Investigation of Heat Transfer Enhancement by Impinging Air Jets

Niranjan Murthy, Raman Singh, Sujay B.J

***Abstract* - The electronic equipments have become a subject of distinct interest in current years due to the increasing capacity and fast 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.**

***Key words-* Multiple air jet cooling, Heat transfer enhancement, Effect of jet nozzle position**

I INTRODUCTION

As the technology advances in electronics and communication. 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.

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 $(r/d) \leq 3$. In addition when $(H/d) < 1$, secondary peaks were observed at($r/d)\approx 0.5$ 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.

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, $Re \leq 1000$

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.

II NOMENCLATURE

A Test plate surface area (cm^2)
d Jet nozzle diameter (mm)
h Heat transfer coefficient (W/cm^2C) ($q / (T_c - T_w)$)

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/ν)
T_b Bulk fluid temperature (^0C)
T_c Test surface temperature (^0C)
T_a Inlet air temperature (^0C)
V Jet velocity (m/s)
ν 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)

III EXPERIMENTAL WORK

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.

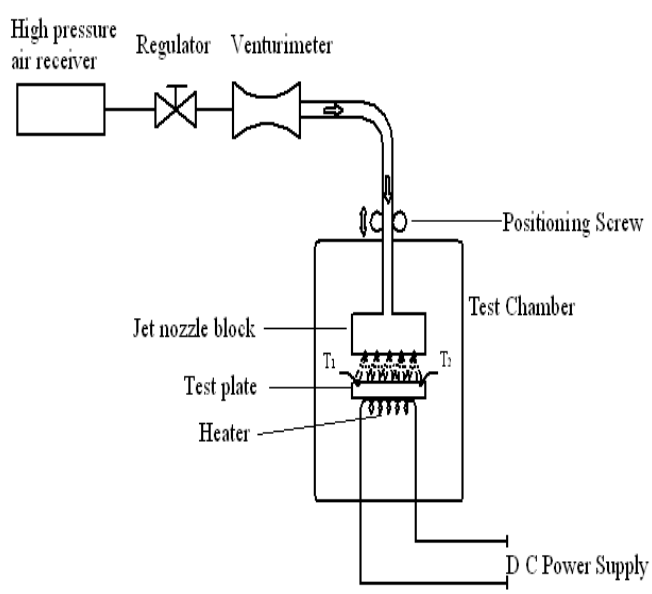
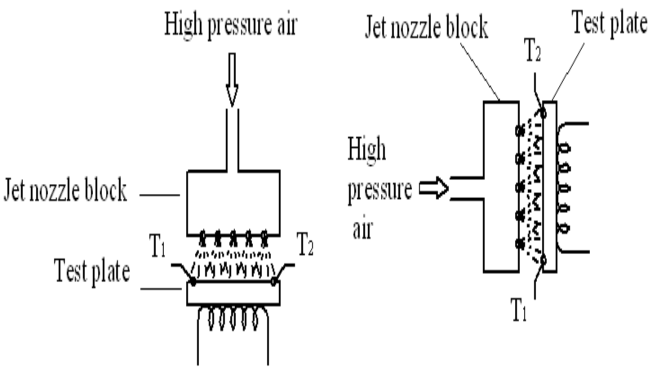


Fig.1(a) Schematic diagram of the experimental set up



(i) Vertical position (ii) Horizontal position

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

IV RESULTS AND DISCUSSIONS

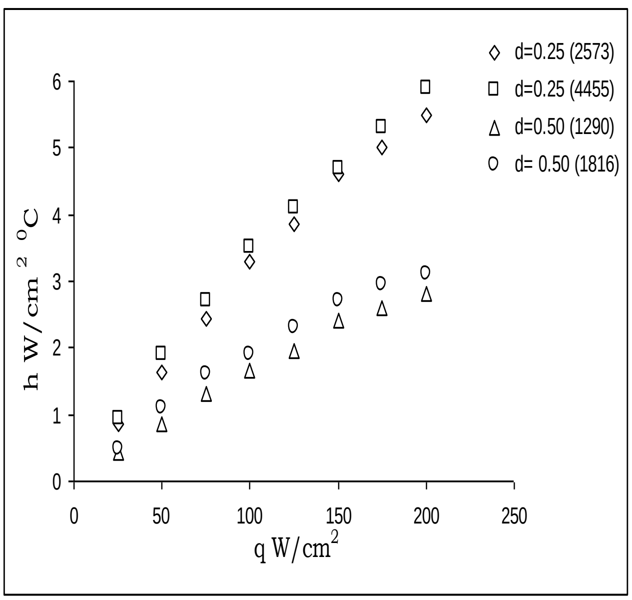


Fig. 2 Variation of heat transfer co-efficient with heat flux for different Reynolds numbers for a horizontal jet at Z=20mm

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 .Similar 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. Reynolds number is calculated based on the fluid flow rate.

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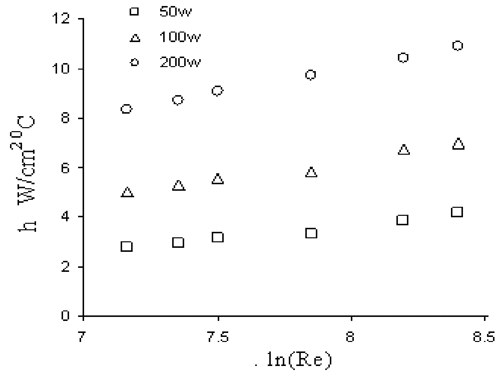

Fig 3 Variation of heat transfer co-efficient with Reynolds numbers at various values of heat flux

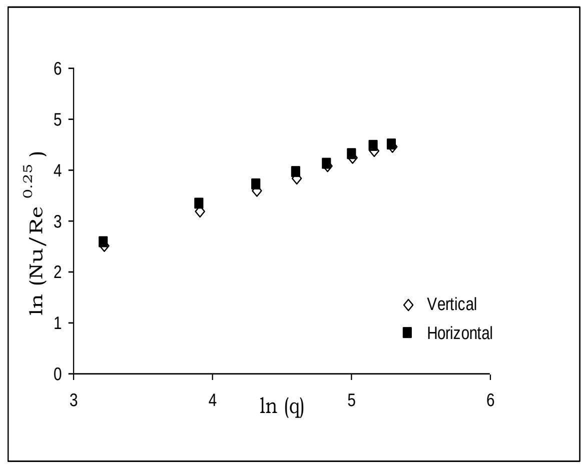

Fig 4 Variation of ($Nu/Re^{0.25}$)with heat flux at Re=1570, d=0.50mm and Z=10mm for both vertical and horizontal jets

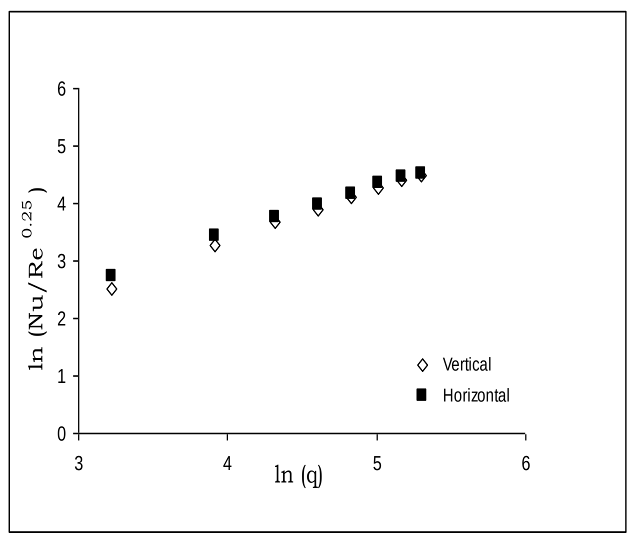

Fig.5 Variation of ($Nu/Re^{0.25}$)with heat flux at Re=1570, d=0.50mm and Z=20mm for both vertical and horizontal jets

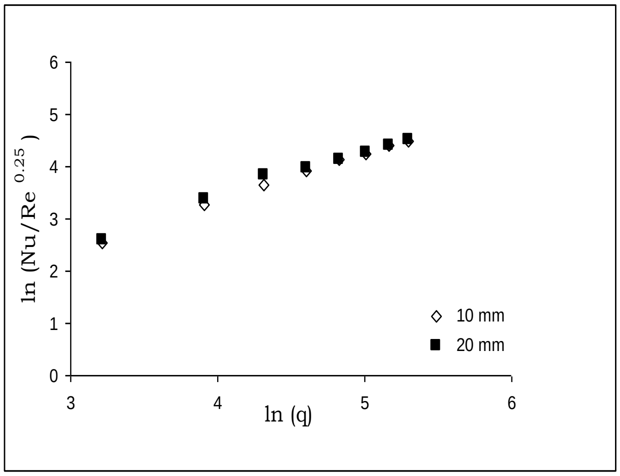

Fig.6 Variation of ($Nu/Re^{0.25}$) with heat flux at Re=1816, d=0.50mm and Z=10 and 20mm for vertical jets.

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.

V 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 $200W/cm^2$, 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.

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Niranjan Murthy [1] Raman Singh [2] Sujay B.J [3]

1. Associate Professor, Dept.of Mech Engg., MSRIT, Bangalore-560054 , India.
2,3 Student Dept. Of Mech Engg., MSRIT, Bangalore-560054, India.