International Journal of Mechanical and Industrial Engineering

Volume 2 | Issue 3 Article 11

January 2013

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Recommended Citation

Zakrea, Syed; Ali, Siddiq; Ahmed, Mohammed Ayaz; and Anwarullah, M. (2013) "Experimental Investigation to Evaluate the Effectiveness of Air and Co2 in Impingement Cooling of Electronic Equipment," *International Journal of Mechanical and Industrial Engineering*: Vol. 2 : Iss. 3 , Article 11.
Available at: https://www.interscience.in/ijmie/vol2/iss3/11

Experimental Investigation to Evaluate the Effectiveness of Air and Co_2 in Impingement Cooling of Electronic Equipment

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Abstract - Experimental investigation is conducted to examine the characteristics of forced convective heat transfer from electronic components, subjected to a confined impinging circular jet of Air and CO_2. Parameters such as Heat transfer coefficient, Jet velocities, Nozzle-to-chip spacing (aspect ratio) (H/d) have been studied. Nozzle diameter ranged from 2mm to 8mm. Local heat flux measurements are made with different diameters of jet in the range of Reynolds numbers from 5,000 to 44,000 for CO_2 and 2,500 to 23,000 for air. H/d is varied from 3 to 45 for both air and CO_2. Variations both in the local heat transfer coefficient and Nusselt number are determined as function of Re. Variations of average Nusselt number and local heat flux with time are obtained in a wide range of Re and H/d ratios. The results of the investigation are presented in graphical form and a comparative study of Air and CO_2 as coolant is made.

Keywords *- Jet impingement, Air jet, CO2 jet, Electronic cooling, transient heat transfer.*

I. INTRODUCTION

Impinging jets have received considerable attention in the field of electronic cooling, due to their inherent characteristics like simplicity and higher rates of heat transfer. The impinging flow devices allow for short flow paths on the surface and relatively high rates of cooling from a relatively small surface area. Single impingement jet can generate high heat transfer rate in specific areas, but lead to a non-uniform temperature distribution on the cooled surface. While impingement cooling has been used for larger electronic components already, there are apprehensions about its applicability for small, high heat density components. Current cooling systems take up a great deal of space, and the volumetric ratio of the cooling system to the electronic component is high. Impingement cooling, if adapted for electronic cooling, could be a more direct and space efficient cooling, could be a more direct and space efficient alternative. One major application of jet impingement is in the cooling of electronic components. Other industrial uses of impinging jets include tempering of glass, annealing of metal and plastic sheets, drying of paper and textiles and cooling of turbine blades [1].

Due to the wide industrial applicability of impinging jets, extensive research has been conducted to understand the heat transfer characteristics. The heat transfer rate from the surface to the impinging jet is a complex function of many parameters namely Reynolds number (Re), Prandtl number (Pr), aspect ratio (H/d), and non-dimensional displacement from the stagnation point (r/d). The primary aim of this experimental study is to investigate the heat transfer characteristics of Air and CO_2 jet impinging normally on the surface of the electronic components. Local Nusselt numbers, temperature profiles and stagnation Nusselt number are determined.

1.1 Abbreviations

A: Surface area of the electronic components (m^2)

d: Diameter of nozzle (m)

h: Local heat transfer coefficient (W/m^2 k)

H: Distance between nozzle-to-electronic component (m)

Nu: Local Nusselt number (hd/k)

Nu_O: Stagnation point Nusselt number

Re: Jet Reynolds number (Vd/**υ**)

Q: Heat flux (W/m^2)

Ts: Surface temperature of component before cooling (C)

$T_{a:}$ Ambient temperature (C)

V: Velocity (m/s)

H/d: Nozzle-to-component spacing to nozzle diameter (aspect ratio)

K: Thermal conductivity (W/m K)

Pr: Prandtl number

r: radial distance from the center of the electronic equipment

II. LITERATURE SURVEY

Jambunathan et al. [2] conducted a detailed survey of jet. impingement cooling. They concluded that the simplest correlation for local heat transfer coefficient is a function of jet Reynolds number (Re), jet height-to-jet diameter ratio (H/d), radial distance-to-jet diameter ratio (r/d) and Prandtl number (Pr). Beitelmal et al. [3] analyzed two-dimensional impinging jets and correlated heat transfer in the stagnation point, stagnation region and wall jet region with approximate solutions, developed using simplified flow assumptions. Koseoglu and Baskayabv [4] studied the heat transfer characteristics of confined circular and elliptical jet, observed that an increase in jet to plate thickness reduces the difference between circular and elliptical flow fields. Baughn and Shimizu [5] experimentally investigated the effect of jet-to jet spacing on the heat transfer for a confined impinging jet array. They found that, for large plate spacing, jet interference causes a significant degradation of the heat transfer. They proposed a correlation for local Nusselt number in impinging axisymmetric jets. Lee et al. [6] have studied effect of nozzle diameter (1.36, 2.16, and 3.40 cm) on impinging jet heat transfer and fluid flow. They reported that local Nusselt numbers in the stagnation point region corresponding to $0<r/d<0.5$ are increased with increasing nozzle diameter. Ichimiya and Yamada [7] have reported that the presence of the recirculation regions on both impingement and confinement surfaces for low spacings. With the increase in Reynolds number and nozzle-to-plate spacing, the recirculation flow on the impingement surface moves downstream and its volume increases correspondingly. Baydar and Ozmen [8], for Reynolds numbers ranging from 500 to 50,000 in confined impinging jets, observed that a sub atmospheric region occurs on the impingement plate for Re>2,700 and the aspect ratio less than 2 and there existed a linkage between the sub atmospheric region and the peaks in local heat transfer coefficients. Abdel-Fattah [9] noted that a sub atmospheric region occurs on the impingement plate and its effect decreases with increasing nozzle-to-plate spacing at the impinging circular twinjet flow. Huber and Viskanta [10] investigated the effect of jet-to jet spacing on the heat transfer for a confined impinging jet array. It was found that, for large plate spacing, jet interference causes a significant degradation of the heat. Dong et al. [11] carried out an experimental study to investigate the heat transfer and wall pressure characteristics of a pair of laminar air jet impinging vertically upon a horizontal flat plate. They concluded that the pressure distribution on the impingement plate and heat transfer from the jet to the plate were greatly influenced by the interference occurred between the two jets. Miao et al. [12] investigated the fluid flow and heat transfer characteristics of a round jet array impinging orthogonally on a flat plate within a confined wall at different cross flow orientations. They computed detailed Nusselt number distribution on the flat plate and reported that the area averaged Nusselt number increases with increasing jet Reynolds number. Pavlova and Amitay [13] and Gillespie et al. [14] studied the influence of H/d ratio on heat transfer to an impinging synthetic jet experimentally for different settings. Both studies indicate that the maximum heat transfer occured for jet-to surface spacings in the range $4<H/d<11$. Very few heat transfer studies have been undertaken for $H<d<4$. The jet-to-surface spacing H/d influences the flow at the heat transfer surface, and the level of confinement and recirculation is shown by Campbell et al. [15]. Goldstein et al. [16] described a recovery factor and the local heat transfer for an axisymmetric impinging air jet formed by a smooth nozzle. The recovery factor is dependent on the jet nozzle to impingement plate spacing, but is independent of jet Reynolds number. San and Shiao [17] studied the effects of jet plate size and plate spacing on the heat transfer characteristics for a confined circular air jet vertically impinging on a flat plate. Jet Reynolds number is in the range of 10,000–30,000 and plate spacing-to-jet diameter ratio was between 1 and 6. The authors observed that the impingement-plate heating condition and flow arrangement of the jet after impingement are two important factors affecting the dependence of the stagnation Nusselt number on H/d. Gardon and Akfirat [18] investigated the variation in local heat transfer rate produced by impinging slot jets with changes in the free stream turbulence at the nozzle exit. They concluded that some seemingly anomalous heat transfer phenomena could be explained in light of the turbulence intensity inherent in jets, and that circular jet with larger nozzle diameter produced higher heat transfer rate. More recently, Zhou and Lee [19] studied heat transfer and fluid flow characteristics due to impinging air jets from sharp-edged rectangular nozzle of aspect ratio of 4.0. The local heat transfer distributions along the minor axis and average Nusselt numbers are correlated with turbulence intensity.

III. FLOW FIELD

The schematic illustration of a single impinging jet is shown in Fig. 1. The jet issues from a circular nozzle of diameter d, with a velocity v, and impinges perpendicularly on surface, where the electronic components are mounted, at a distance H from the nozzle. In the impingement jet flow, as seen in Fig. 1, there are three regions of distinct flow namely free-jet region, wall-jet region and impingement region. Within free jet region are two sub regions, the potential core with velocity equal to the jet exit velocity and the lower velocity shear layer, which results from the entrainment of the surrounding fluid. Downstream of the nozzle, the shear layer progressively grows and displaces the potential core, eventually reaching the jet centerline. The wall jet region is where the dominant velocity component is radial and the boundary layer thickens as it moves radially outward.

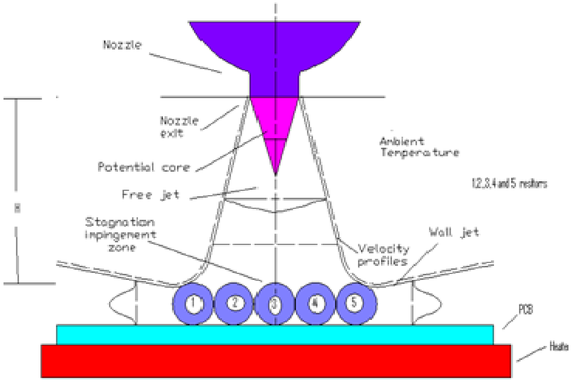


Fig. 1 : Schematic diagram of flow regions

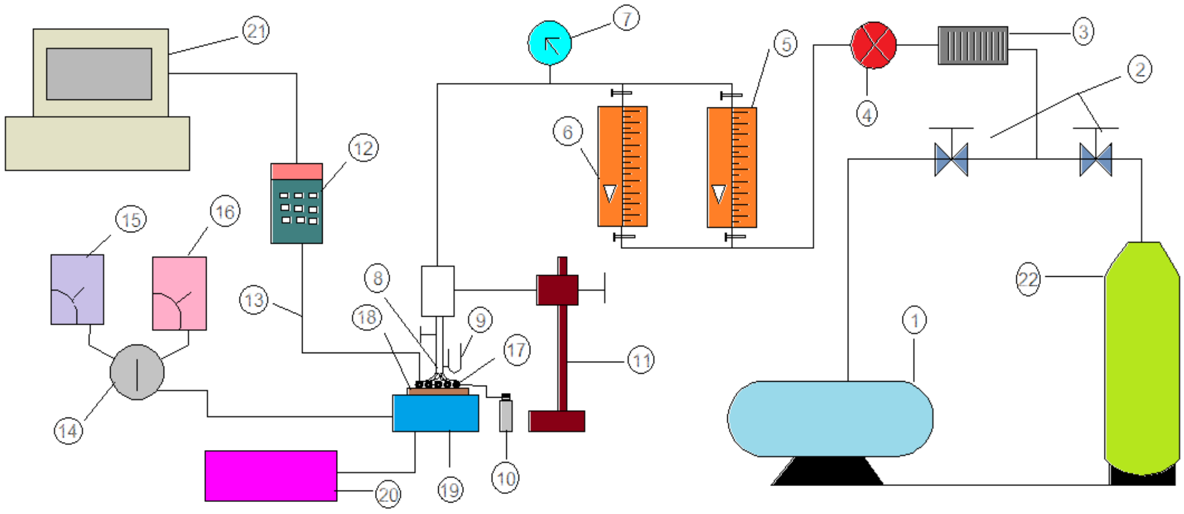
IV. EXPERIMENTAL SETUP AND PROCEDURE

4.1 Experimental Setup

Figure 2 shows the overall experimental setup with the relevant apparatus and instruments. The setup is composed of four major parts: (1) two stage reciprocating air compressor, (2) rotameter, (3) electric heater, and (4) control panel. During experiment, a large reciprocating air compressor supplied the high-pressure air for jet impingement. This high-pressure air was stored in a large storage tank of 20-bar pressure and 160 liters capacity. A pressure regulator is installed at the exit of the tank to stabilize the pressure of the supply air. Compressed air flows through an air filter, an air filter/regulator and then through a flow meter (Rotameter) with ±1 % reading accuracy. A pressure gauge connected at the outlet of the flow meter is used to correct the flow rate. CO_2 is also one of the working fluid used. For which a special heater for CO_2 heater is used to convert it into gaseous form. The control panel consists of voltmeter (0–250 V), ammeter (0–240 mA), Autotransformer, and temperature display unit. An aluminum heater plate rated 500 W and 240 V, insulated on all sides by mica sheets, is used to heat the printed circuit board (PCB). Five cylindrical electrical wire wound resistors with 5 watt heat capacity, 220 ohms resistance are fixed on printed circuit board of diameter 100 and 2 mm thick are located centrally on the aluminum heater plate. A 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 dimmer stat (Auto transformer) to control the heating rate to the base plate. The total power supplied is monitored using two digital multimeter one for the voltage and the other for the current. Teflon coated J-type (Iron–Constantan) thermocouples are used to measure the surface temperatures of the electronic components (resistors). All thermocouples are thoroughly calibrated by using a constant temperature water bath, and their accuracy has been estimated to be ±0.1%. The central resistor in the jet array is considered for the analysis. Two thermocouple leads measure the temperature of the hot aluminum plate. One thermocouple is used exclusively to measure the temperature of the air in the enclosure. All these eight thermocouples are connected to a temperature display unit called the data acquisition system (masibus digital scanner 85 XX). A custom built software capable of acquiring temperature data as a function of time is loaded on to a personal computer. This software has a provision to set the sampling frequency of temperature as low as 0.1 sec. The storage capacity of the data acquisition system is kept sufficiently large so that the temperature data can be acquired over a large interval of time. The axis of the nozzle is always aligned with the central resistor and is normal to the plane on which heat sources are mounted.

4.2 Experimental Procedure

The air jet emanating from the nozzle and impinging on the resistors is taken as free jet and wall jet region respectively. Power is supplied to the resistors through a step down transformer and the aluminium plate through an Autotransformer. The volumetric heat generation due to heating of resistor using AC current is assumed to be uniform. The temperature of the resistors is allowed to rise up to 95^0 C, and then cooled by forced convection mainly from the top surface by the air stream flowing in the wall jet region. The heat loss from the bottom of the resistors is assumed to be negligibly small.



1. Two stage air compressor 2. Valve 3. Air Filter 4. Regulator 5. Rotameter-I 6.Rotameter-II, 7.Pressuregauge.8. Circular nozzle, 9. U-tube manometer, 10. Step-down Transformer.11. Adjustable Stand, 12. 85 XX Digital Scanner Units, 13. J-Type Thermocouples, 14 Autotransformer, 15. Voltmeter, 16. Ammeter, 17. Electronic Components, 18. PCB 19. Heater, 20. Power supply, 21. Computer 22. CO_2 cylinder

Fig.2 : Experimental setup of single circular jet apparatus

V. RESULTS AND DISCUSSIONS

Figure 3 shows the variation of the temperature of the electronic component with time at a single jet Reynolds number 8500 and H/d ratios of 5 and 13 for both Air and CO_2. In this figure Air and CO_2 jets are impinged over the surface of electronic equipment through a nozzle of 4mm diameter when the equipment attained a steady state temperature of 94°C. It is observed that, for both CO_2 and Air, the temperatures are lower for lower H/d ratio. The temperatures are lower in the case of Air compared to CO_2, indicating that heat transfer rates are higher for Air. This is because of the difference in the physical properties of Air and CO_2, and the difference in the molecular structure of Air and CO_2. Air is a mixture of basically nitrogen and oxygen, whereas CO_2 is a stable compound of carbon and oxygen with a specific molecular structure. It also shows that, response time is dependent on the type of the gas being used and the H/d ratio.

Variation of local Nusselt number with dimensionless radial distance (r/d) is presented in figure 4. Experimental results are plotted at Reynolds numbers of 8500 and12000 for Air and 15500 and 22000 for CO_2. In this experiment, Air and CO_2 from a circular nozzle of 4mm diameter directly impinges on the surface of an electronic component at an H/d ratio of 13. In the figure, as expected, the local Nusselt number decreases with increase in 'r/d' for both Air and CO_2. It is also observed from figure 4, that the stagnation point heat transfer is function of Reynolds number and is higher for higher Reynolds number. This is true for both Air and CO_2.

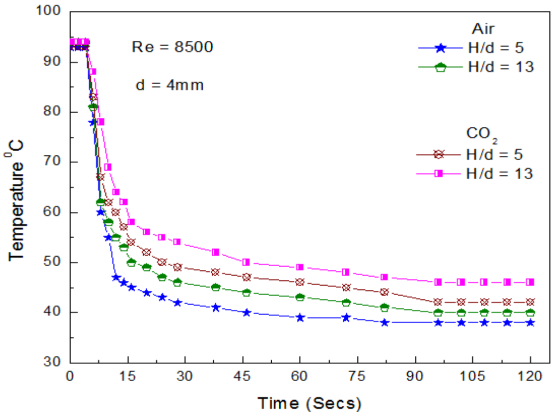


Fig. 3 : Transient variation of temperature for Air and CO_2 at H/d ratios 5 and 13 at a constant Reynolds number (Re) of 8500

The variation of heat transfer coefficient with velocity shown in figure 5. indicates which among Air and CO_2 is a better cooling media. In the figure, the variation of heat transfer coefficient with the velocity is plotted for both Air and CO_2 at a constant H/d ratio of 13. From the figure it is observed that the heat transfer rates are always higher in the case of Air when compared to CO_2 for the same velocity. As mentioned already this is because of the inherent differences between Air and CO_2 though both are categorized as gases.

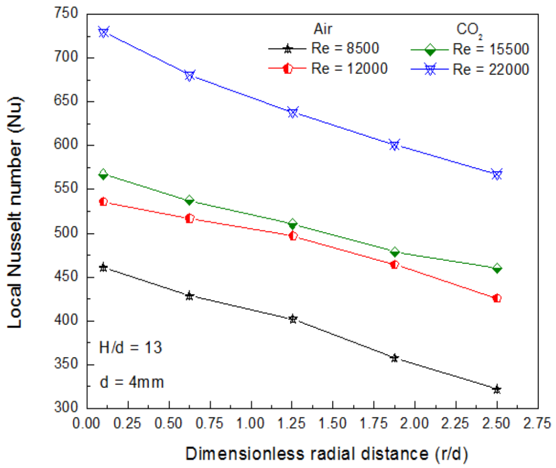


Fig. 4 : Variation of local Nusselt number with dimensionless radial distance (r/d) for different Reynolds numbers

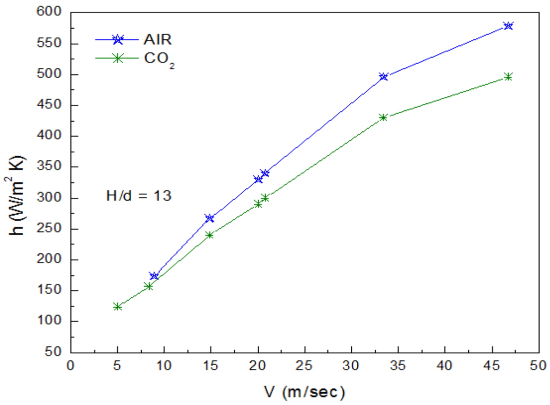


Fig. 5 : Variation of Heat transfer coefficient with velocity for both Air and CO_2

One of the important outcome of the present work, the variation of stagnation Nusselt number with the Reynolds number for a constant value of H/d ratio 13, which is presented in figure 6. The graph can be used for all the gases at the given H/d ratio of 13. In the figure variation of log Nu_o with log Re is plotted. It is seen that, the variation can be represented by a straight line, indicating that a relation $Nu = A\ Re^m$ is possible. For H/d equal to 13 the correlation is $Nu = 0.268\ Re^{0.7805}$, valid for both Air and CO_2.

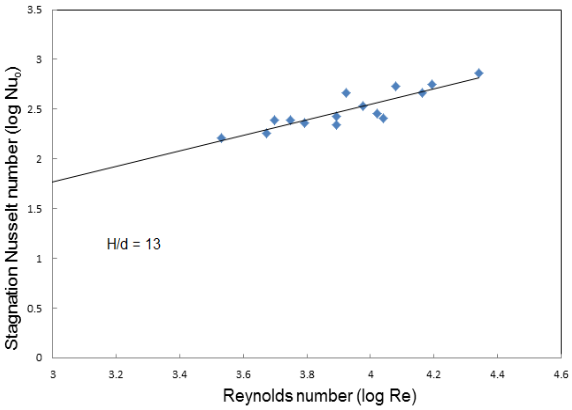


Fig. 6 : Logarithmic variation of Nusselt number with Reynolds number for both Air and CO_2

VI. CONCLUSIONS

Experimental investigation are conducted to study the heat transfer from the surface of electronic equipment when jet of Air or CO_2 impinges with Re in the range of 2500 to 23000 for air and 5000 to 44000 for CO_2 with H/d ratios of 3 to 45.

From the study it is concluded that:

1. As in the case of Air, for CO_2 better temperature gradients are at lower H/d ratios.
2. For a constant Reynolds number, the temperature gradient is better for Air when compared to that of CO_2.
3. Nusselt number decreases with increase in dimensionless radial distance.
4. At similar jet velocities for Air and $CO_{2,}$ better heat transfer rates are obtained for Air.
5. Stagnation Nusselt number increases with increase in Reynolds number for both Air and CO_2.
6. Nusselt number is a function of Reynolds number and H/d ratio and the variation of Nusselt number with Reynolds number is different for different H/d ratios for both Air and CO_2.

VII. ACKNOWLEDGEMENT

The authors gratefully acknowledge the useful discussions and help given by Dr. K. N. Krishnan, Department of Mechanical Engineering, MJCET, Hyderabad.

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