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# Effect of Nozzle Spacing on Heat Transfer and Fluid Flow Characteristics of an Impinging Circular Jet in Cooling of Electronic Components

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**Abstract**

An experimental investigation is conducted to study the effect of nozzle-to-surface spacing of the electronic components and Reynolds number on the heat transfer in cooling of electronic components by an impinging submerged air jet. Reynolds number based on nozzle diameter d is varied between 6000 to 23000. Distance from the tip of the nozzle-to-surface of the electronic components H varied from 2 to 10 nozzle diameters. Experiments are conducted with nozzle diameter of 5mm. Local heat transfer rates at a fixed radial location are measured and the stagnation Nusselt numbers for different H/d ratios calculated. They are correlated and compared with the data of earlier investigators. The following correlation for stagnation Nusselt number has been developed based on the experimental data. The results are expected to help the designers in coming up with more effective designs for cooling of electronic components $Nu_{Cor} = 0.8\,(Re_d)^{0.5}\,(Pr)^{0.36}\,(H/d)^{-0.06}$

***Keywords:*** *Heat transfer coefficient, Air jet impingement, Circular jet nozzle, Local Nusselt number, Electronic cooling*

## 1. Introduction

Jet impingement cooling is widely used in many applications where high convective heat transfer rates are required. For example, the existing method of heat removal, involving extended surfaces and fin arrays, frequently used in cooling of electronic components is clearly insufficient, as the components become more powerful, generating more heat. The space around these components continues to be reduced due to miniaturization trends. Applications of impinging air jets also include, the drying of paper and textiles, and the cooling of high temperature gas turbine blades. Single impinging air jets are widely used in many industrial applications because of high heat transfer coefficients which are developed in the impingement region.

A large number of investigations have been carried out in the area of jet impingement heat transfer over the years. Jambunathan et al. [1] reported the details of flow, geometry and turbulence conditions required for impinging jets. Gardon and Akfirat [2] concluded that the effect of nozzle exit turbulence on heat transfer is relatively small for aspect ratio H/d>6. Colucci and Viskanta [3] concluded that the local heat transfer coefficients for confined jets are more sensitive to Reynolds number and nozzle-to-plate spacing than those for unconfined jets. Tavfek [4] concluded that the pressure distributions along the impingement surface are similar and closer to the heat transfer variations at the same configurations for H/d >6. Saad et al. [5] commented that heat transfer data obtained with unconfined jets cannot be used reliably for design of confined jets. Baydar and Ozmen [6] experimentally investigated confined impinging jets in the range of Reynolds numbers from 500 to 50,000. They observed that a sub atmospheric region occurs on the impingement plate for Re>2,700 and the nozzle-to-plate spacing's less than 2.

Ichimiya and Yamada [7] have reported the presence of the recirculation regions on both impingement and confinement surfaces for low spacing's. They have observed that the recirculation flow on the impingement surface moves downstream and its volume increases with the increase in Reynolds number and nozzle-to-plate spacing. Deshpande and Vaishnav [8, 9] presented details of the flow field arising in a body of fluid when a submerged, axisymmetric laminar jet impinges normally on a rigid plane. Marple et al. [10] observed that the flow is laminar for Reynolds numbers up to 2300.They use a flow visualization technique in confined water jet impingement with both circular and rectangular jets. The laminar flow fields of partially enclosed axial and radial jets impinging on a plate have been investigated by Laschefski et al. [11]. They concluded that the impinging jet flow is turbulent at the Reynolds numbers greater than 2000 [10,12,13].

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Fitzgerald, and Garimella [14] reported that the pressure gradient distribution on the impingement plate to be irrelevant to nozzle diameter, but strongly depended on nozzle exit configuration [15], nozzle-to-plate spacing [16], jet Reynolds number and jet type. Zhou et al. [17] presented a numerical study of the pressure gradient controlled flow pattern of the working fluid close to the impingement plate, which in turn determined the profile of radial heat transfer rate distribution. Zumbrunnen and Aziz [18] observed that the effect of flow intermittency on convective heat transfer is like planar water jet impinging on a constant heat flux surface. The effects of slot jet on the cooling of heated flat plat are studied by Haydar Eren and Nevin Celik [19]. Experiments on the heated flat plate of different angles (90° to 30°) and dimensionless distance (H/d) are conducted. They found that the minor variations of local temperatures with respect to dimensionless distance (H/d].Fenot[20] has investigated experimentally, the convective heat transfer on a flat plate with a single circular jet. He found that the heat transfer coefficients and the effectiveness from the jet injection temperature is independent of jet injection temperature within the range of 20 to 600C. Vadiraj and Prabhu[21] conducted theoretical and experimental investigations for the local heat transfer distribution between smooth flat surface and impinging air jet from a circular nozzle. They found that an increase in Reynolds number increases the heat transfer at all radial locations for a given radial distance. Amy and Sharareh [22] conducted an experimental study on the influence of a protruding pedestal on a single circular impinging air jet on heat transfer rate with different Reynolds numbers, jet exit diameters and jet exit-to-surface distances. They found that, at constant Reynolds numbers, the Nusselt number increases due to increase in jet diameters. Lytle and Webb [23] focused their study on low nozzle-to-plate spacing, and measured the heat transfer coefficient for distance of 6 diameters. They also used an infrared thermal imaging technique for temperature measurements. The surface curvature effect on the impinging flow structure and the heat transfer along a concave and a convex surface are obtained from experiments of Gao et al[24].They found that an increase of surface curvature can increase the size of the counter rotating vortices, which results in further increase of the stagnation point Nusselt number.
The present experimental study is undertaken to investigate the effects of the nozzle to plate spacing on impinging jet heat transfer and fluid flow. Local Nusselt numbers and stagnation Nusselt numbers are determined for a submerged air jet issuing from a circular nozzle.

## 2. Experimental Setup

A schematic diagram of the experimental setup is shown in Fig. 1. In the experimental system, the important components are two stage reciprocating air compressor, Rotameter, electric heater, and control panel. The control panel consists of voltmeter, ammeter, dimmer stat, and temperature display unit. A 500 W aluminum heater plate, insulated on all sides by mica sheets, is used to heat the printed circuit board (PCB). Five cylindrical electrical resistors fixed on the 2mm thick printed circuit board of diameter 100mm are located centrally on the aluminum heater plate. The chip assembly on PCB is simulated with the electrical resistors, which are 25 mm long and 5 mm in diameter. The power is supplied to the heater through the dimmerstat to control the heating rate to the base plate. The current flow and voltage are measured by ammeter and voltmeter respectively. The air flow rate through the nozzle, located above the resistors is measured with a Rotameter. Air at 20-bar is made available to the nozzle from a reciprocating air compressor of 160 liter storage capacity through the Rotameter. Teflon coated J- type thermocouples are used to measure the surface temperatures of the electronic components (resistors). The central resistor in the jet array is considered for the analysis. Two thermocouple leads are inserted into the holes drilled in the aluminum heater plate. The gap between resistors is filled with aluminum powder to ensure good thermal contact between the resistors. One thermocouple is used exclusively to measure the temperature of the air in the enclosure. All the eight thermocouples are connected to a temperature display unit through a temperature scanner (masibus digital scanner 85 XX) to observe the readings and store the values in a computer ($P_4$).

## 3. Experimental Procedure

The air jet issuing from the nozzle and impinging on the resistors is considered to be a free jet and the wall jet regions respectively. The five cylindrical electrical resistors fixed to an insulating plate (PCB) of diameter 100mm and 2mm thick located centrally on an aluminum heater plate is shown in Fig.2. Power is supplied to the electronic components through a step down transformer and to the aluminum plate through a dimmerstat. The volumetric energy generation due to heating of the resistors using alternating current is assumed to be uniform. The temperature of the resistors is allowed to rise up to $95^0$ C. Then resistors are cooled by forced convection, mainly from the top surface by the air stream flowing in the wall jet region. The transient surface temperature of the resistors (electronic components) are recorded till they attain $45^0$C The procedure is repeated at different flow rates of air with temperature values recorded in the Reynolds number range of 6000 to 13500. The velocity of jet is measured using a Pitot tube and U-tube Manometer (water) to an accuracy of ± 1 %. The heat loss from the bottom of the resistors is assumed to be negligibly small.

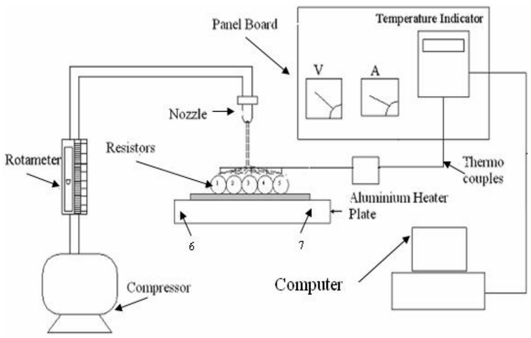


**Fig.1 Schematic diagram of experimental setup**

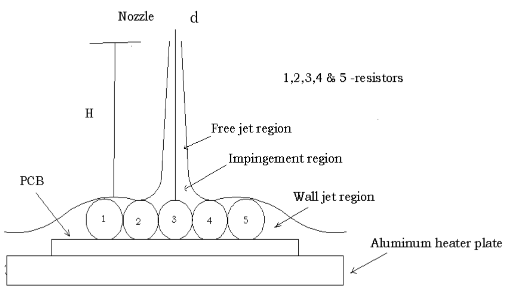


**Fig. 2. Schematic diagram of flow coming out of the nozzle and impinging on surface of the electronic components**

## 4. Results and Discussion

Fig.3 presents the transient temperature variation for different $Re_d$ and H/d ratios. Experimental data are obtained for $T_S$ = 95°C, $Re_d$ = 8250, and 13500, and H/d ratios of 5 and 10. It is observed that the surface temperature of the resistors drop down rapidly in approximately 50 seconds from the time of starting of the air flow. It is also observed from Fig.3 that, the temperature gradient is higher at larger values of Reynolds number and lower values of H/d ratios .The rapid decrease in temperature is also due to large temperature difference between the surface and the ambient.

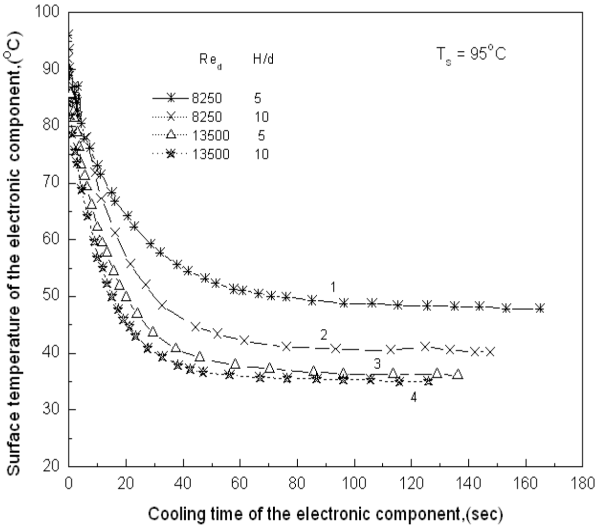


**Fig.3. Effect of cooling time on temperature at different $Re_d$ and H/d ratios**

The effects of the system parameters H/d, diameter of the circular nozzle and Reynolds number on the local Nusselt number, Nu are presented in Fig. 4(a,b) as a function of the dimensionless radial distance r*. The experimental results are obtained for the chosen common parameters of Reynolds numbers of 6000 and 12500, and nozzle-to-resistor spacing, H/d = 2, 4, 8 and 10. From the experimental results, it is observed that the local Nusselt number of the jet array increases with an increase in nozzle-to-resistor spacing H/d and decreases with the dimensionless radial distance r*. This indicates the importance of maintaining proper distance between the component and the nozzle for best performances.

The local Nusselt number computed for the surface of the electronic components are shown plotted in Fig.5, which shows satisfactory agreement with the theoretical data of Lytle and webb [23] and Gao et al [24]. The agreement is within 10%. The minor discrepancy can be attributed to the difference in the experimental conditions.

The effects of the dimensionless distance H/d on local Nusselt number for the different Reynolds numbers with a different circular nozzle are presented in Fig.6. The results shown in Fig.6 correspond to d = 5mm and Ts = 90°C. Fig.6 indicates that local Nusselt numbers increases with increase in dimensionless distance H/d. It also shows that heat transfer coefficient increases with lower nozzle-to-resistor spacing, due to the acceleration of the fluid through the gap between surface of the electronic component and nozzle exit.

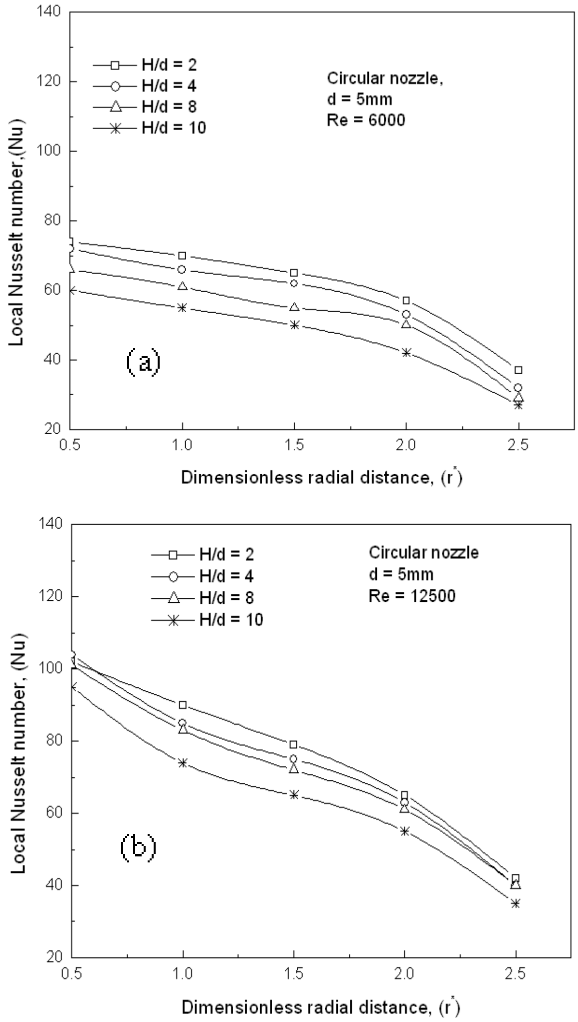


**Fig.4 (a,b) Effect of local Nusselt number on dimensionless radial distance for different H/d ratios**

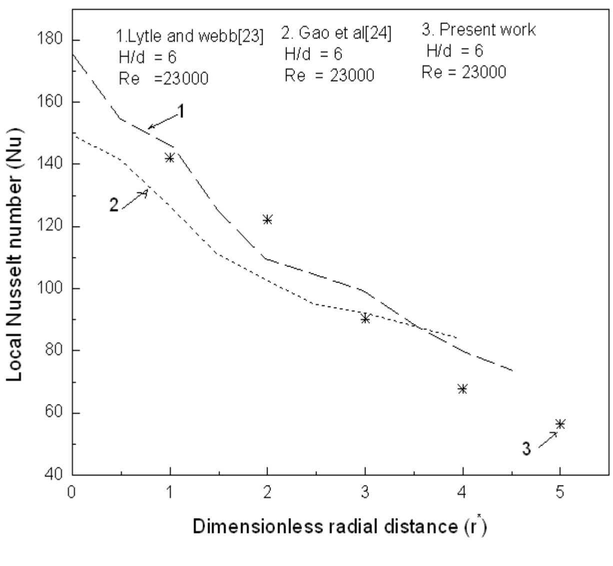


**Fig.5 Comparison of experimental data with theoretical results of Lytle and webb[23] and Gao et al[24]**

## 5. Data Reduction and Uncertainty Analysis

The local heat transfer coefficient is calculated using the following equation:

$$h = q / (T_s - T_a) \tag{1}$$

The local Nusselt number on the resisters surface is defined by:

$$Nu = h\, d / k_{air} \tag{2}$$

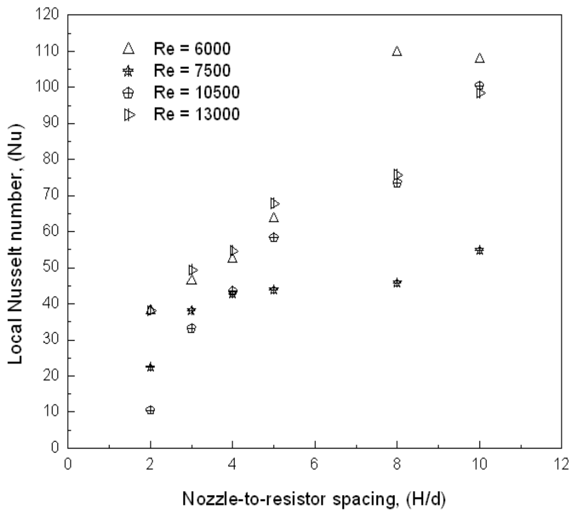


**Fig 6. Effect of local Nusselt number on distance between nozzle-to-resistor spacing for different Reynolds number, Re**

The nozzle Reynolds number is defined as follows:

$$Re = Vd / \nu \tag{3}$$

Present widely used correlation, Ref. [26] is:

$$Nu = 0.62\, Re^{0.6}\, Pr^{0.38} \tag{4}$$

A detailed systematic error analysis is made to estimate the errors associated with experimentation by Beckwith et al.[25]. In the present experiments, the temperature measurements were accurate to within ±1°C, the uncertainty of $Re_d$ and Nu for the ranges of parameters studied under steady state conditions is within ± 2% and ±5 %, respectively.

### 5.1 Correlation for Stagnation Nusselt Number

The correlation for stagnation Nusselt number has been developed based on the experimental values in the ranges of 6000< $Re_d$ < 12500, 2 < H/d < 10 and Pr ~ 0.71with average deviation (AD) 8% and standard deviation (SD) 10 %.The equation is

$$Nu_{Cor} = 0.8( Re_d)^{0.5} (Pr)^{0.36} (H/d)^{-0.06} \tag{5}$$

The present experimental data is in good agreement with the values of Nusselt number obtained Eq.5 as illustrated in Fig.7.

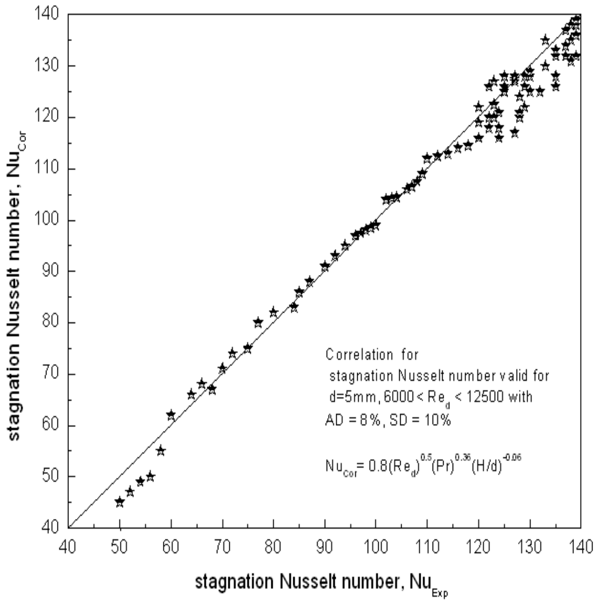


**Fig.7 Comparison of experimental data with the correlation (5)**

## 6. Conclusions

The heat transfer characteristics of an impinging circular air jet on surface of the electronic components have been experimentally investigated. The impingement surface temperature and heat flux distributions of electronic components with turbulent jet impingement cooling are determined experimentally. It is shown that for different Reynolds numbers, the surface temperature can be significantly decreased by reducing the jet diameter.

The effect of nozzle aspect ratio is less evident as the spacing nozzle- to- surface of the electronic component is increased. The jet Reynolds number does not control the role of nozzle aspect ratio on heat transfer rate.

The effects of the jet Re and nozzle tip-to-resistor spacing on the Nu of impinging jet are determined to develop an optimum parameter of heat transfer enhancement. The heat transfer rate increases as the jet spacing decreases owing to the reduction in the impingement surface area. Correlation for the stagnation point Nusselt number are developed in terms of jet Reynolds number, air Prandtl number, nozzle- to- surface distance and nozzle aspect ratio.

This study provides details of flow fields and heat transfer mechanisms in jet impingement, which is expected to help the designers in coming up with more effective designs for of cooling electronic components.


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## Nomenclature

**A** Surface area of the resistor, $m^2$

**Cp** Specific heat at constant pressure, J/ (kg K)

**d** Ddiameter of nozzle, m

**H** Distance between nozzle tip to resistor, m

**Nu** Local Nusselt number,

**q** Heat flux, $W/m^2$

**t** Cooling time, seconds

**Ts** Surface temperature of the resistor before cooling, ºC

**T∞** Ambient temperature, ºC

**V** Velocity of air, m/sec

**H⁄d** Nozzle-to-resistor spacing to nozzle diameter

**NuO** Nusselt number at stagnation point

**K** Thermal conductivity of air, W/ (m K)

**Pr** Prandtl number

**r** Radial distance measured from the stagnation point, m

### *Non dimensional Numbers*

**Re** Jet Reynolds number, Vd/ν

**r*** Dimensionless radial distance ,r/d

### *Greek symbols*

ρ Density of air, kg/m3

γ Kinematic viscosity of air, $m^2/s$

μ Dynamic viscosity, kg $m^{-1}$ $s^{-1}$

### *Subscripts*

**Cor** Correlation

**Exp** Experimental

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