameters used in the present study are given below:

- Jet diameter = 0.25mm, 0.5mm
- Heat flux range =25 to 200W/cm^2
- Flow Reynolds number range =1200 to 4500
- Distance between the nozzle head and test plate =10mm, 20mm
- Positioning of the nozzle =Horizontal, Vertical

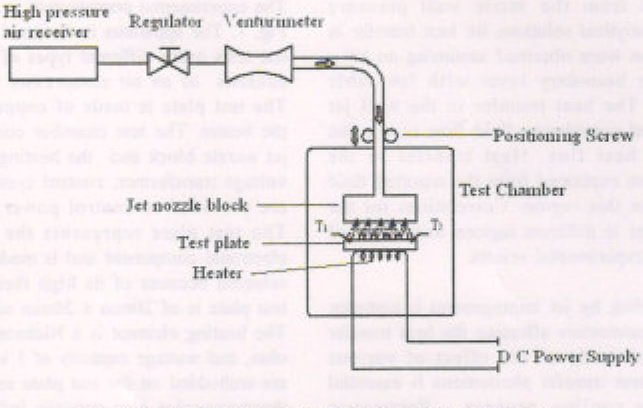

Fig. 1(a): Schematic diagram of the experimental set up

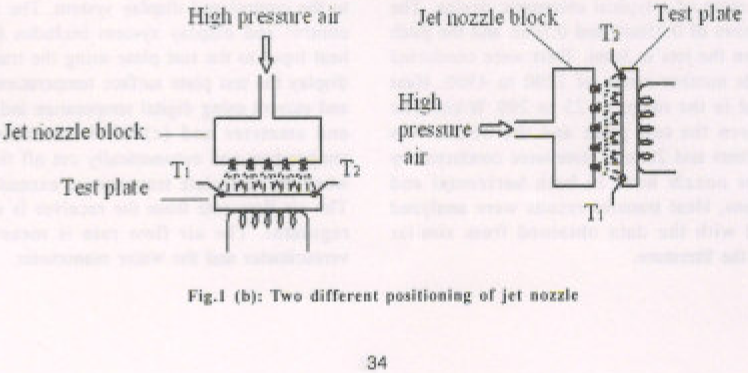

Fig.1 (b): Two different positioning of jet nozzle

RESULTS AND DISCUSSIONS

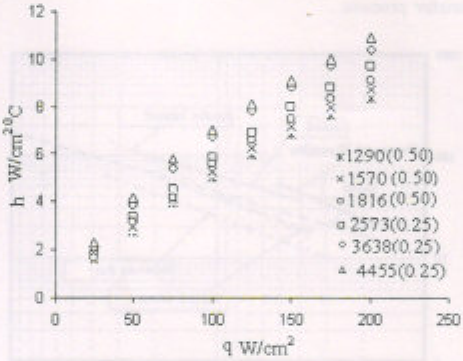

Fig. 2: Variation of heat transfer co-efficient with heat flux at various Reynolds numbers (Z=20mm and horizontal position.Numbers within brackets show the jet diameter in mm)

Fig.[2] shows the variation of heat transfer co-efficient (h) with heat flux at various jet flow Reynolds numbers. Different Reynolds numbers are obtained by varying the mass flow rate and the jet diameter. It is observed that (h) increases with increase in heat flux in all cases.Similer trends in the variation of (h) with heat flux have been noticed with different values of (Z) for both horizontal and vertical positioning of the jet nozzle. The effect of Reynolds number can be easily noticed.

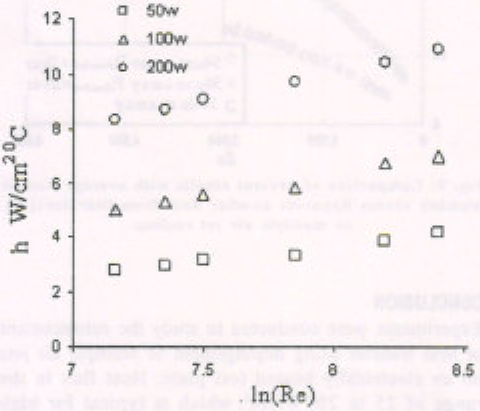

Fig. 3: Variation of heat transfer co-efficient with Reynolds numbers at various values of heat flux

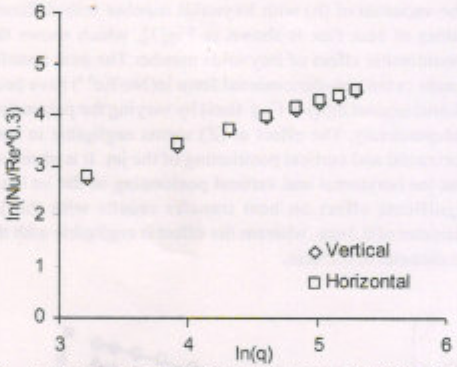

Fig. 4: Variation of Nu/Re$^{0.3}$ with heat flux (Re=2573, d=0.25mm and Z= 20mm) with different jet nozzle position

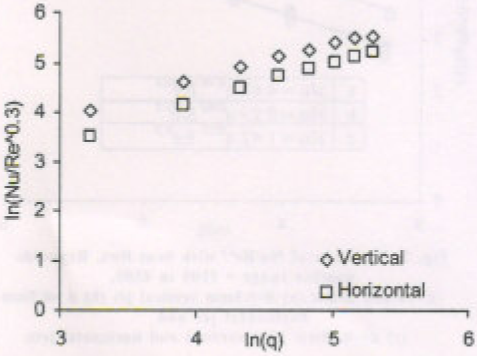

Fig. 5: Variation of Nu/Re$^{0.3}$ with heat flux (Re=1816, d=0.5mm and Z= 20mm) with different jet nozzle position

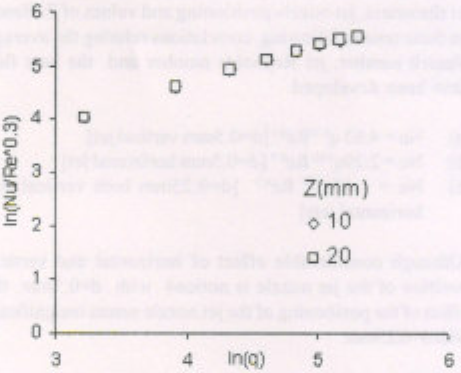

Fig. 6: Variation of Nu/Re$^{0.3}$ with heat flux(Re=1816, d=0.5mm and Horizontal position)

The variation of (h) with Reynolds number with different values of heat flux is shown in Fig[3]; which shows the considerable effect of Reynolds number.The heat transfer results in the non-dimensional form $\ln(Nu/Re^{0.3})$ have been plotted against $\ln(q)$ in Fig(4to6) by varying the parameters independently. The effect of (Z) seems negligible in both horizontal and vertical positioning of the jet. It is observed that the horizontal and vertical positioning of the jet has a significant effect on heat transfer results with the jet diameter of 0.5mm, whereas the effect is negligible with the jet diameter of 0.25mm.

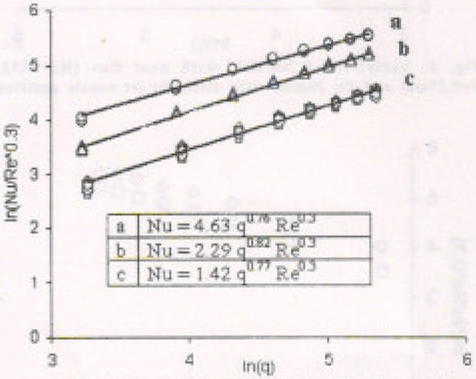

Fig. 7: Variation of $Nu/Re^{0.3}$ with heat flux, Reynolds number range = 1100 to 4500,
Z=10 and 20mm (a) d=0.5mm vertical jet (b) d =0.5mm horizontal jet and
(c) d= 0.25mm both vertical and horizontal jets.

Fig(7) shows the comparison of results obtained with various values of heat flux, different jet Reynolds numbers, jet diameters, jet nozzle positioning and values of Z. Based on these results following correlations relating the average Nusselt number, jet Reynolds number and the heat flux have been developed.

(a) $Nu = 4.63\, q^{0.76} Re^{0.3}$ [d=0.5mm vertical jet]
(b) $Nu = 2.29 q^{0.82}\, Re^{0.3}$ [d=0.5mm horizontal jet]
(c) $Nu = 1.42 q^{0.77}\, Re^{0.3}$ [d=0.25mm both vertical and horizontal jets]

Although considerable effect of horizontal and vertical position of the jet nozzle is noticed with d=0.5mm, the effect of the positioning of the jet nozzle seems insignificant with d=0.25mm.

Figs (8 and 9) show the comparison of the present results with the data on multiple air jet cooling available in the literature. There is a satisfactory agreement between the results, although the multiple jet air cooling problem is complex because of several parameters influencing the heat transfer process.

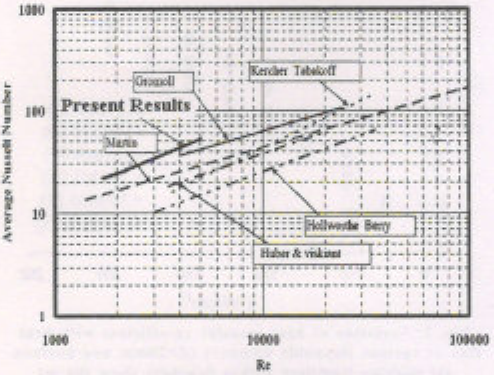

Fig. 8: Comparison of present results with different average Nusselt number versus Reynolds number data from literature[16] on multiple air jet cooling.

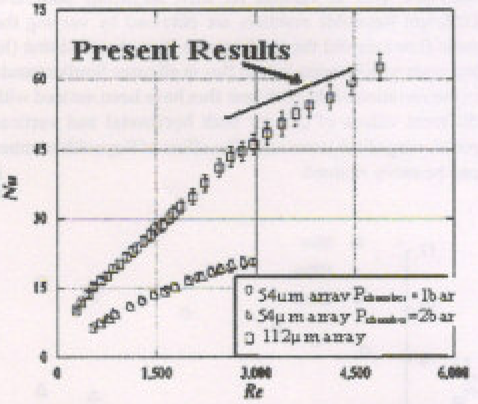

Fig. 9: Comparison of present results with average Nusselt number versus Reynolds number data from literature[17] on multiple air jet cooling.

CONCLUSION

Experiments were conducted to study the enhancement of heat transfer using impingement of multiple air jets on an electrically heated test plate. Heat flux in the range of 25 to 200W/cm², which is typical for high power electronic components, was dissipated using multiple air jets of 0.25mm and 0.5mm diameter. Tests were conducted by varying the heat flux, air flow rate, distance between the heated test plate and the nozzle exit and by keeping the jet 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 the distance between the test plate and the jet nozzle exit is negligible. The horizontal or vertical positioning of the jet nozzle has considerable effect with the jet diameter of 0.5mm. Overall, the heat transfer data can be correlated using the relationship $Nu=Aq^mRe^n$. where the constants A, m and n depend upon the jet diameter and horizontal or vertical positioning of the jet nozzle. The values od $m=0.8$ and $n=0.3$ can be used to explain the effect of heat flux and Reynolds number on the Nusselt number The results of this investigation were compared with the heat transfer data from similar studies available in the literature [Fig 8and 9]. In view of the complex nature of the heat transfer problem associated with cooling by multiple air jets, the agreement between the present results and the data available in the literature is satisfactory.

REFERENCES

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

[2] 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.

[3] 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.

[4] 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.

[5] 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.

[6] 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.

[7] Jung-Yang San, Yi-Ming Tsou, Zheng-Chieh Chen, "Impingement Heat Transfer of Staggered Arrays of Air Jets Confined in a Channel", International Journal of Heat and Mass Transfer 2007, Vol. 50 pp 3718-3727.

[8] Tzer-Ming Jeng, Sheng-Chung Tzeng, "Height Effect on Heat Transfer Characteristics of Sintered Porous Blocks with a Confined Slot Jet", International. Communication in Heat and Mass transfer, 2008, Vol. 35, pp 30-38.

[9] Yahya Erkan Akansu, Mustafa Sarioglu, Kemal Kuvvet, Tahir Yavuz, "Flow Field and Heat Transfer Characteristics in an Oblique Slot Jet Impinging on a Flat Plate", International Communications in Heat and Mass Transfer, 2008, Vol. 35 pp 873-880.

[10] Vadiraj Katti, S.V. Prabhu, "Experimental Study and Theoretical Analysis of Local Heat Transfer Distribution between Smooth Flat Surface and Impinging Air Jet from a Circular Straight Pipe Nozzle", Department of Mechanical Engineering, Indian Institute of Technology, Bombay, India.

[11] D. Lytle, B.W. Webb, "Air Jet Impingement Heat Transfer at Low Nozzle Plate Spacings", International. Journal of Heat Mass Transfer, 1994, Vol. 35 pp 1687-1697.

[12] D.H. Lee, J. Song, C.J. Myeyong, "The Effect of Nozzle Diameter on Impinging Jet Heat Transfer & Fluid Flow", Journal of Heat Transfer, 2004, Vol. 126, pp 554-557.

[13] A.H. Beitelmal, A.J. Shah, M.A. Saad, "Analysis of Impinging Two Dimensional Jet", Journal of Heat Transfer , 2006, Vol. 128, pp 307-310.

[14] J.H. Lienhard, "Heat Transfer by Impingement of Circular Free-Surface Liquid Jets", in: 18th National & 7th ISHMT – ASME Heat and Mass Transfer Conference, January 4-6, 2006.

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

[16] M Attalla " Experimental Investigation of Heat Transfer Characteristics from Arrays of Free Impinging Circular Jets and Hole Channels" Ph.D. Thesis, Otto-Von-Guericke-University Magdeburg Deutschland, 2005

[17] Eric A. Browne, Gregory J.Michna , Michael K.Jensen, Yoav Peles "Experimental Investigation of Single –Phase Microjet Array Heat Transfer", Journal of Heat Transfer April 2010 , Vol.132

[18] Jiang, S., "Heat Removal Using Micro Jet Arrays and Micro droplets in open and close systems for Electronic Cooling.", PhD Dissertation, University of California, Los Angeles, CA, 2002.