Effect of jet positioning on the heat transfer of a multiple jet impingment

Dr Niranjan Murthy, Ram madhavan, Rohith Virinchi, David Zomuanpuia

Abstract— **The use of impinging multiple water jets in electronic thermal management is attracting some consideration due to their very high heat transfer coefficients. In this investigation an experimental study of cooling capabilities of impinging water jet array is presented. Investigations were carried out using electrically heated test plate. Heat flux in the range of 25 to 200W/cm2, which is a typical requirement for cooling high power electronic components was dissipated**

Index Terms—**jet, electronics, jet impingment, heat transfer**

I. INTRODUCTION

The power consumption and heat dissipation from the electronic components is very vital. The restrictions in both speed and size of the electronic components compelled to upgrade the circuit design and materials to decrease power dissipation considerably through cooling technologies such as free convection and forced convection. Large numbers of industries are interested in high speed computing. Most of the industries considered the cooling of electronic components as a thermal management problem and tried to solve it by incorporating the heat sinks. The requirements of high speed initiated smaller devices and systems. The speed of the personal computers is increasing constantly and is reaching a point where traditional cooling methods are insufficient. Because of this concern, the electronic world is looking for new and more effective cooling techniques. The solution to this problem may be through the introduction of new materials, latest cooling technologies and change in cooling technology concepts and methods of execution.

Vadiraj Katti, S.V. Prabhu [1] Conducted an experiment to study the effect of jet-to-plate spacing and Reynolds number on the local heat transfer distribution to normally impinging submerged circular air jet on a smooth and flat surface. A single jet from a straight circular nozzle of length-to-diameter ratio (l/d) of 83 is tested. Reynolds number in the range of 12000 to 28000 and jet-to-plate spacing between 0.5 and 8 nozzle diameters were tested. The local heat transfer characteristics are estimated using thermal images obtained by infrared thermal imaging technique. Measurements for the static wall pressure distribution due to impingement jet at different jet-to-plate spacing were made. The local heat transfer distributions were analyzed based on 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 solution for heat transfer in the stagnation region is obtained assuming an axisymmetric laminar boundary layer with favorable pressure gradient. The heat transfer in the wall jet region is studied considering fluid flow over a flat plate of constant heat flux. However Heat transfers in the transition region are explained from reported fluid dynamic behavior in this region. Correlations for the local Nusselt numbers in different regions are obtained and compared with experimental results.

Lytle and Webb [2] conducted the experiments to study the effect of very low nozzle to jet spacing ($z/d < 1$) on the local heat transfer distribution on a flat plate impinged by circular air jet issued by long pipe nozzle which allows for fully developed flow at the nozzle exit and found that in the acceleration range of nozzle plate spacing ($z/d < 0.25$), maximum Nusselt number shifts from the stagnation point to the point of secondary peak and the effect being more pronounced at higher Reynolds number

C. Kinsella, B. Donnelly, T.S. O'Donovan, D.B. Murray [3] performed a research concerned with the design of swirl jet which aims to enhance the surface heat transfer from a heated surface in a radially uniform manner. Tests were conducted in the Reynolds number range of 10000 to 30000 for a wide range of parameter . The surface to nozzle distance was varied in the range of 0.5 to 0.6 and degree of swirl (S= 0 to 2.25^{o}/mm). Results have shown that the swirl generator increases the heat transfer overall but this is may be due to the increased jet turbulence which has a greater influence on the surface heat transfer than the swirling motion of the flow. At low H/D, the surface heat transfer is reduced in the stagnation zone due to the swirl generator blockage of the jet flow. It has also been found that the optimum degree of swirl from a heat transfer perspective is a function of the nozzle to impingement surface distance.

Slayzak et al. [4] conducted the experiments to study the local heat transfer coefficient on a surface with a constant heat flux. They were used two jets but two quarter as the fluid. The experiments were carried out for a slot nozzle and only for one nozzle-to-plate distance. They showed that there is an oscillating interaction zone midway between the impingement points. Within the stable interaction zone, there is a local maximum, in a heat transfer coefficient.

Beitelmal et al [5] investigated the effect of the inclination of an impinging two dimensional air jet on the heat transfer from a uniformly heated flat plate. Their measured data was in the range of $4000 \leq Re \leq 12{,}000$, $4 \leq z/D \leq 12$ and $40^{o} \leq \theta \leq 90^{o}$. They found that, for low values of inclination angle, the local

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Nusselt number on the uphill side from the maximum heat transfer point was insensitive to jet exit-to-plate spacing.

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 Schematic arrangement of experimental setup is shown in Fig. 1. The experimental setup is designed and fabricated to carry out tests using different types of jet nozzles with the varying positions for horizontal and vertical positioning of jets. It consists of an air compressor auxiliary reservoir ,flow control valve 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 fixed 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 flow rate from the receiver is varied using the regulator. The flow rate is measured using the water manometer .The experiments were conducted for vertical and horizontal positioning of jets 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 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 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 and horizontally.

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

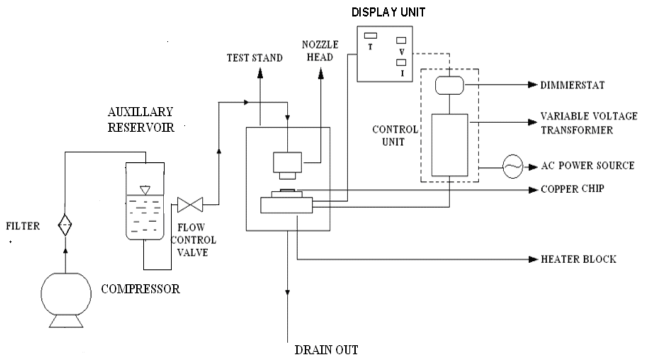

Fig1: Schematic diagram of multiple water jet experimental setup

IV. RESULTS AND DISCUSSIONS

Fig 2 show the variation of heat transfer coefficient as a function of temperature difference between the water inlet (Δt) and test surface. The flow rate varied and jet diameter to jet exit-to-test plate surface distances (Z) was kept at 20mm. The study of horizontal and vertical positioning of the jets was carried out. Results have been plotted for the jet diameter of 0.25mm. For a given value of (Δt), the heat transfer coefficient increases with increase with flow rate in all cases.

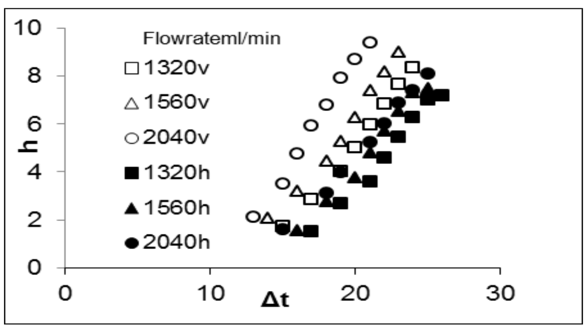

Fig 2: Variation of heat transfer co-efficient with temperature difference for different flow rates at Z=20mm and d=0.250mm for vertical and horizontal jets.

Fig 3 show the variation of heat transfer coefficient as a function of flow rate between the water inlet (Δt) and test surface. The heat flux is varied and jet diameter to jet exit-to-test plate surface distances (Z) was kept at 20mm. The study of horizontal and vertical positioning of the jets was carried out. Results have been plotted for the jet diameter of 0.25mm. For a given value of heat flux, the heat transfer coefficient increases with increase with heat flux in all cases.

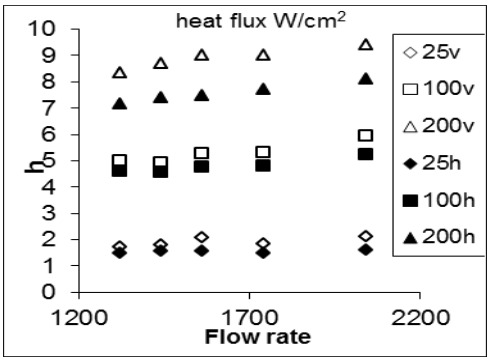

Fig 3: Variation of heat transfer co-efficient with flow rate for Z=20mm and d=0.25mm for vertical and horizontal jets.

Fig 4 and 5 shows the variation of heat transfer coefficient as a function of heat flux and variation of Nusselt number with Reynolds number between the water inlet (Δt) and test surface. The study of horizontal and vertical positioning of the jets was carried out. Results have been plotted for the jet diameter of 0.25mm. Thus, the observed increase in heat transfer coefficient is due to the combined effect of the variation in the heat flux and the Reynolds number. Similar qualitative variations of (h) with (Δt) were also observed with the horizontal positioning of the jets

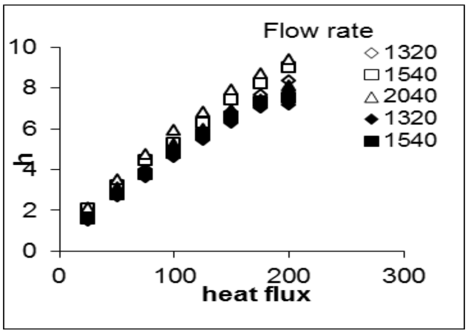

Fig 4: Variation of heat transfer co-efficient with heat flux for different flow rates at Z=20mm and d=0.25mm for vertical and horizontal jets.

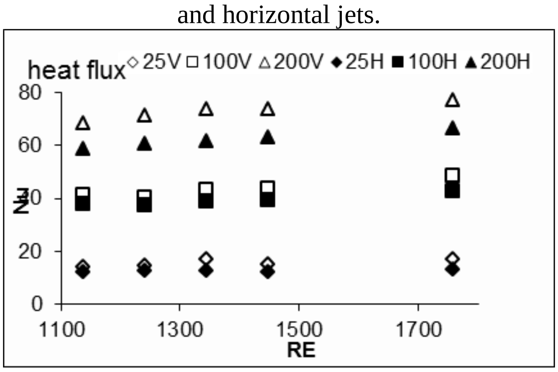

Fig 5: Variation of Nusselt number with Reynolds number for different flow rates at Z=20mm and d=0.25mm for vertical and horizontaljets.

V. 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 air jets of 0.25mm diameter. Tests were conducted by varying the heat flux, water 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 there is no significant effect of position of jets were noticed.

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