Cooling Characteristics of a Surface using Inclined Air Jet at 75 Degree

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Abstract— Jet impingement is exceedingly operational for numerous field applications including electronics cooling and process industry. Its implementation comfort makes it common for many applications. The paper deals with investigation of thermal profile of a flat surface. It is cooled by air jet impinged at an angle of 75 degrees (angle of jet to target plate). For understanding variation in cooling performance, comprehensive experiments are performed with different configurations of jets on hot surface. For simplicity in using air, it is recommended for verity of applications as cooling fluid. Air jet with Reynolds Number of 2000 to 10000 is examined for the circular jet of constant diameter. The target to jet perpendicular height (H) is varied from 10mm to 55 mm for understanding effect of H on temperature of different locations on target plate. The 'cool ellipse' is drawn with specific major and minor diameter. Its size variation is noted for typical correlations of current cases.

Index Terms— Air Jet, Jet impingement cooling, cool ellipse.

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1 Introduction

More number of electronics components are mounted on one chip to make it more beneficial for verities of electronics applications and appliances. Advanced materials like Graphitic, Diamond, Carbon foams and composite materials are used for improved performance of heat transfer throughout electronics cooling applications. Spreader sheets are described to cool PCBs. Also techniques like VCC, Vortex tube cooling etc. are observed during survey. [1] Efforts are made to reduce thermal resistance or to increase the heat transfer coefficient for PCBs. The electronics cooling is viewed in three levels. First, the maintenance of chip temperature at a comparatively low level despite of high local heat density. Second, this heat flux must be handled at system or module level. Finally, the thermal management of the computer machine area, office space, or telecommunication arena. The thermal design of the system is influenced by the key drivers like chip size, power dissipation, junction temperature and ambient air temperature. With the increase in power dissipation and reduction in the size, the growth in power density is expected to increase from 20 (minimum) – 50 (Maximum) W/cm^2 to 60 - 190 W/cm^2. [2] Heat can be removed by using two basic modes of heat transfer i.e. Combined convection and conduction of heat. Around 55 % of electronics components fail due to heating above their sustainable limit. Mainly following two categorization are used for cooling systems.

1. Passive cooling: Passive techniques of cooling do not require any additional source of energy. They work on principle of natural convection as well as conduction. The most advantageous notable factor is, a clean and leak proof method of cooling. It is applicable for compact arrangements and smaller capacity systems. For example; Heat sinks on motherboards.
2. Active method: If additional power is consumed for running cooling system, it is called as active method of cooling. In this a fan forcing air is the popular example. This needs additional cost of fan or pumping a liquid, additional cost of energy. The cooling method also demands additional space during installation.
3. Combined methods: Efforts are always made to efficiency of these systems. One of the best ways is to combine active and passive methods. E. G. Cooling of PC using fins and fan. [3]

Active cooling techniques are more famous for their effectiveness, obviously with the expenses of energy. Cost of heat pipes and liquid cooling systems are to be higher compared to air flow systems. Flow through micro channel, Jet impingement, Spray cooling, use of fans are seen to be used. Boiling gives high performance but its operational complexity is prominent, whereas normal air gives very low heat transfer coefficient. Air jet is most easy operational system with good performance outcomes.

Majority of systems uses the approaches which are cost effective, and as well appropriate for that particular application. Like for electronics applications water cooling is explored, even difficult to use for smaller systems or subsystems. For very high heat generating units, it is not trustable on only natural cooling, but extended surfaces will be helpful for during emergency. Similarly air is the preeminent for avoiding system complexity and return lines.

TABLE I
Convective Heat Transfer Coefficient for various electronics cooling Techniques [4]

Cooling methods	Heat Transfer coefficient (W/m^2K)
Gas (Natural Convection)	2 to 25
Liquid (Natural convection)	50 to 1000
Gas (Forced Convection)	25 to 250
Liquid (Forced Convection)	100 to 20000
Boiling	> 2500

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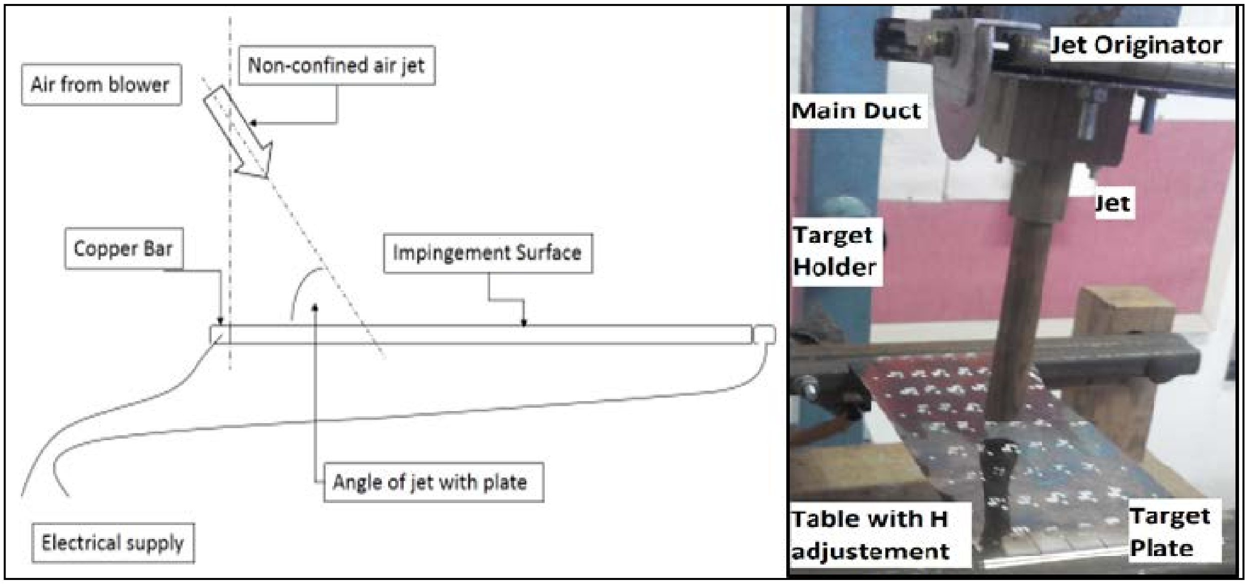

Figure 1: Experimental setup and alied arrangements

2 Jet impingement cooling

For the application of high heat flux removal, by understanding above pros and cons, it can be stated that fluid impingement on electronic components is need to be tested using various fluid. The physical jet configuration are of types given in Table II. The concept of using a focused jet for restricted cooling is comparable to that used for metal quenching. Jet impingement offers not only the ability to remove high heat fluxes but also the ability to target hot spots or uneven heating**.**

TABLE II
Classification of Jets as per Physical Configuration

Condition	Types
Flow	Free jet
	Confined jet [5]
Number of Jets	Single
	Multiple [6]
Geometry of jet	Slot jet
	Circular jet
	Elliptical jet [7]
Direction of jet [8]	Normal jet
	Inclined jet [9]

3 Objectives

Objectives of present study is to investigate temperature profile of target hot plate with inclined air jet and to know the cooling zones for different Reynolds Number. Also to study effect of variation of target to jet height on temperature profile with developing a correlation to know cool ellipse spread.

4 Experimenttal Setup

The experimental setup is as shown in Figure 1; in which jet is impinged on the target surface. The test target hot plate (100W) is made up of small thin foil of Steel. The wattage is applied is by passing an electric current of high rating. The heating element is placed in between two copper bus bars. This heated target plate is cooled by impinging air through circular cross-section jet. The plate is placed horizontal and jet will be impinged from top (only one side of it). For cooling of target plate, air is used as a fluid in present study. Air is supplied by a blower for the experimentation. Air passes through a hose pipe of 25mm diameter and its flow is controlled through a flow regulating valve. This will also satisfy requirements of air at various Reynolds Number varying from 2000 to 10000. A heat exchanger is provided that keeps the temperature of the jet air close to that of the ambient air. The air then passes through a straightened passage to force it for straight flow. After the straightened chamber, the air passes through a Nozzle unit. The jet to target plate distance is much more important. To understand the effect of change in height; i.e. target to jet spacing (H), it is varied from 10 mm to 55 mm. The axis of jet makes an angle of 750 with that of horizontal target plate. The parameters which are constant during this study are; the internal jet diameter (D) as 8 mm, heater wattage 100W and angle of impinged jet 750.

An infrared thermometer is used to take temperature readings of the target plate. The velocity of air jet is measured in m/s by using anemometer. For accuracy in velocity measurement, average of readings at three/five different locations,

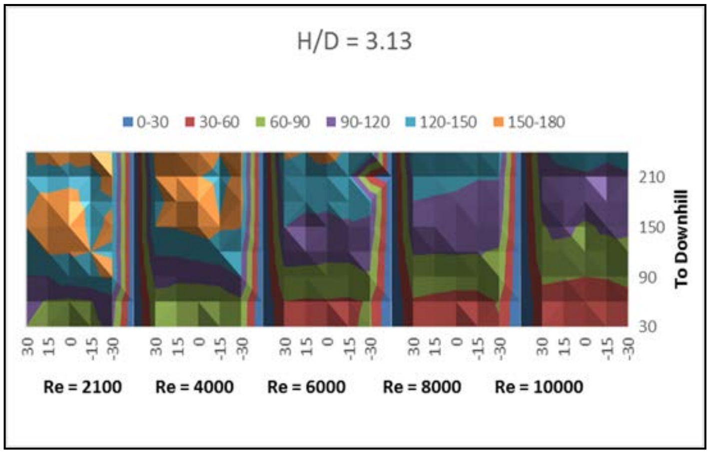

Figure 2 : Temperature profile for H/D = 3.13

immediately after jet plate is measured. All readings are taken at steady state conditions.

5 Data Reduction

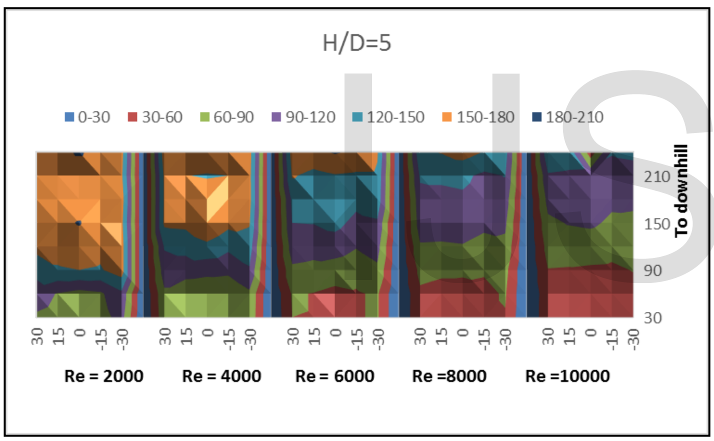

Figure 3 : temperature Profile for H/D = 5

The careful observations are taken at steady state condition of experiment. The readings of velocity is measured using Hot Wire Anemometers at the exit of jet. It will be considered as jet exit velocity, and used as governing parameter for data reductions further. Same velocity is used to calculate jet Reynolds Number. To calculate Jet Reynolds number, jet diameter is considered as the characteristics dimension.

6 Observations

Extensive experimentations are conducted for Reynolds number of 2100, 4000, 6000, 8000 and 10000. The observed temperature profiles are plotted for various H as 10mm, 25mm, 40mm and 55mm. Graphs are plotted for non-dimensional H/D for better correlative understanding. Figure 2, 3 and 4 shows the temperature profile of different configurations with H/D as 3.13, 5 and 6.8 respectively.

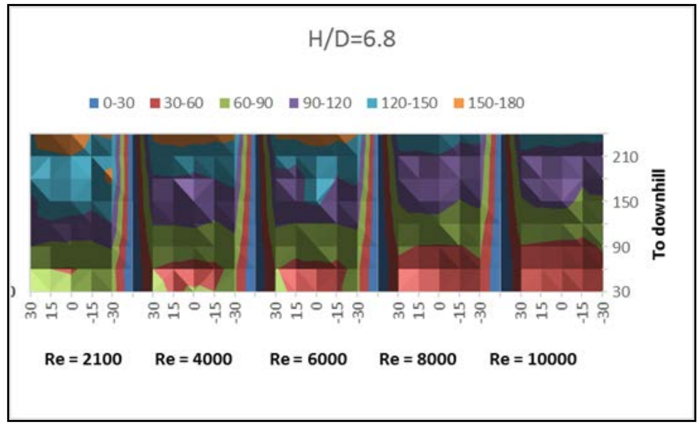

Figure 4 : Temperature Profile for H/D = 6.8

7. Cool Ellipse – Sample Nomenclature

The target of investigators is to find Maximum Nusselt Number, or to find minimum temperature position on target. [9] Average Nusselt number is also calculated for understanding the effectiveness of such jets. In presented investigation, aim is to know cooling region for a specific jet configuration. This tend to development of the concept of 'cool ellipse'. 'Cool ellipse' is defined as the ellipse inscribed on the temperature profile up to half of the maximum temperature (of target plate) achieved because of jet cooling. By the inclined jet cooling on target plate, it gives elliptical cooling zones. The objective is to investigate the ellipse (Called 'cool ellipse') accomplished. The hypothesis is the Y axis of ellipse increases as H

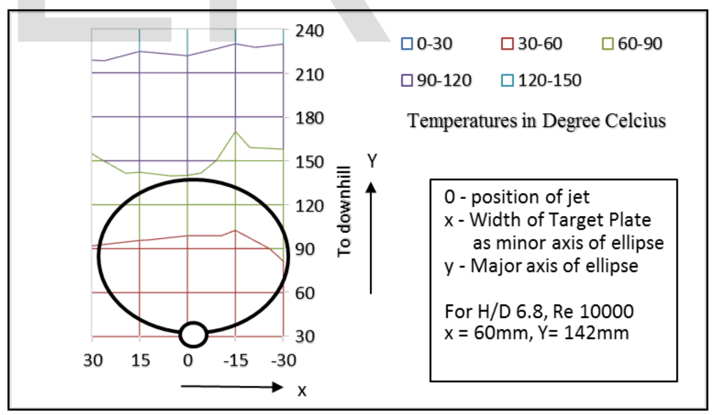

Figure 5 : Cool zone Nomenclature

increases with the assumption of X axis of ellipse to be constant, for this study. Sample cool ellipse nomenclature is shown for H/D = 6.8 with Re = 10000, in Figure 5.

8. Results And Discussions

From extensive experimentation, results are obtained for temperature variation of surface simulating the electronic PCB, or such product. It is observed that the zone of cooling will change as per variation of Reynolds Number. It will increase considerably with respect to Reynolds Number. The values of Y of 'Cool Ellipse', are shown in Figure 6 for various H/D. It is interesting to conclude from graph, that the Y value will aproximately lie in same zone for H/D of 1 to 5. It can be concluded that there is no major variation in the size of cool ellipse if also target to jet distance is varied up to specific value. But for H/D of 6.9, higher value of Y are seen. The higher trend is observed for all Reynolds Numbers. Initially 50% increase in Y/D is observed for H/D of 6.9, compared to other values of H/D. Which will show lower increment, consequently for higher Reynolds Number. Higher cooling zone is observed for higher H/D with lower Reynolds Number, may be due to smoother impingement of jet on target.

The relationship of Y/D to Reynolds Number and Prandtl Number can be established by experimental observations for different values of H/D. By curve fitting, in fig. 6, following correlations are suggested.

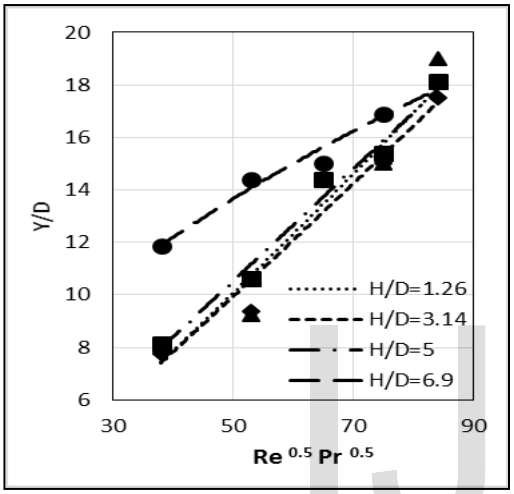

Figure 6 : Variation between (Y/D) for different Jet to target spacings

$$(Y/D) = C.\, Re^{a}\, Pr^{b} \quad (1)$$

From the experimental range conducted, the above equations are applicable for $\theta = 75^0$, D=8mm with ranges of Re as 2000 to 10000 and H = 10 to 55.

TABLE IIII
CONSTANTS IN EQUATION (1) SUGGESTED

For (H/D)	c	a	b
1.26	0.134	0.55	0.55
3.14	0.15	0.53	0.53
5	0.2	0.5	0.5
6.9	1.83	0.255	0.255

9. CONCLUSION

'Cool Ellipse' is defined for understanding effectiveness of inclined jet for cooling a target. For H/D 6.9, cooling of target plate – 'Cool Ellipse' size is increasing from Reynolds Number 2000 to Re 9000, with comparative margin with respect to other H/D values. For remaining values of H/D almost overlapping of trend lines is observed, except H/D as 6.9. But maximum Y/D, i.e. cooling is observed at Re 10000 and H/D as 1.26. Correlations of Y/D, and Re are suggested for various H/D for particular ranges of experiments. The concept of 'cool ellipse' and work done is intern useful for selecting physical parameters for cooling of hot spots or typical areas of electronics systems by using inclined jets. The drawback is that a high pressure head is needed that converted to high kinetic energy of the jet. Also, there may be some noise concerns because of the high speeds.

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