Investigation on flow boiling heat transfer on multiple jet impingement

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Abstract—*An experimental investigation was carried out to study the effect of multiple jet impingement on a simulated electronic component using air as working fluid. It consists of an electrically heated test plate of size 2cmX2cm area. Heat flux is varied from 25 to 250W/cm^2 was dissipated using 0.25 and Tests were conducted by changing the [i] heat flux, [ii] flow rate, [iii] distance between the test surface and jet exit. It was found that heat flux, jet diameter and Reynolds number are important factors in determining the heat transfer. The effects of distance between test surface and jet exit [Z], and positioning of the jets (Vertical/horizontal) were insignificant.*

Key words— *Jet impingement, heat transfer, Reynolds num- ber*

I. Introduction

A jet impingement cooling is an promising technique which has attained important consideration. This is a very good cooling method because of its ability of accomplishing high heat transfer rates. Different industrial uses such as annealing of metals, cooling of electronic components use this method of cooling gas turbine blades. The capacity to dissipate exceptionally high heat flux is possible by jet impingement, which is of specific interest in the cooling of electronic components. A liquid coolant, a dielectric fluid, is impinged on the chip surface in the form of jets/ micro jets. Cooling is achieved due to sensible heat removal. However, certain two-phase systems which remove heat through the latent heat of the fluid are also being studied. Jet impingement cooling method can be used for an extensive range of fluids like water, air and dielectrics.

Attalla.M., Specht.E.[1] have conducted multiple air jet impingement experiment on a flat plate to study the convective heat transfer. The test plate is a thin metal sheet which is electrically heated and cooled using an array of nine jets arranged in inline configuration. An IR camera is used to measure the temperature distribution. The range of Reynolds number is 1400 to 41400. The ratio of the distance between the test sheet and nozzle exit (Z/d) is in the range of 1 to 10. The ratio of jet pitch to the jet diameter (S/d) is in the range of 2 to 10. It was found that the local and average heat transfer is higher in the case of multiple jets compared to single jet. The ratio of the distance between jet exit to the test surface (Z/d) and jet diameter in the range of 2 to 4 have significant effect on the heat transfer. The maximum heat transfer is obtained at (S/d) =6. The relationship between average Nusselt number and Reynolds number is given by

$Nu_{av} = 0.104\ Re^{0.7}$

Xiaojun.Y, Nader S. [2] have conducted experiments to study the effect of the distance between the test surface and nozzle exit (Z/d) and jet spacing on the local heat transfer. Experiments were conducted with two circular air jets impinging on a flat plate . The range of Reynolds number is 23000.The ratio of (Z/d) and (S/d) were varied in the range of 2 to 10 and 1.75 to 7 respectively . The results showed that, when the (S/d) is below 3.5, the local Nusselt number at the centre of two jets is higher than that at the jet stagnation point. The maximum value of local heat transfer co-efficient occurs at (Z/d) =2, (S/d) greater than 5.25 and the stagnation point to the jet diameter ratio (R/d) of =0.3 and 1.3.

Dae Hee Lee, Jeonghoon Song, Myeong Chang Jo [3] have conducted the experiments to study the effect of jet diameter on the fluid flow and heat transfer. For this study they have used a single round air jet . At the nozzle exit the flow has a fully developed velocity profile. At the plate surface the uniform heat flux boundary is created and the liquid crystals were used to measure the surface temperature of the plates. The following are the range of parameters used for the study, Reynolds number of 23000,the distance between test plate surface to jet exit (Z/d) is between 2 to 14 and jet diameter from 1.36 to 3.4 cm. In the stagnation point region corresponding to $0 \le (r/d) \le 0.5$, the Nusselt number increases with increase in jet diameter. It was observed that in the wall jet region corresponding to (r/d) =0.5, the effect of jet diameter on the local Nusselt number is very small. Increase in the intensity of turbulence and jet momentum with the larger jet diameter increases the heat transfer co-efficient.

Anwarullah.M., Vasudeva Rao.V., Sharma.K.V. [4] have conducted experiments to study the effect of test parameters with the confined jet and heat transfer. A circular, square and rectangular cross section jets with equivalent and different diameters were used for the study. The study includes 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 estimated. They developed the relation between the stagnation Nusselt number, ratios of (r/d) and local heat transfer ratio.

II. Nomenclature

A Area of test surface, cm^2

d Jet diameter, mm
P Supply power, W
h_{avg} Heat transfer coefficient (q / (T_s –T_i), W/cm^2 °C
k Thermal conductivity, W/cmK
L Test section length, mm
n Number of jets
Nu Nusselt number
Pr Prandtl number
Q Flow discharge, ml/s
q Heat flux (P/A), W/cm^2
Re Reynolds number (Vd/ν)
V Jet velocity, m/s
Z Distance from nozzle exit to test surface, mm
Δt Temperature difference

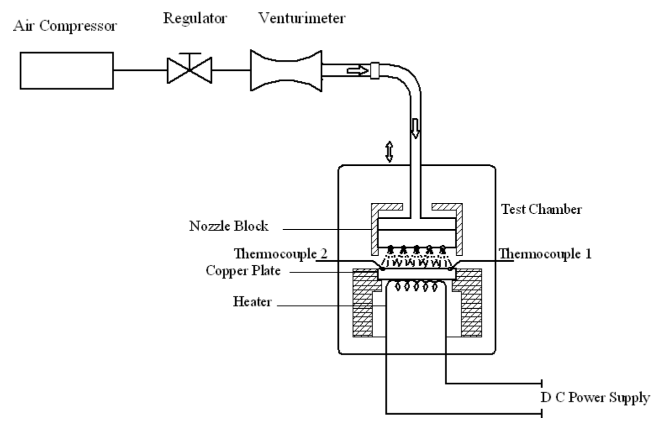

Fig. 1. Schematic diagram of multiple air jetexperimental setup.

III. EXPERIMENTAL APPARATUS AND TEST PROCEDURE

The test setup is shown schematically in Fig. 1. The device is designed and fabricated to carry out tests using different types of jets . The test rig consists of an air compressor and the test chamber. The copper test plate is heated using the heating element. The test chamber consists of the test plate, jet nozzle block and the heat- ing element. The adjustable voltage transformer, control system and display system are provided to control power supply to the heater.The test plate is made up of copper. Copper is selected because of its high thermal conductivity. The test plate is of 2cm x 2cm 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. To get the uniform surface temperatures**.**

The complete test assembly is mounted and insulated us- ing a Teflon jacket. The leads from the thermocouples are connected to the control and display system. 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 1cm and 2cm.

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 values of test parameters used in the present study are given below:

Jet diameter = 0.25mm, 0.5mm Heat flux range =25 to 250W/cm^2 Reynolds number range =1300 to 4600 Distance between the nozzle head and test plate =cm, 2cm Positioning of the nozzle = Vertical

IV. RESULTS AND DISCUSSIONS

It should be note that the heat flux is varied while con- ducting the experiments at constant Reynolds number. The heat flux (q) is an independent parameter and (Δt) depends upon the heat flux in the experiments conducted during this investigation. In order to discrete the effect of heat flux (q) and the Reynolds number on the heat transfer coefficient, the results are plotted with the heat flux as an independent parameter .

Figs 2 and 3 show the heat transfer results for d=0.5mm, Z=1cm and 2cm for vertical positioning of the jets when plotted in (h) versus (q) coordinates. In all the cases, heat flux was varied from 25 to 250 W/cm^2. The heat transfer coefficient increases with heat flux. As the heat flux increases, the surface temperature also increases, which causes more turbulence in the impingement zone resulting in a higher heat transfer coefficient. The Reynolds number effect is insignificant and heat transfer coefficient increases slightly with increase in Reynolds number.

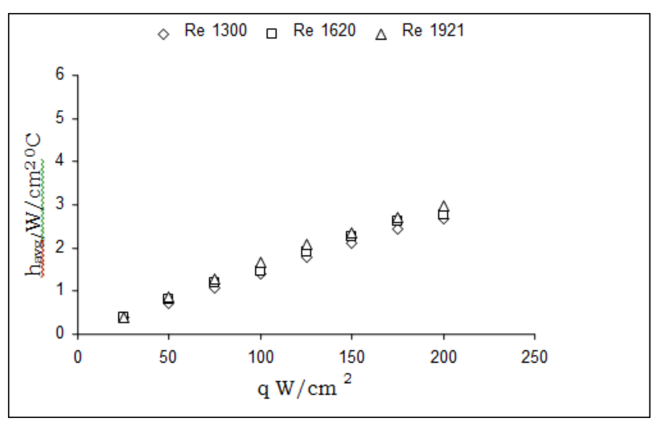

Fig. 2. :Variation of heat transfer co-efficient with heat flux at Z=1cm and d=0.50mmfor vertical jets

Figs 4 and 5 show the heat transfer results obtained using d=0.25mm with different Reynolds numbers, Z=1 and 2cm for vertical positioning of the jets.

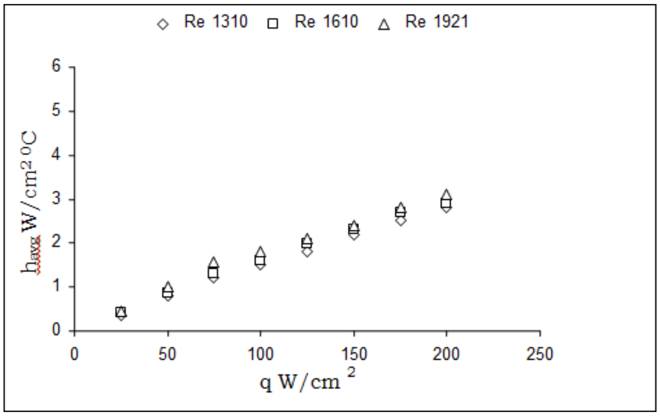

Fig. 3. Variation of heat transfer co-efficient withheat flux at Z=2cm and d=0.50mm for vertical jets

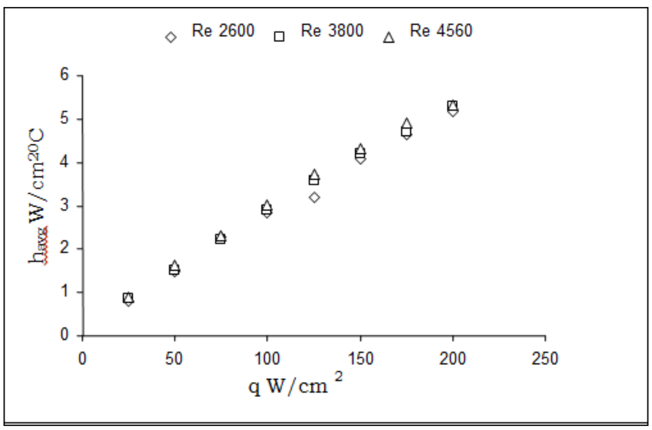

Fig. 4. Variationof heat transfer co-efficient with heat flux at Z=1cm and d=0.25mm for verticaljets

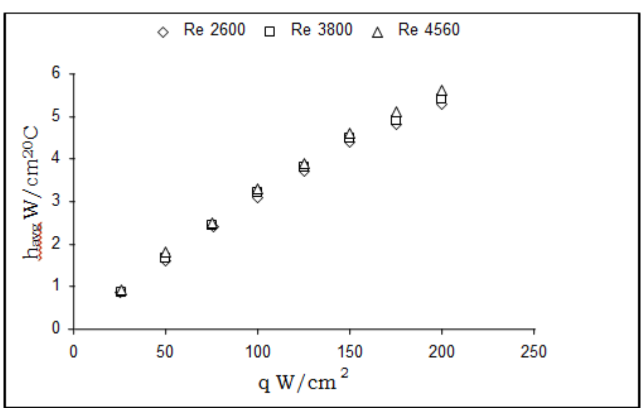

Fig. 5. Variation of heat transfer co-efficient withheat flux at Z=2cm and d=0.25mm for vertical jets

Similar qualitative variation of heat transfer coefficient with heat flux as observed in the tests of d=0.5mm have been noticed in all cases; the effect of Reynolds number, (Z) and horizontal and vertical positioning of the jets are insignificant. Figs 6 and 7 show the comparison of results obtained using d=0.5mm and d=0.25mm diameter jets.

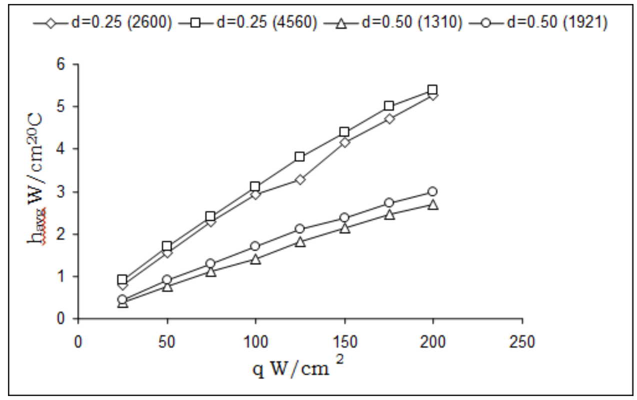

Fig. 6. Variation of heat transfer co-efficient withheat flux for different Reynolds numbers for vertical jets at Z=1cm

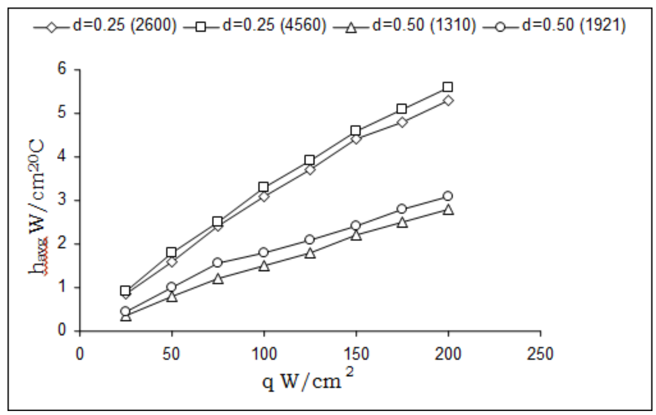

Fig. 7. Variationof heat transfer co-efficient with heat flux for different Reynolds numbers forvertical jets at Z=cm

V. CONCLUSION

Experiments were carried out by varying the flow rate, heat flux, distance between the the jet exit and heated test surface and by keeping the test plate and the jets in vertical positions. The effects of heat flux, jet diameter and the Reynolds number on heat transfer are 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 enhancing the heat transfer at a given Reynolds number

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