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A Study On Heat Transfer Characteristics For Distinct Geometrical Arrangements Of Jet Arrays

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ABSTRACT: The delinquent of cooling of electronic apparatuses has become a topic of distinct interest in current years owing to the growing capacity and fast declining size of electronic components. Multiple jet impingement cooling is one of the most active and powerful method .In this work an investigation is carried out with a simulated copper plate which acts as a test plate. The size of the plate is 2X2 cm. The 0.25 and 0.5mm diameter jets were used for the test.These jets are arranged in a 7X7 array with a pitch of 3mm.The heat flux and Reynolds number range were 30 to 250W/cm^2 and 100 to 4500 respectively. From the results show that the Reynolds number plays a notable role and with the increase in heat flux the heat transfer co-efficient also increases.

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

I. INTRODUCTION

By the development in technologies in the field of electronics and communication, lesser and high powerful components are being acquaint with in the market. As many applications requires electronic mechanisms be capable of handling high power density's with smaller size and more reliable, therefore the call for high performance components has increased. To avoid high temperature failure due to very small size and high power density's inappropriately lead to high heat flux that must be removed from the electronic components. The conventional cooling methods such as boiling and evaporation forced convection etc will not meet the requirements of present day high power dissipation and cooling capabalities. The direct cooling by jet impingement is a well known and effective solution. The multiple jet impingement is a complex heat transfer phenomenon and careful and systematic approach is essential in order to find its effectiveness.

M. Atlata and E. Specht (1) have conducted experimental investigation of the convective heat transfer on a flat surface using multiple air jets. A thin metal sheet was heated electrically and cooled using an arrangement of nine jets inline on one side while the other side is black coated. The temperature distribution was measured using an IR camera. The jet Reynolds number was varied in the range of 1400 to 41400.The ratio of the distance between the nozzle and the metal sheet (H/d) was in the range of 1 to 10.The ratio of nozzle spacing to the jet diameter (S/d) was in the range of 2 to 10. The results show that the multiple jets enhance the local and average heat transfer in comparison with the single jet. The maximum heat transfer occurred at the spacing (S/d) = 6. The variation of (H/d) in the range of 2 to 4 seems to have negligible effect on the heat transfer. The relationship between average Nusselt number and the jet Reynolds number follow the relationship $Nu_{av}=0.104\, Re^{0.7}$ Xianjin and Nader (2) have investigated the effect of the spacing between the jets (S/d) and the distance between the nozzle and the heated plate (H/d) on the local heat transfer at the Reynolds number of 23,000. Tests were conducted using two circular air jets impinging on a flat plate. The ratios of (S/d) and (H/d) were varied in the range of 1.75 to 7.0 and 2 to 10 respectively. The investigations showed that the local Nusselt number at the centre of the two jets exceeds that at the jet stagnation point when (S/d) is below 3.5. With the values of (S/d) greater than 5.25 and (H/d) =2, the local heat transfer distribution in the region between the jets reaches the maximum values at the ratio of the distance from the stagnation point to the jet diameter (R/d) =0.3 and 1.3.

Dae Hee Lee, Jeonghoon Song and Myeong Chang Jo (3) have investigated the effect of jet diameter on the heat transfer and fluid flow using a round turbulent air jet impinging on a flat plate surface. The flow at the nozzle exit has a fully developed velocity profile. The uniform heat flux boundary is created at the plate surface using gold film intrex, and liquid crystals were used to measure the plate surface temperature. The experiments were performed for the jet Reynolds number (Re) of 23,000, with the dimensionless distance between the nozzle and plate surface (L/d) ranging from 2 to14 and the nozzle diameter (d) ranging from 1.36 to 3.40 cm. The results show that the local Nusselt number increases with increase in jet diameter in the stagnation point region corresponding to $0 \leq (r/d) \leq 0.5$. This was attributed to the increase in the jet momentum and turbulence intensity level with the larger nozzle diameter, which results in the heat transfer augmentation. The effect of nozzle diameter on the local Nusselt number was found to be negligibly small in the wall jet region corresponding to(r/d) > 0.5.

M. Anwarullah, V. Vasudeva Rao and K.V. Sharma (4) have performed experimental investigation to study the effect of various geometric parameters on the confined impinging jet flow field and heat transfer characteristics. The array of electronic resistors with three different nozzle cross-sections, viz. square, rectangular and circular each with different and equivalent diameter were used. The study involved the investigation of the effect of Reynolds number and the distance between the nozzle and test plate to jet diameter ratio (H/d) on Nusselt number. Measurements of surface temperatures of the resistors were made in the range of $6500 < Re < 12,500$ and $2 < (H/d) < 10$ and heat transfer coefficients were evaluated. Local and stagnation Nusselt numbers on the impinged resistor surface have been presented for all the nozzle configurations. The local heat transfer rate at a fixed radial location and the stagnation Nusselt number for different (r/d) ratios were correlated and compared with the data of the earlier investigators.

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.

Jung-Yang San, Yi-MIng Tsou and Zheng-Chieh Chen (7) have experimentally investigated the heat transfer with impingement of circular air jets confined in a channel. The impingement plate was supplied with a constant surface heat flux. Five jets, including one at the center and four neighbouring jets arranged in a staggered array were used. The jet Reynolds number (Re) was in the range 5000-15,000; the jet height to diameter ratio (H/d) was in the range 1.0-4.0; the jet spacing to jet diameter ratio (S/d) was in the range 4.0-8.0; the jet width to jet diameter ratio (W/d) was in the range

6.25-18.75. Tests were conducted with the jet plate length to jet diameter ratios (L/d) of 31.7 and 83.3. For the center jet at a given Reynolds number, the stagnation Nusselt number was found to linearly increase with the jet Reynolds number of the four neighboring jets. For all the five jets with the same Reynolds number, the correlation shows that the stagnation Nusselt number at the center jet is proportional to the $Re^{0.7}$ $(W/d)^{-0.49}$. A weak dependence of the stagnation Nusselt number on H/d, S/d and L/d was observed.

II. TERMINOLOGY

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 PROCEDURE

The experimental set up is shown schematically in Fig. 1. The device is designed and made-up to perform tests by means of unlike types of jet nozzles. The setup comprises of an test chamber and the air compressor. The test plate is of copper and is heated using the heater. The test set

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up comprises of the heating element , jet block and the test plate..The test plate characterizes the surface of a representative electronic module and is made of Copper. Copper is carefully chosen due of its high thermal conductivity. The test plate is of 2X2 cm size and thickness 1mm. The heating capacity of 1 kW. Two thermocouples are rooted on the test plate on the centre line. These thermocouples give indication of the surface temperature consistency on the plate. The whole test set up is placed and insulated by means of a Teflon jacket. The temperature leads are connected to the control system

The leads from the thermocouples are connected to the control and display system. The purposes of the control and display system are (a) To differ the heat input to the test plate. (b) To show the input voltage, current and test plate surface temperature with digital temperature indicator, ammeter and voltmeter the mass flow rate of fluid is varied by the regulator. The air flow rate is measured using the venturi meter.The jet nozzle plate is made of stainless-steel plate with a thickness of 3mm thick. The jets of 0.25mm were used.The holes are laser drilled and having a pitch of 3mm.The variation between the test plate to exit of nozzle is varied from 10 to 20mm.The test plate is cleaned before starting the experiment. The mass flow rate and heat input are varied during the experiments

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 =10mm

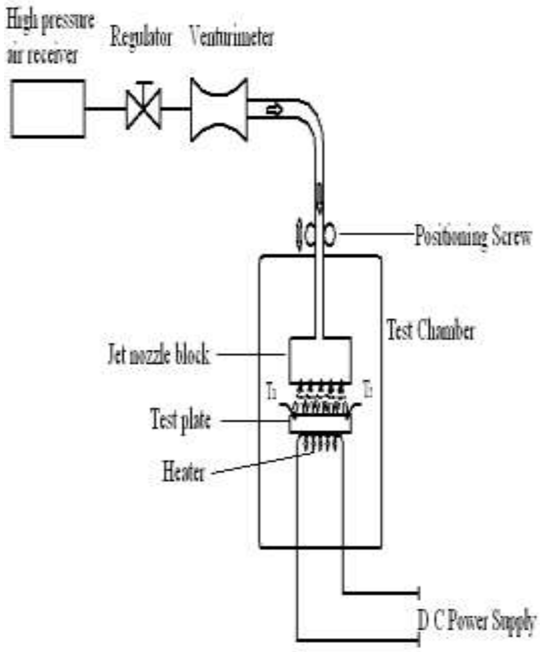
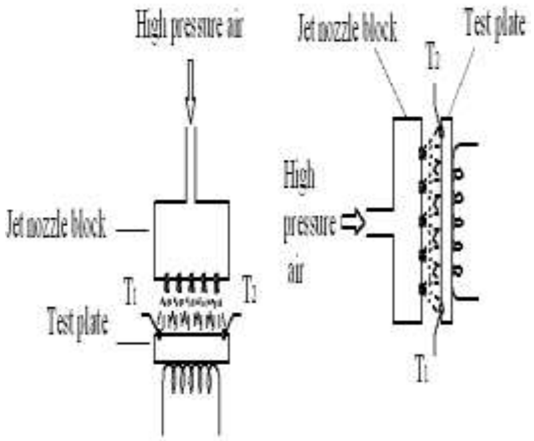


Fig.1(a) Schematic diagram of the experimental set up



(b) Two different positioning of jet nozzle

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IV. RESULTS AND DISCUSSIONS

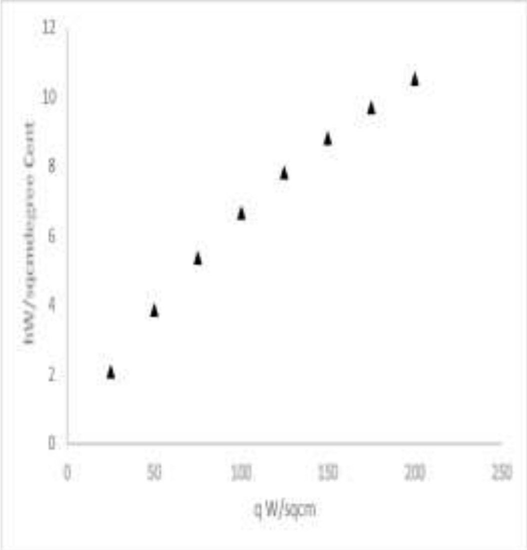

Fig 2. Variation of heat transfer co-efficient with heat flux at 4455 Reynolds numbers (Z=10mm for vertical jet of 0.25mm diameter)

Fig. [2] shows the variation of heat transfer co-efficient (h) with heat flux at 4455 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.

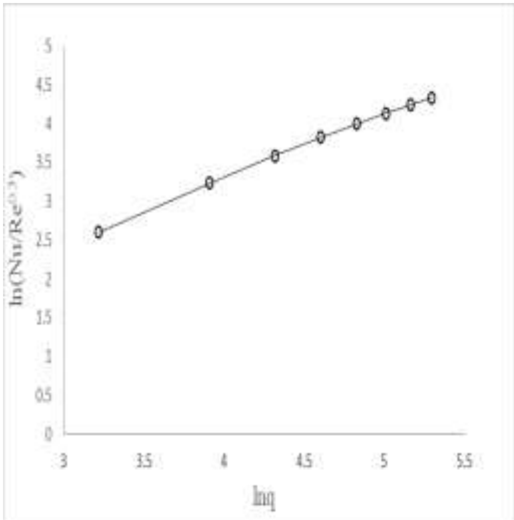

Fig 3 Variation of Nu/Re$^{0.3}$ with heat flux (Re=2573, d=0.25mm and Z= 10mm) for vertical jets

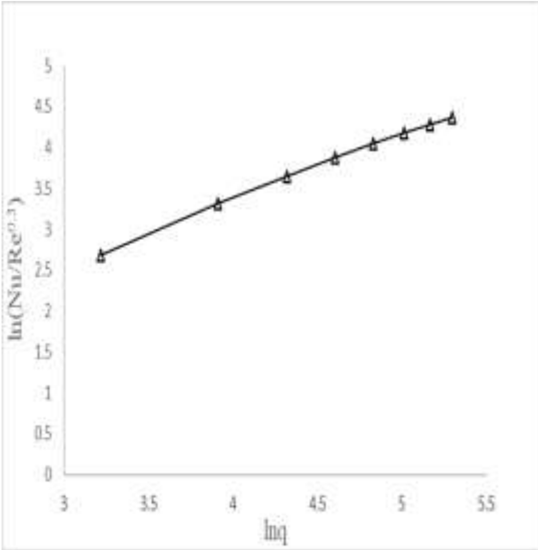

Fig 4. Variation of Nu/Re$^{0.3}$ with heat flux (Re=3638, d=0.25mm and Z= 10mm) for vertical jets

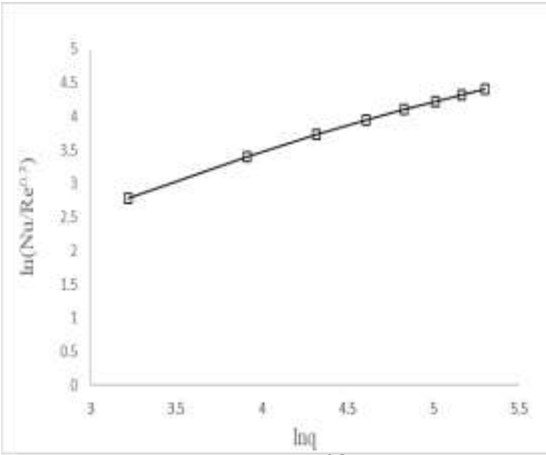

Fig 5. Variation of Nu/Re$^{0.3}$ with heat flux (Re=4455, d=0.25mm and Z= 10mm) for vertical jets

The heat transfer results in the non-dimensional form ln(Nu/Re$^{0.3}$) have been plotted against ln(q) in Fig(3 to 5) by varying the parameters independently. The effect of (Z) seems negligible in both horizontal and vertical positioning of the jet which shows the considerable effect of Reynolds number. The effect of Reynolds number can be easily noticed.

V. CONCLUSION

Tests were conducted to study the improvement of heat transfer by means of impingement of multiple air jets on an electrically heated test plate. The range of heat flux were 25 to 250 W/cm2 which is a quite high for electronic devices. Tests were conducted by varying the mass flow rate and heat flux . It is noted that the heat transfer co-efficient is a solid function of heat flux.Reynolds number plays an vital role. The effects of the distance between the test plate and the jet nozzle exit is insignificant. The horizontal or vertical positioning of the jet nozzle has substantial effect with the jet diameter of 0.5mm.

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