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Experimental Heat Transfer Investigation of Perpendicular Turbulent Jet for Cooling Application

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Abstract

Jet impingement in electronics cooling is extremely active for field applications because of advantage of use of different fluids. Use of air is extremely desirable in case of moderate cooling applications. The paper deals with experimental investigation of high temperature surface cooling application which is modelled as high heat generating PCB. A non-confined air jet is used with a fixed diameter of 16 mm and its heat transfer characteristics are tested for Reynolds Number of 4000 to 20000, which is considered to be turbulent jet. The target to jet distance is varied from 10 to 55 mm. At low target to jet distance, it is observed that very high turbulence is created which in turn gives highest Nusselt Number for a particular case of high Reynolds Number. An effort is made to give experimental correlation for Nusselt to Reynolds Number for conducted range of experiment.

Keywords: Air Jet impingement, Turbulent Jet, Cooling, Nusselt Number.

Introduction

Use of different techniques are prominent for cooling applications. Jet cooling has its own advantages because of its simplicity. Jets are also categorized depending on type of flow as free jet and confined jet. Cooling effectiveness is governed by diameter, cross-section of jet, number of jets, etc. Experimentally flow structures of air jets by impinging normally upward onto a flat target plate are also investigated.[1] Staggered arrays of five air jets confined in a channel using experiment technique are also analyzed.[2] Diverse fluids are used to carry away heat from hot foundation. Type of fluid depends on various factors like use, type of component, dimension of component, maximum temperature of system, cooling necessities, heat generation rate, space availability for cooling system; energy essential and allowed to use cooling system, etc. Even to save source energy, sprays and micro jets are studied. [3] But it would be very difficult to manufacture jets of 69 to 250 microns, but the micro jet arrays proved better-quality to the sprays since they required less pumping power per unit of power removed. Blowers, fans and compressors are used for supply of air during convective cooling systems. [4] [5] [6] It is concluded that;

Effective cooling = f (Diameter of jet, Room temperature, Jet to target distance, Fluid properties, Angle of inclination of jet, Physical structure of jet)

Experimentation

A thin Steel plate is used which is replicated as a hot electronic PCB, which is to be verified for cooling application. The cooling system used is the air jet which is non-confined, i. e. free jet. The jet is provided with air from blower supplied through the circular duct made up of plastic. The air supplied is converted to normal room temperature by proper arrangement. Once jet air gets exit from jet outlet, it is free to move without restricted flow. The jet of constant diameter of 16 mm is used for this experiment which is pointed at the defined center of the plate. In this case, the geometrical stagnation point is at 120mm length from end and zero line as on width. The velocity of air is measured by using hot air anemometer, and at the exit of the jet only. All calculations are made by assuming air velocity measured by same anemometer. If also velocity at different impingement points on target surface differs, it will be very challenging to quantity it. Because of turbulence created, mainly at high Reynolds number (>5000), the behavior is turbulent and highly complex. The target surface is furnished with two bus bars made up of copper which are linked to electric AC supply of 2 Ampere and 50 Volt. (Figure 1: Experimental Configuration) The step down transformer is used for the proper supply which is measured by power meter. The target plate is equipped with two springs for avoiding buckling due to expansion through heating. The plate is divided into various X and Y lines for comfort in measurement of surface temperature profile. The temperatures of each cross points of X and Y lines are measured by using noncontact thermometer. The noted temperatures and room temperature will intern help for calculations. The target to plate distance is varied from 10 mm to 55 mm, this gives H/D from 0.62 to 3.44.

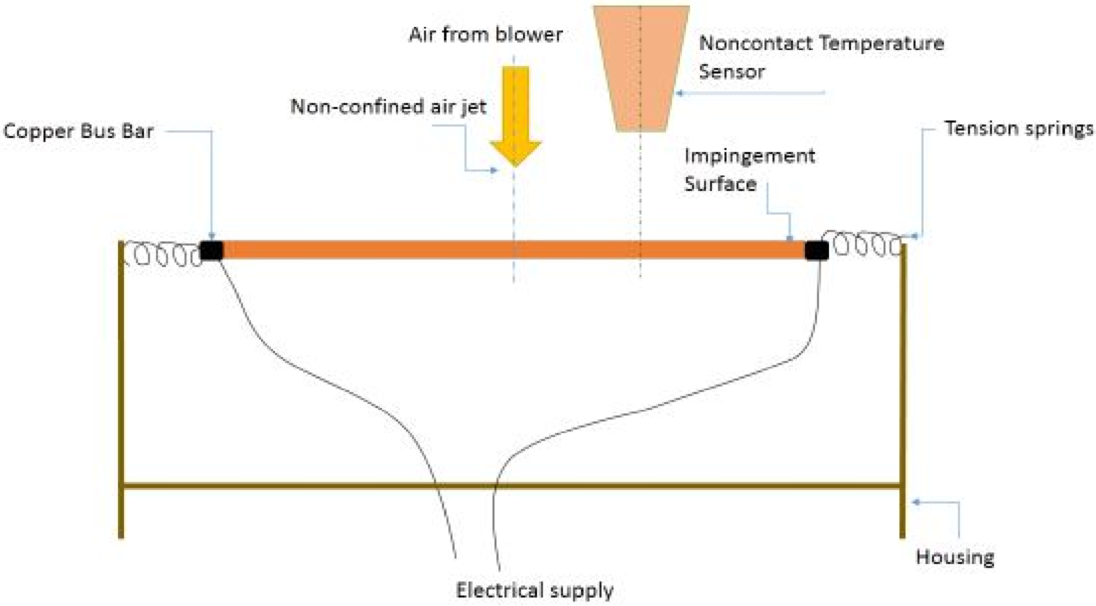

Figure 1: Experimental Configuration

Observations

Temperatures of target plate at all forty points are noted under steady state condition. The temperature distribution graphs are plotted for various cases to understand physics of flow. The sample data is as shown in Figure 2: Temperature distribution for **H/D=0.63**. Similar data is identified for different configurations of H/D as 0.63, 1.56, 2.5, and 3.44. The aim is to find variation in temperature pattern during impingement of jet at a particular point. The jet impingent nearer to target plate shows that after high impact, it is echoed in outside direction from geometrical stagnation point.

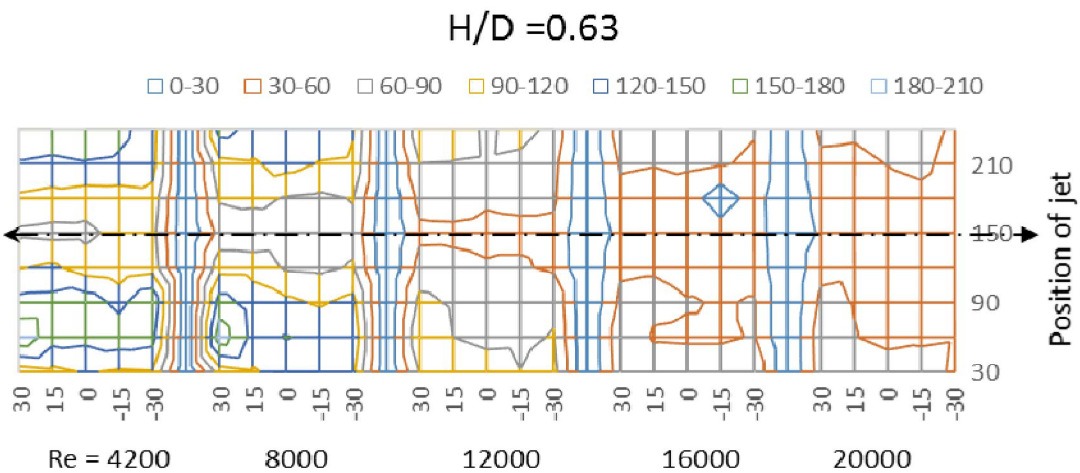

Figure 2: Temperature distribution for H/D=0.63

For higher value of height; H, it will be smooth flow during cooling of such plate. But it will be not at all operative for very large distance. It occurs because the jet dissolves in the surrounding air due to greater height.

Figure 3: Variation in average Nusselt Number in Y direction for various H/D ratios Data reduction is carried out for data collected. The bottom side of plate is considered as with natural convection and calculated using standered imperical relation for bottom of plate. Local Nusselt number is calculated at every point of plate, for complete range of experimentation.

Result and Discussions

Nusselt number is indications of usefulness of convective heat transfer throughout cooling process. It is observed that it could be possible to calculate local Nusselt number on the target plate. But it may give us disordered results because of verity of numbers. As Nusselt number is function of convective heat transfer coefficient, and inturn of temperature difference, ultimatily the same profiles of Nusselt numbers will be observed as that of temperature. To make simplicity in understanding the Nusselt Number variation, average Nusselt number in Y direction ($Nu_{avg\text{-}Y}$) is calculated. Its variation is shown in Figure 3: Variation in average Nusselt Number in Y direction for various H/D ratios

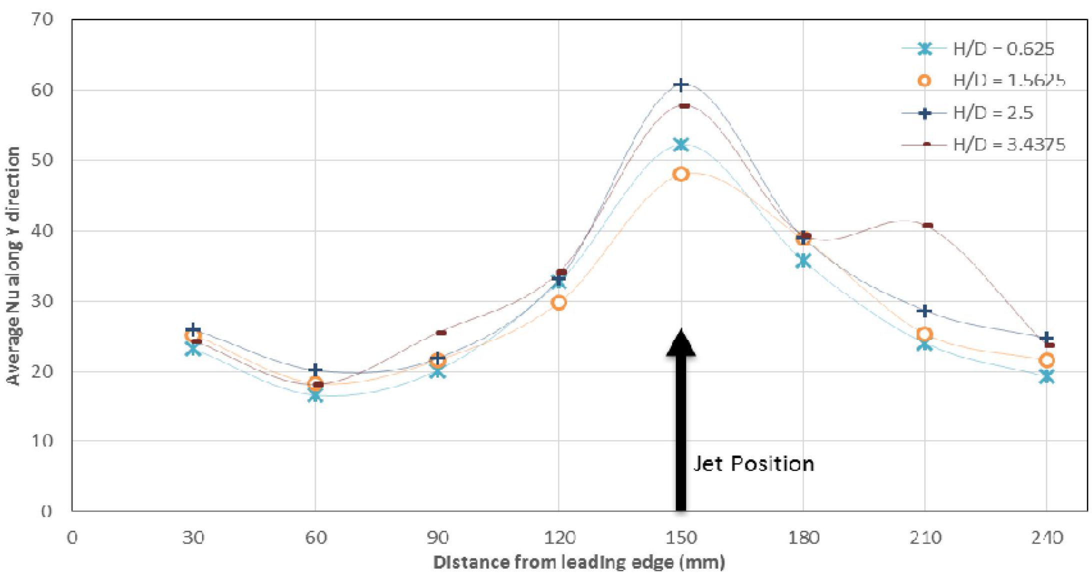

Figure 3: Variation in average Nusselt Number in Y direction for various H/D ratios

It is to be noted that jet position is at 150mm from leading edge (Zero of X - axis). Highest Nusselt number is observed at stagnation point of jet. The tendencies are similar for all values of H/D. It is observed that highest stagnation $Nu_{avg\text{-}Y}$ is achieved for H/D as 2.5. It increase for H/D 0.62, 1.5, 2.5, respectively. But it shows decrease for H/D 3.4

To know variation of Nu $_{avg-Y}$ against Reynolds Number, observations are plotted (Figure 4: Nusselt Number Distribution H/D = 0.63).

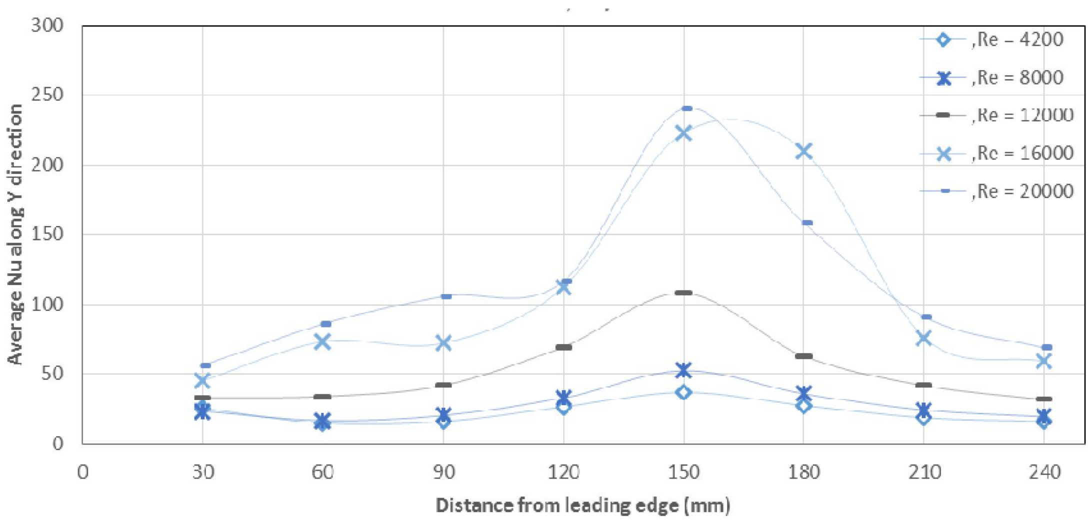

Figure 4: Nusselt Number Distribution H/D = 0.63

In this case of H/D as 0.63, Nu $_{avg-Y}$ is observed to be maximum at stagnation point (150mm, distance from zero end). Highest value of Nu is 240 for Re as 20000. The universal law of Nusselt Number increases as per Reynolds Number is found factual in this case also. The Nu is very less up to Re 8000, later it increases considerably.(Figure 5: Nusselt Number Distribution H/D = 1.56) This also shows deviation of Nu is following similar trends with maximum Nu as 200. It is observed that values of Nu are lesser that that of H/D = 0.63 for respective Reynolds Number.

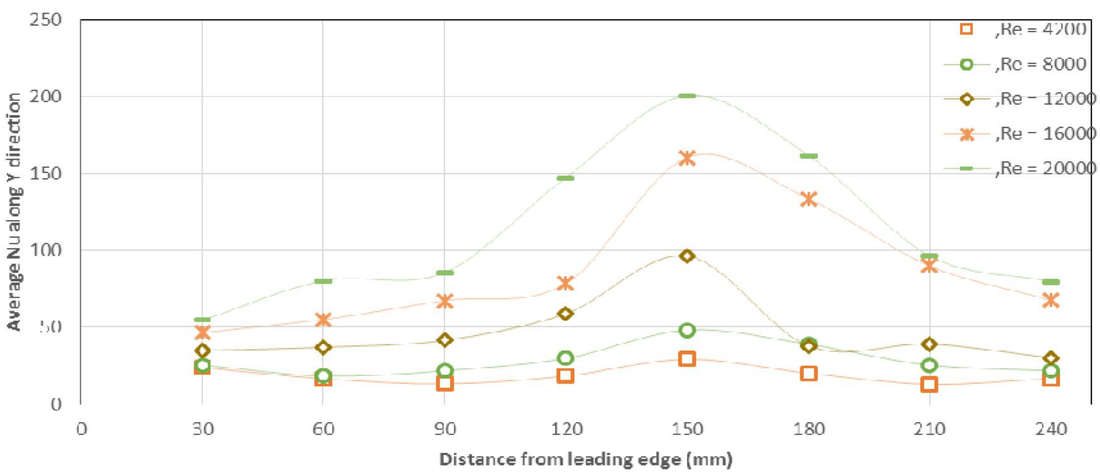

Figure 5: Nusselt Number Distribution H/D = 1.56

One of the objective is to identify the deviation of Maximum Nusselt Number for average in Y direction (Numax-avg-Y) for all such cases, with respective of Re and also to find correlations between them. Figure 6: Maximum Nusselt Number Nu max-avg-Y variation for various H/D. It is observed that as Re increases, Numax-avg-Y also increases. The upsurge level is uppermost for H/D of 0.63. This indicates for lesser target to spacing distance, maximum Nu max-avg-Y is obtained, which is more important conclusion for cooling applications of electronics components and PCBs.

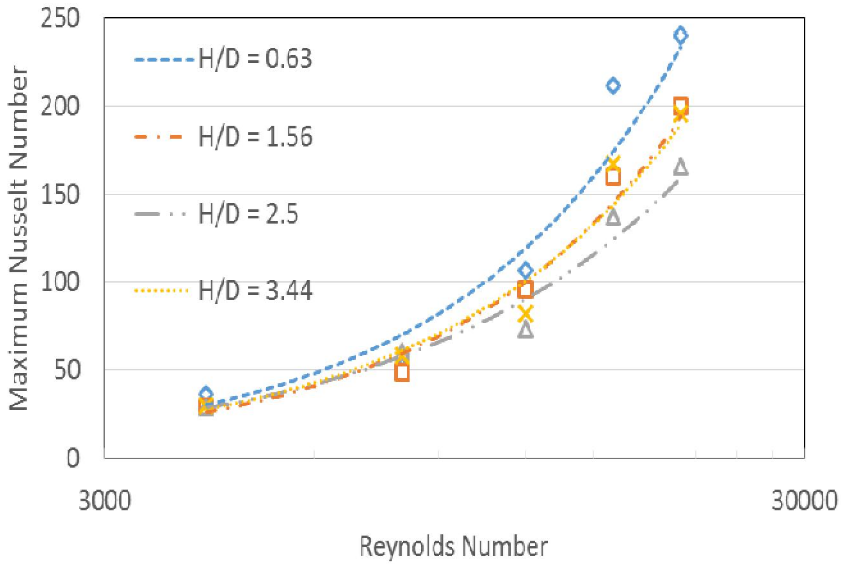

Figure 6: Maximum Nusselt Number

By using simple regression analysis, following correlations are suggested for understanding relative changes between Nu $_{\text{max-avg-Y}}$ and Re for different H/D.

$$Nu_{\max-avg-Y} = 0.0005\mathrm{Re}^{1.314} \ldots\ldots\ldots For H/D = 0.63$$

$$Nu_{\max-avg-Y} = 0.0005\mathrm{Re}^{1.295} \ldots\ldots\ldots For H/D = 1.56$$

$$Nu_{\max-avg-Y} = 0.0037\mathrm{Re}^{1.11} \ldots\ldots\ldots For H/D = 2.5$$

$$Nu_{\max-avg-Y} = 0.0009\mathrm{Re}^{1.239} \ldots\ldots\ldots For H/D = 3.44$$

The above suggested correlations are valid for the range of the specific H/D stated, Re = 4000 to 20000, Diameter of jet as 16mm with perpendicular impingement and at Pr = 0.8 to 1.

Conclusion

The experimental analysis of high temperature surface cooling application is carried out. A non-confined air jet is used with a static diameter of 16 mm and its heat transfer features are verified for Reynolds Number of 4000 to 20000, which is considered to be turbulent jet. Highest Nusselt number is observed in stagnation point of jet. The results are similar for all values of H/D. It is detected that maximum Stagnation Y direction average Nusselt Number ($Nu_{max\text{-}avg\text{-}Y}$) is for H/D as 2.5. It upsurges for H/D 0.62, 1.5, 2.5, respectively. But it shows decrease for H/D as 3.4. In case of H/D as 0.63, also $Nu_{max\text{-}avg\text{-}Y}$ is observed to be maximum for stagnation point with highest value 240 for Re 20000. The Nu is very less up to Re of around 8000, afterwards it increases drastically. The experiments can be performed at various diameters for understanding its effect. At low target to jet distance, it is perceived that very high turbulence is created which in turn gives highest Nusselt Number. An effort is made to suggest experimental correlations for $Nu_{max\text{-}avg\text{-}Y}$ and Re at various H/D ratio.

References –

[1] Y. O. E. Baydar, "An experimental investigation on flow structures of confined and unconfined impinging air jets," *Heat Mass Transfer,* vol. 42, pp. 338-346, 2006, pp. 338–346.

[2] Y.-M. T. Z.-C. C. Jung-Yang San, "Impingement heat transfer of staggered arrays of air jets confined in a channel," *International Journal of Heat and Mass Transfer,* vol. 50, pp. 3718-3727, 2007.

[3] S. J. V. K. D. Matteo Fabbri, "A Comparative Study of Cooling of High Power Density Electronics Using Sprays and Microjets," *ASME Journal of Heat Transfer,* vol. 127, p. 38 – 48, Matteo Fabbri, Shanjuan Jiang, Vijay K. Dhir, ‘A Comparative Study of Cooling of High Power Density ElecJan 2005.

[4] S. Dave, Cooling Techniques for Electronic Equipment, Second Edition ed., A WILEY-INTERSCIENCE PUBLICATION John Wiley & Sons, Inc..

[5] N. C. Haydar Eren, "Cooling of a heated flat plate by an obliquely impinging slot jet," *International Communications in Heat and Mass Transfer, Vol. 33, 2006, pp. 372–380,* vol. 33, pp. 372-380, 2006.

[6] Ingole S. B., K. K. Sundaram, "Review of Experimental Investigation in Heat Transfer for Jet Impingement cooling," *International Review of mechanical Engineering,* vol. 6, no. 3, pp. 346 - 356, March 2012.

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