Impingement Heat Transfer with array of Multiple air Jets

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Abstract:- The use of impinging air jets in electronic thermal management is attracting some consideration due to their very high heat transfer coefficients. Direct contact cooling using multiple jet impingements 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. In this investigation an experimental study of cooling capabilities of impinging air jet array is presented. 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 the Reynolds number range of 1200 to 4500. Results shows higher values of heat transfer coefficient are obtained with the lower diameter jets.

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

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I. INTRODUCTION:

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

Anwarullah.M., Vasudeva Rao.V., Sharma.K.V. [1] have conducted experiments to study the effect of test parameters with the confined jet and heat transfer. A square, circular and rectangular cross section jets with different and equivalent diameters were used for the study. The study involves the effect of Reynolds number and the ratio of distance between test plate and jet exit to the jet diameter and Nusselt number. The range of Reynolds number is 6500 to 12500 and of (Z/d) is between 2 to 10. For all the jet configurations, the stagnation and local Nusselt number were evaluated. Authors have developed the correlation between the stagnation Nusselt number, ratios of (r/d) and local heat transfer ratio.

Huber,A.M., Viskanta,R. [2,3] have investigated the effects of orifice-target distance separation (Z/d) and Reynolds number on the heat transfer using an array of nine confined air jets. At large orifice target spacing's (Z/d), a single jet yielded higher heat transfer coefficients than jets in the array for (Z/d) ratio and a Reynolds number. For (Z/d) values less than unity, the local Nusselt numbers for the jet arrays is nearly equal in magnitude to those of a single jet at the similar Reynolds number. As the orifice target spacing (Z/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 (Z/d) < 1, secondary peaks were observed at (r/d) =0.5 and 1.6. Inner peak is due to a confined reduction of a boundary layer. The outer peak is due to the change of a turbulent wall jet.

Jung-Yang San, Yi-MIng Tsou, Zheng-Chieh Chen [4] have studied the heat transfer with a circular air jets confined in a channel. Tests were conducted with five jets arranged in a staggered array. The constant heat is supplied to the impingement surface. The following are the range of test parameters used in this study (i) Reynolds number range of 5000 to 15000. (ii) Ratio of distance between jet exit and test surface to jet diameter (Z/d) of 1 to 4. (iii) The ratio of jet plate length to jet diameter (L/d) of 32 to 84. (iv) The ratio of jet width to jet diameter of (W/d) of 6.25 to 18.75. (v) The ratio of jet spacing to jet diameter of (S/d) of 4 to 8. It was found that stagnation Nusselt number linearly increases with jet Reynolds number. At the same Reynolds number for all the jets tested, the relation shows that the Nusselt number is proportional to the $Re^{0.7}$ $(W/d)^{-0.49}$. The variation of stagnation Nusselt number with (S/d), (L/d) and (W/d) was observed.

Tzer-Ming Jeng, Sheng-Chung Tzeng [5] have studied numerically the heat transfer with a confined slot air jet. The following parameters were considered for the study (i) Ratio of porous block height to jet nozzle width (Z/w) (ii) Reynolds number (iii) Constant jet width of 5mm (iv) Constant ratio of porous block length to jet width (L/W) of 12. Heat transfer results were correlated and better performance was obtained with sintered porous block as compared to aluminum foam block. It was also observed that the Reynolds number effect is insignificant on the heat transfer in the range of Re $\leq$ 1000. The decreased ratio of (Z/w) and (L/w) shows an increased Nusselt number.

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 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

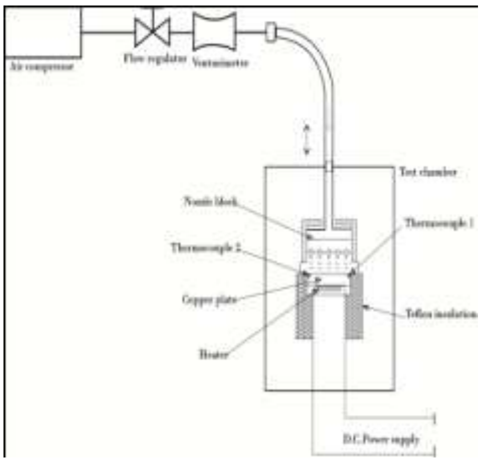

Fig1: Schematic diagram of multiple air jet experimental setup

IV. DATA ACQUISITION

The test plate was allowed to reach a steady state. The test data on air flow rate, velocity, power dissipation and temperatures was acquired. Prior to the recording of the heat transfer data for analysis, experiment was conducted to obtain the time required to reach the steady state. It was found that the average test plate temperature was within 0.1^0C of its steady state value within 10 minutes of required power to the test plate. Test surface temperature measurements were recorded using thermocouples which are mounted underneath of a test surface. The fluid inlet temperature is recorded using a 1.5mm diameter type T thermocouple. The thermocouples were calibrated prior to installation and measurements were compared. The wattmeter was used to measure the heat flux input to the test plate. A Venturimeter is used to measure the air flow rate in the case of multiple air jet experiments. The U-tube water manometer is connected to the inlet and throat of the venturimeter to measure the pressure drop between these two points and hence the volumetric flow rate.

V. RESULTS AND DISCUSSIONS

Figs 1 and 2 show the comparison of results obtained with different jet diameters. Significant effect of jet diameter has been noticed. Higher values of heat transfer coefficient are obtained with the lower diameter jets. This is possibly due to the reason that as the jet proceeds towards the impingement region, the thickness of boundary layer reduces, which causes higher heat transfer coefficients.

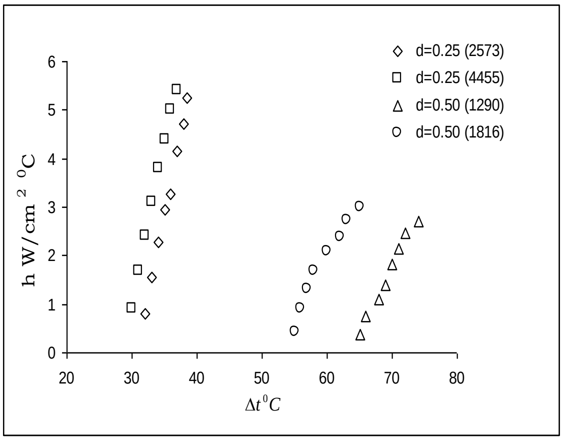

Fig 1: Variation of heat transfer co-efficient with temperature difference for different Reynolds numbers at Z=10mm for vertical jets

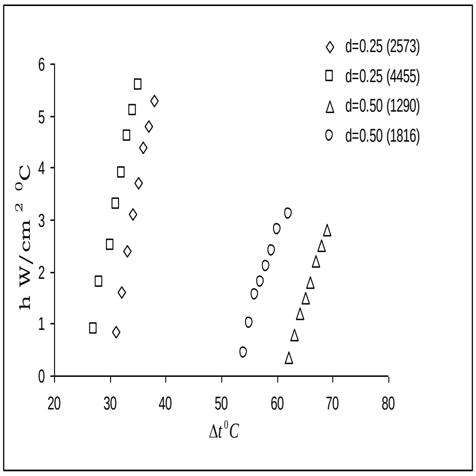

Fig 2: Variation of heat transfer co-efficient with temperature difference for different Reynolds numbers at Z=20mm for vertical jets

With the jet diameter of 0.25mm, lower values of (Δt) have been obtained. Although the tests have been carried out with different jet diameters, the plots show consistent variations with Reynolds number.

Figs 3and 4 show the comparison of results obtained using d=0.5mm and d=0.25mm diameter jets. 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 enhancing the heat transfer at a given Reynolds number.

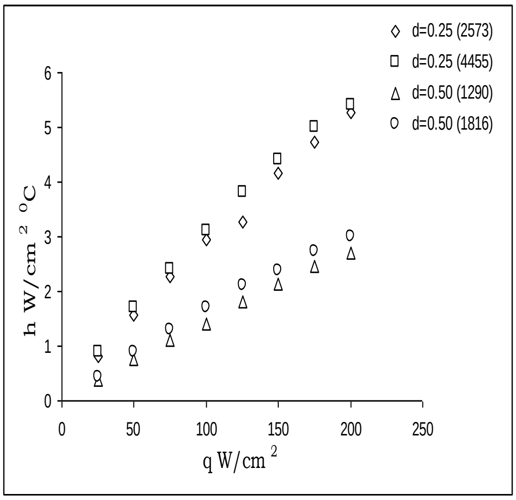

Fig 3: Variation of heat transfer co-efficient with heat flux for different Reynolds numbers for vertical jets at Z=10mm

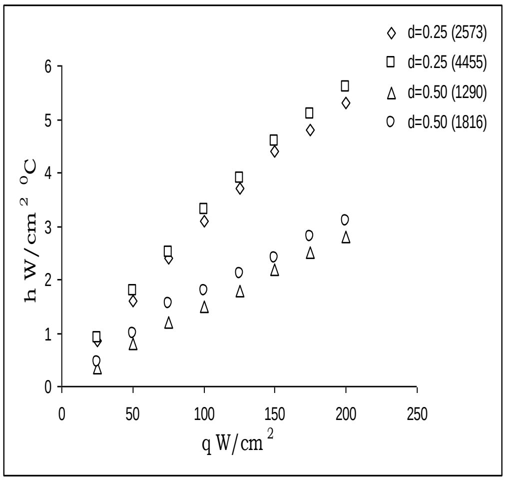

Fig 4: Variation of heat transfer co-efficient with heat flux for different Reynolds numbers for vertical jets at Z=20mm

Figs 5 and 6 show the variation of heat transfer co-efficient with heat flux at Re=1570, d=0.50mm and Z=10 and 20mm for vertical and horizontal positioning of the jets. The heat transfer co-efficient is slightly higher in vertical jets as compared to horizontal jets. The reason being, horizontal surface with vertical jets cools faster as compared to the vertical surface with horizontal jets due to the lower film thickness on the surface.

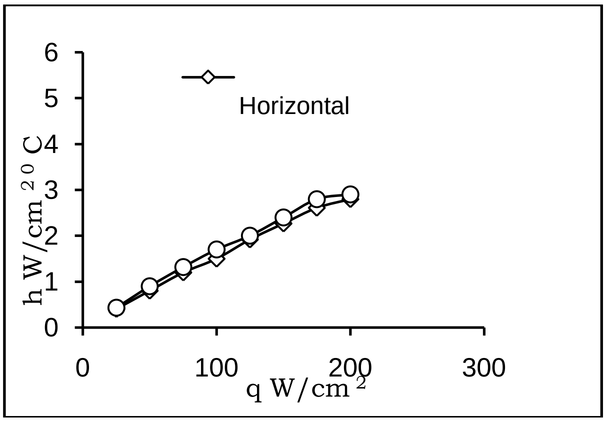

Fig 5: Variation of heat transfer co-efficient with heat flux at Re=1570, d=0.50mm and Z=10 mm for both vertical and horizontal jets

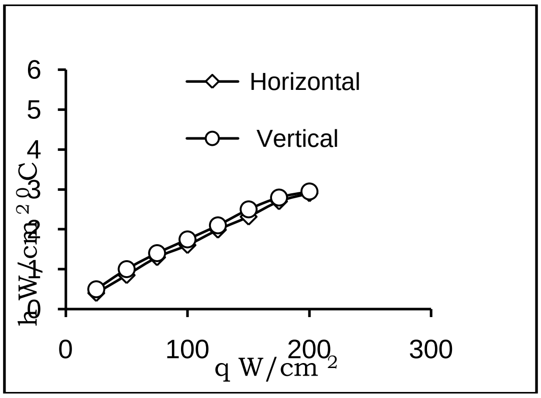

Fig 6 : Variation of heat transfer co-efficient with heat flux at Re=1570, d=0.50mm and Z=20 mm for both horizontal and vertical jets

VI. 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. The effect of Z is negligible.

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