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# Multiple Jet Impingements Cooling Of Simulated Microelectronic Chip

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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 0.2mm 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 shows higher values of heat transfer coefficient are obtained with the lower diameter jets.

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

## 1 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.

Attalla.M.,Specht.E.[1] have conducted multiple air jet impingement experiment on a flat surface to study the convective heat transfer. The test surface 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 nozzle exit to the test surface (Z/d) and inter jet spacing on the local heat transfer. Studies were carried out with two circular air jets impinging on a flat surface. The ratio of (Z/d) and (S/d) were varied in the range of 2 to 10 and 1.75 to 7 respectively at the Reynolds number of 23000. The results showed that, when the (S/d) is below 3.5, the local Nusselt number at the centre of two jets is more 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.

DaeHee Lee, Jeonghoon Song, Myeong Chang Jo [3]have studied the jet diameter effect on the fluid flow and heat transfer. A single round turbulent air jet was used for this study. At the nozzle exit the flow has a fully developed velocity profile. The uniform heat flux boundary is created at the plate surface 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, the distance between test plate surface to jet exit (Z/d) between 2 to 14, jet diameter from 1.36 to 3.4 cm and Reynolds number of 23000. In the stagnation point region corresponding to $0 \leq (r/d) \leq 0.5$, 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.

Tzer-Ming Jeng, Sheng-Chung Tzeng[4] 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 0.2mm 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 = 0.2mm, 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

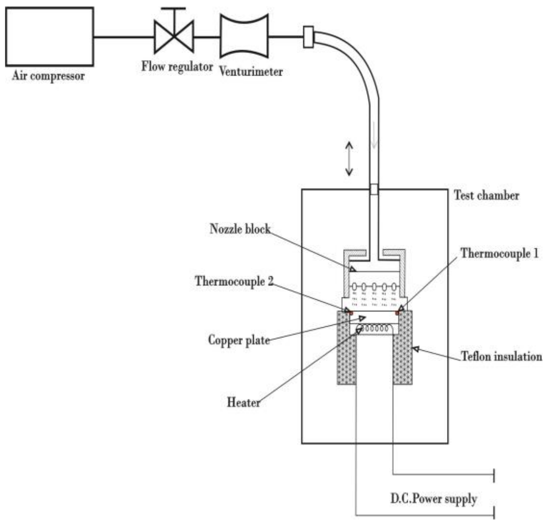


**Fig1: Schematic diagram of multiple air jet experimental setup**

## IV RESULTS AND DISCUSSIONS

Figs 2and 3 show the variation of heat transfer coefficient as a function of temperature difference between the air at inlet (Δt) and test surface. The Reynolds number (Re) based on jet diameter and jet exit-to-test plate surface distances (Z) were varied. The study of horizontal and vertical positioning of the jets was carried out. Results have been plotted for the jet diameter of 0.2 and 0.5mm. For a given value of (Δt), the heat transfer coefficient increases with increase in Reynolds number in all cases. Note that in addition to the variation of Reynolds number, heat flux is also varying along the constant temperature difference line (Δt).

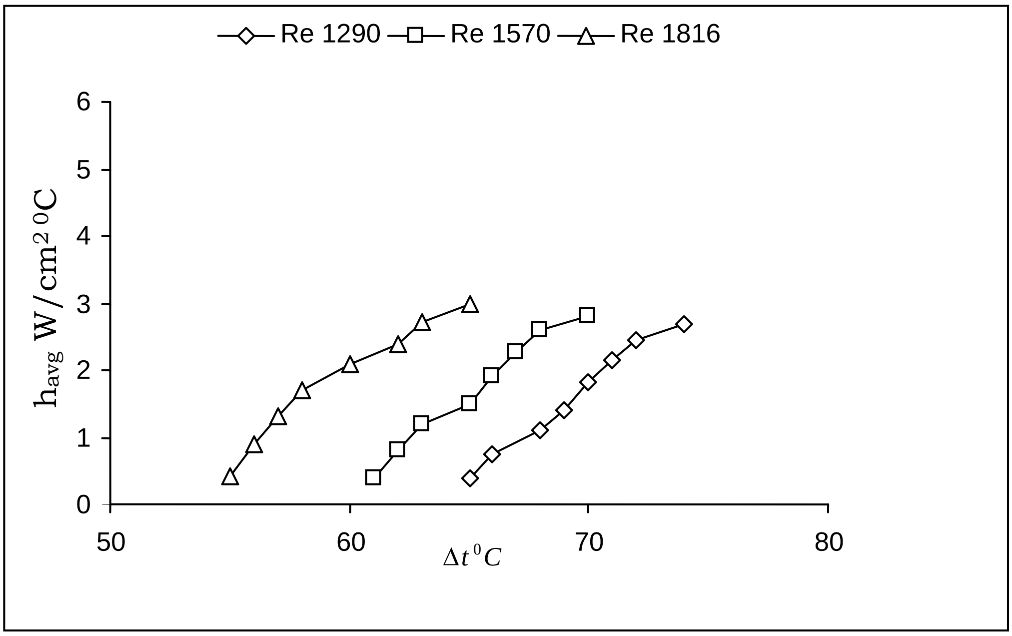


**Fig 2: Variation of heat transfer co-efficient with temperature difference for different flow rates at Z=10mm and d=0.50mm for vertical jets**

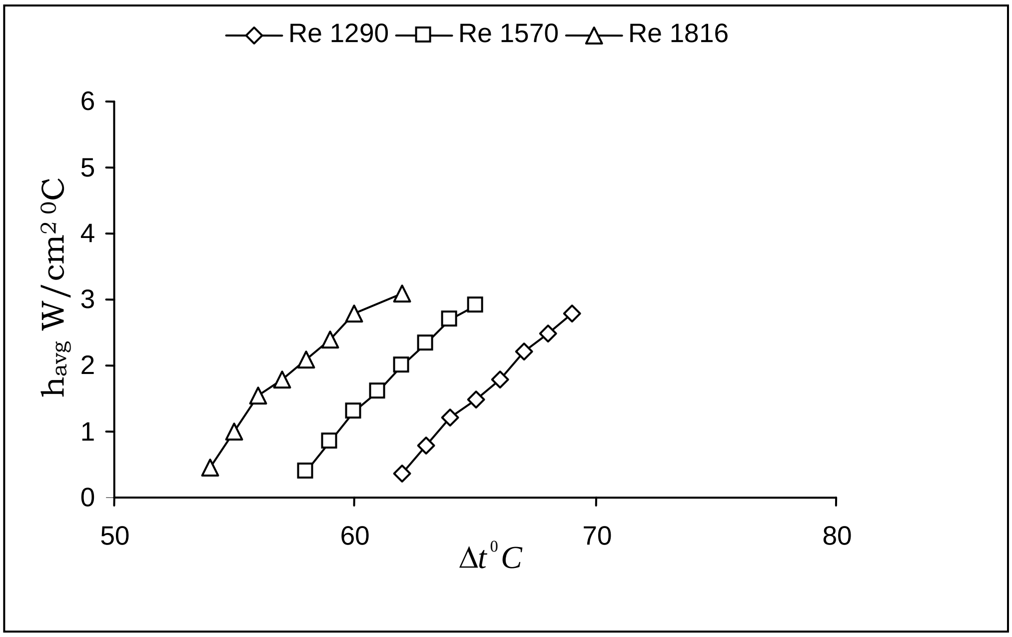


**Fig 3: Variation of heat transfer co-efficient with temperature difference for different flow rates at Z=20mm and d=0.50mm for vertical jets**

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.

The variations in the heat transfer coefficient with (Δt) for d=0.2mm are shown in Figs 4 and 5.. Higher values of heat transfer coefficient are obtained with 0.2mm diameter jet compared to that obtained with 0.5mm diameter jet. The jet diameter of 0.2mm is found to be more effective in causing higher values of heat transfer coefficient, because smaller diameter jets have higher air jet velocity associated with them.

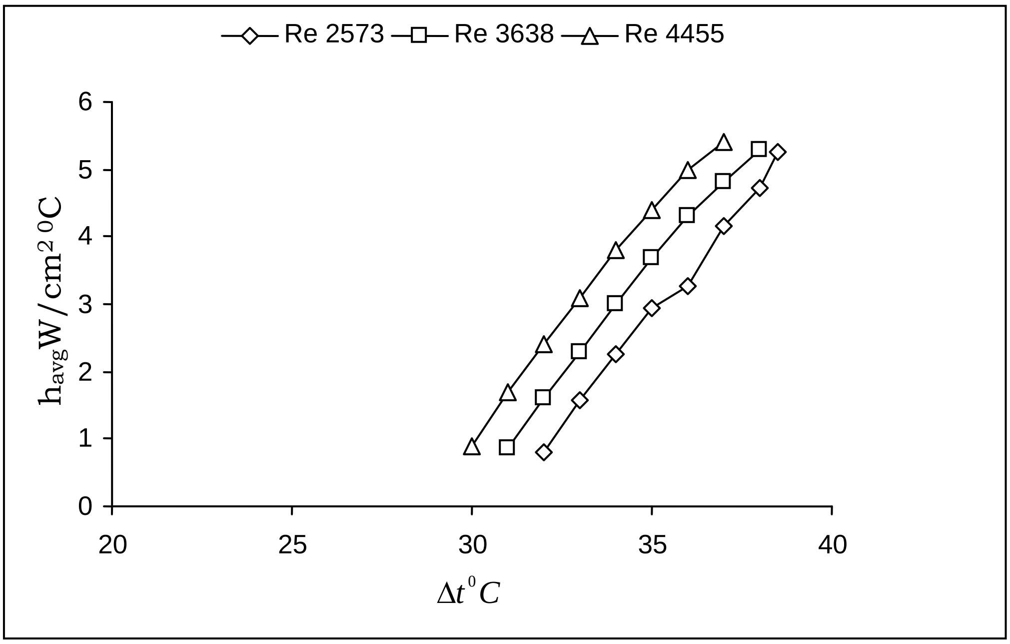


**Fig 4: Variation of heat transfer co-efficient with temperature difference for different flow rates at Z=10mm and d=0.2mm for vertical jets**

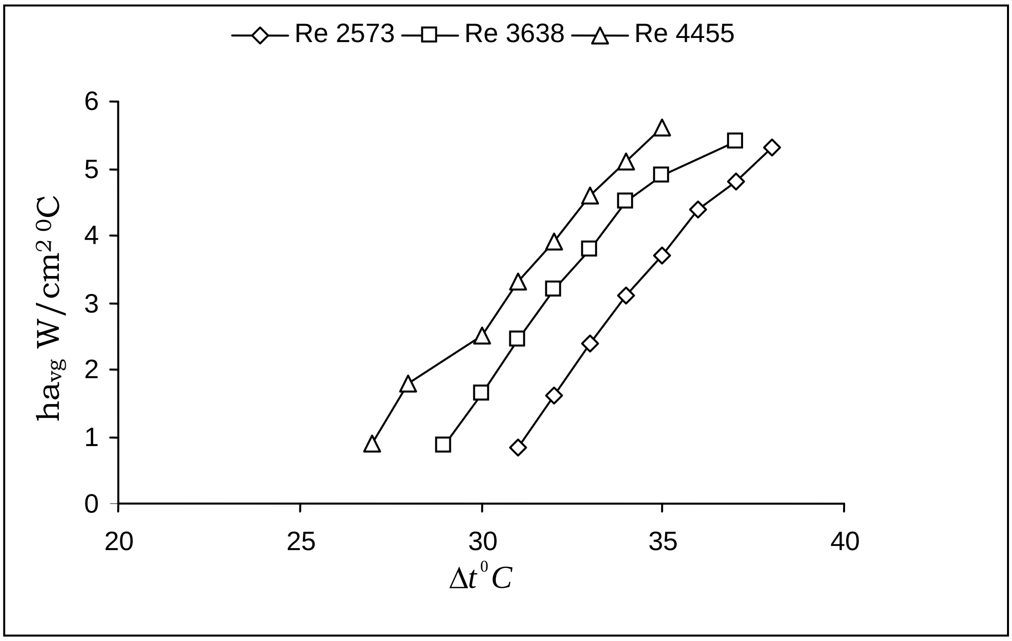


**Fig 5: Variation of heat transfer co-efficient with temperature difference for different flow rates at Z=20mm and d=0.2mm for vertical jets**

The slope of the (h) versus (Δt) curves is more for the jet diameter of 0.2mm. It should be noted that (Δt) values have decreased with a smaller diameter jet. There is a significant difference in the values of Reynolds number obtained with the two tested jet diameters. The results show that the effect of (Z) and horizontal and vertical positioning of the jets is insignificant.

## 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 0.2mm 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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