EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER ON AN INCLINED PLATE IMPINGED WITH COLD AIR JET

[1]NARESH R and [2]Ravinarayana Bhat N
[1]MTech Scholar (IAR), ME Department, Srinivas Institute of Technology, Valachil, Mangalore – 574 143.
[2]Associate Professor, ME Department, Srinivas Institute of technology, Valachil, Mangalore – 574 143.

Abstract- **The present work experimentally investigates the variation in heat transfer with the shape of the nozzle on a inclined plate impinged by a cold air jet. The experiment consists of a reciprocating air compressor for supplying compressed air and a plate of dimension 150mmX150mmX0.5mm which is heated uniformly. A copper tube of diameter 10mm is used as a circular nozzle and an aluminium nozzle is used as a square nozzle. Both the circular nozzle and square nozzle have the same area. For getting a fully developed flow the length of the nozzle is taken as 300mm. The cold jets having different Reynolds number is used to impinge on the plates. Variation in Nusselt's number is analysed over the plate in the various Z/D ratio and at the various plate angles.**

The main objective is to study the variation of Nusselt number for various distances or various Z/D ratios where Z is the distance between nozzle exit and plate. Experimental analysis for study the variation in heat transfer by using 10 mm circular and square nozzle of side 8.87mm at *Z/D* = 1, 2, 4 , 6 , 8, 10 and 12 and for the plate angles 0^0,30^0, 45^0,60^0 for different Reynolds numbers.

From the experiment the maximum Nusselt number obtained in the stagnation region (r/D=0). The maximum Nusselt number in the plate is observed when the ratio between the plate centre and the diameter of the plate (Z/D) is 6. When the plate angle is zero degree the Nusselt number distribution is symmetric. As the plate angle increases the Nusselt number at the topside decreases and downside increases.

Index terms- **plate angle, impinging jet**

1. INTRODUCTION

The world is now progressing towards the different modern and sophisticated technologies in the field of mechanical, electrical/electronics, aeronautical engineering and so on. In fact such advanced technologies will lead to large heat emissions. Cooling of such devices has become a challenge for decades. Numerous researches have been carried out in this field to enhance the rate of cooling of heat generating devices. One of the common day to day examples is the cooling of microprocessor chips used in almost all modern electronic devices such as laptops/computers. Some of the industrial appliances also require cooling such as turbine cooling, IC engines cooling, casting industries and the electronics components in rockets during launch and so on.

The impingement cooling found application in early 1960s especially in high heat flux region such as in the gas turbine blades. After that Impinging jets have received considerable attention due to their inherent characteristics of high rates of heat transfer besides having simple geometry. Round jets impinging on heated/cooled surfaces, held normal to the axis of flow, are very attractive in a variety of cooling/heating applications. In comparison with the heat transfer rates obtainable by ordinary methods of convective cooling or heating, a substantial increase in heat transfer coefficients can be realized with their use. Impinging jets may be used for both cooling and heating

ISSN: 2278 – 7798

purposes, but entrainment of ambient temperature fluid by the impinging hot jet will reduce its heating effectiveness, except for short nozzle-to plate distances .The main advantage of this technique lies in the high localization of the cooling, as the use of high speed jets allows removing a large amount of heat on the impinging surface, around the stagnation region.

Impinging jets are widespread in industrial applications, as they have the highest heat and mass transfer rates in the impingement region. Impinging jets have been used to transfer heat in diverse applications, which include the cooling and heating. Various industrial processes involving high heat transfer rates apply impinging jets. Few industrial processes which employ impinging jets are drying of food products, textiles, films and papers, processing of some metals and glass, cooling of gas turbine blades and outer wall of the combustion chamber, cooling of electronic equipment's etc.

Heat characteristics of impinging jets were initially studied by Gauntneret.al.[1] at NASA Lewis research center and developed an impingement cooling program to develop the heat transfer correlations for cylindrically shaped leading edge of vanes/blades and for impingement cooling along vane or blade suction and pressure surfaces. Heat transfer from round impinging jets to a flat plate was studied by Hrycak [2]. Average heat transfer inside the potential core was shown to be essentially independent of the nozzle-to-plate spacing, however was influenced by the condition. of the target plate surface and was inversely proportional to the diameter of the target plate. Tianshu Liu and Sullivan [3] did the experiment on heat transfer and flow structures in an excited circular impinging jet. They concluded that the heat transfer near the stagnation point remains unchanged. When the excitation frequency is close to the natural frequency of the impinging jet the initiated intermitted vortex pairing produces the chaotic 'lump eddy' which contains a great deal of the small scale random turbulence. Huang and El-Genk [4] studied the heat transfer and flow visualization of swirling, multi-channel, and conventional impinging jets. The smoke flow technique showed the flow field between the jet exit and impinged surface. Smoke wires technique was used to demonstrate the flow field close to the impinged surface. Water jet technique showed the swirl effect on flow field and mixing on impinged surface.

Simultaneous visualization of flow field and evaluation of local heat transfer by transitional impinging jets was studied by Angioletti et.al. [5]. Heat transfer measurement carried out by the naphthalene sublimation method based on the heat mass transfer analogy. They determined radial variation of local heat transfer due to initially uniform and laminar round Jet impingement. The entrainment and related pattern of structure creation is also discussed by PIV post-processing capability and an axial velocity pulsation is found which contributes to weaken the boundary layer stability at stagnation and affects local heat transfer. Jungho Lee and Sang-Joon Lee [6] conducted experiment on the effect of nozzle configuration on stagnation region heat transfer enhancement of axisymmetric jet impingement. They obtain in the stagnation region, the sharp-edged orifice jet yields significantly higher heat transfer rates than either the standard-edged orifice jet or square-edged orifice jet. Flow visualization of a round jet impinging on cylindrical surfaces by Cornaroet.al. [7]. Smoke wire visualization is used to investigate the behavior of a round jet issuing from a straight tube impinging on concave and convex surfaces with high relative curvature values.

Katti and Prabhu [8] had done experimental study and theoretical analysis of local heat transfer distribution between smooth flat surface and impinging air jet from a circular straight pipe nozzle. Three regions on the impingement surface are identified based on flow characteristics of impinging jet. They are stagnation region ($0.6 < r/d < 1.0$), transition region ($1.0 < r/d < 2.5$) and wall jet region ($r/d > 2.5$). Increase in Reynolds number increases the heat transfer in all the radial locations for a given z/d. Heat transfers in the stagnation region estimated based on the simplified assumptions of an axisymmetric laminar boundary layer with favorable pressure gradient match well with present experimental results within ±6%.

Effects of Mach number and Reynolds number on jet array impingement heat transfer studied by Goodroet.al. [9]. Study show substantial, independent Mach number effects for an array of impinging jets. The present discharge coefficients, local and spatially averaged Nusselt numbers, and local and spatially averaged recovery factors are unique because (i) these data are obtained at constant Reynolds number as the Mach number is varied, and at constant Mach number as the Reynolds number is varied, and (ii) data are given for jet impingement Mach numbers up to 0.74, and for Reynolds numbers up to 60,000.

Murray et.al [10] is Studied Jet impingement heat transfer of Mean and root-mean-square heat transfer and velocity distributions. At low nozzle to impingement surface spacing's the mean heat transfer distribution in the radial direction exhibits secondary peaks. the free jet flow has the effect of suppressing turbulence in the wall flow, and upon 'escaping' from the lip of the free jet the wall jet can undergo transition to a fully turbulent flow. This transition to turbulence does not occur immediately after the wall jet escapes the free jet flow.

Murray et.al. [11] again studied Jet impingement heat transfer of temporal investigation of heat transfer and local fluid velocities. They obtain regions of high heat transfer are associated with regions of high local fluid velocity and turbulence intensity. The heat transfer distributions have been shown to coincide with locations where velocity fluctuations normal to the impingement surface are large. Vortices that roll-up naturally in the shear layer of the free jet, close to the nozzle exit, have been shown to merge forming larger yet weaker vortices, before being broken down into smaller scale random turbulence.

The effect of flow field and turbulence on heat transfer characteristics of confined circular and elliptic impinging jets studied by Koseoglu and Baskaya [12]. The flow field of confined circular and elliptic jets was investigated through velocity and turbulence measurements using laser Doppler anemometry, for two different jet to plate distances at Reynolds number 10000.

2. EXPERIMENTAL PROCEDURE

Figure 1 shows the layout of in-house fabricated experimental setup. Cold air jets for the experiments are generated using air compressor. Air cooled and oil splash lubricated reciprocating air compressor issued for the current study. The compressor can generate the compressed air at the mass flow rate of 0.010 kg/s. The air is stored in a storage tank of capacity 0.5 m^3 (500 Liters). The compressed air is passed through a 25.4 mm pipe line.

Figure 1 : Experimental setup

A flow regulator valve is connected to the pipeline for varying the air mass flow rate, and orifice meter is used to calculate the flow rate. The inclined mercury manometer is connected for measurement of pressure head. Using a pipe reducer, a pipe nozzle of 10 mm diameter is attached through which the jet is issued out. Pipe nozzle of 300mm long is considered for the study.

Impinging plate is a square geometry made of AISI 304 stainless steel. It has the dimensions of 150mm ×150mm ×0.5mm thick. The impinging plate has shinning and

ISSN: 2278 – 7798

smoothened flat area. The plate is fixed with a 240 V electrical coil for heating the plate. That is the heating coil is sandwiched in between two stainless steel plates. The coil is connected to an autotransformer for supplying AC voltage which in turn heats the coil to the desired temperature. Precaution has been taken to wrap the heating coil in circle along the stainless steel plate for the uniform heating. Teflon insulating material is placed in between the plates for safety purpose. The back surface of the impinging plate is coated with black paint for maximum emissivity. The plate is reinforced by an iron channel which is in turn connected to a slider mechanism which will be discussed shortly in the future section. Ten thermocouples are attached to the stainless steel plate by hard soldering technique at various radial locations for measuring the temperature distribution along the plate surface as shown in fig. It is to be noted that any other possibilities of fixing the thermocouple to the stainless steel plate was not successful. These thermocouples are connected to the data logger for recording the temperature at respective points.

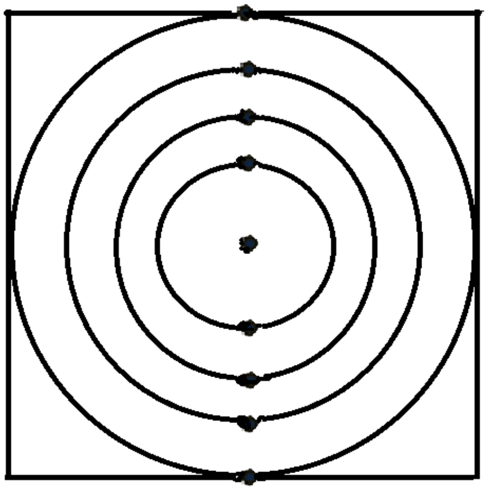

Figure 2: Thermocouple arrangement on impinging plate

The present work investigates the heat transfer on a plate impinged with cold air jet. Investigations are carried out with two different types of jets are used namely the circular and square jets. The Reynolds numbers of these jets are varied in the range of around 10000 to 60000. The distance between the jet exit and impingements plate (*Z/D*) is varied in the range of $1 \leq Z/D \leq 12$. The temperature measurements are carried using K type thermocouple along the radius (*r/D*) of the plate. The methodology followed for the conducting the experiment is discussed below:

The AC current is supplied to the heating coil and thus the plate is heated to a desired temperature value. The actual current and voltage across the heating coil is measured using Ammeter and Voltmeter. Two different shape nozzles are used for issues the different Reynolds number jet flow. The Reynolds number varied by using pressure regulator valve and range of Reynolds number is 10000 to 60000. The pressure head difference across the orifice meter was noted down by connecting the manometer. The obtained temperature for plate surface is in between 70 °C to 110°C. Radiation losses are also considered for experiment work. The natural convection from the back side of the plate is small. So it is considered as negligible. The nozzle exit to impinging plate distance (*Z/D*) is varied from the range of 1, 2, 4, 6, 8, 10 and 12 by using the slider mechanism. And the angle is varied in the range of 0^0, 30^0, 45^0, 60^0.

3. RESULTS

The jet impingement heat transfer study the nozzle diameter to distance between nozzle exit to impinging plate (*Z/D*) ratio and radial distance ratio (*r/D*) because all heat transfer characteristic depends on the *Z/D* and *r/D* ratio. The basic layout of *Z/D* and *r/D* ratio is shown in Fig 3.

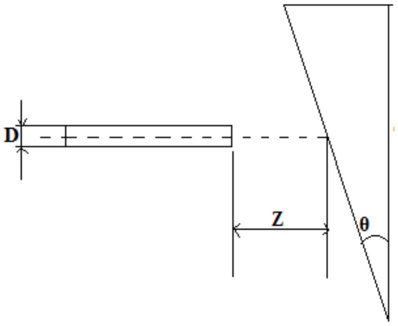

Figure 3: Layout of Z/D and r/D ratio

For the current study 10 mm circular, 6mm circular and square shape nozzle of 10mm equivalent diameter is used for get different Reynolds numbers flow for studying the heat transfer characteristics of jet impingement. The different shape and size of nozzle gives different heat transfer rate, velocity and Nusselt numbers.

A. COMPARISON OF 10 mm CIRCULAR AND SQUARE NOZZLE RESULTS

Reynolds number with different *Z/D* ratio may be due to the same cross sectional area of circular and square nozzle.

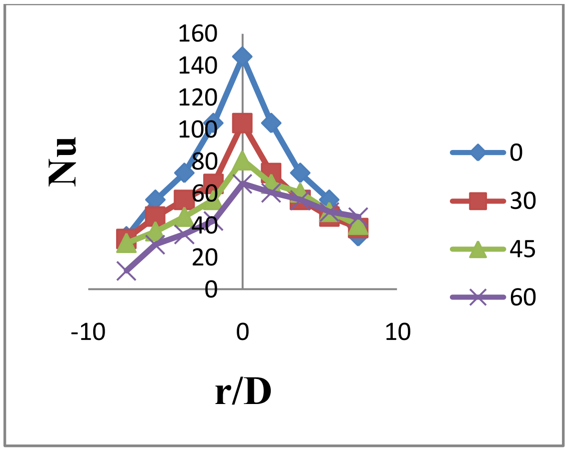

Figure 4: comparison of circular nozzle at various angles at Z/D= 6

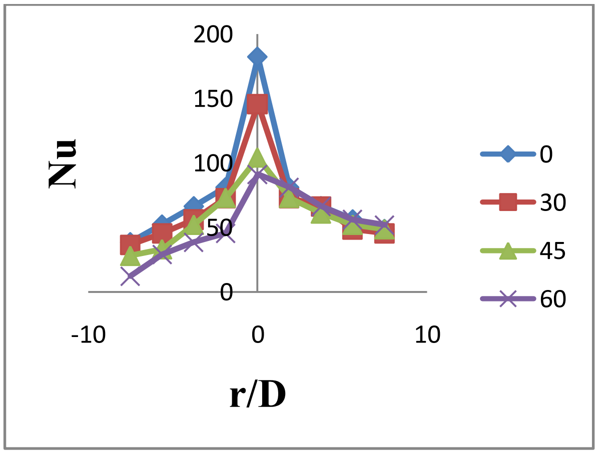

Figure 5: compariswon of square nozzle at various angles at Z/D= 6

Comparing the Nusselt number obtained while using square nozzle and circular nozzle, square nozzle will give more heat transfer coefficient.

The Nusselt number variation for other Reynolds numbers are also gives the same comparison results. The comparison shows that the all size and shape of nozzle gives same Nusselt number variation trend. The Nusselt number while using square nozzle is very high as compared to the circular nozzle. the Nusselt number increases till Z/D =6 and decreses thereafter. Maximum Nusselt number is found at Z/D =6.

4. CONCLUSION

The experimental results of the heat transfer on a plate impinged with cold air jet in this study copper tube pipe is used as circular nozzle and square pipe is used as a square nozzle are used to issue out the jet flow at various Reynolds numbers. Study of heat transfer done on stainless steel flat plate with Reynolds no 10066.20, 20056.63, 30070.03, 40020.26, 50026.93 and 60061.79 for different *Z/D* (1, 2, 4, 6, 8, 10, 12) and with different *r/D*. impinging plate temperature measured by using J- type thermocouples. Computational work did for all shape and size of nozzles for study the heat transfer, velocity and pressure characteristics of jet impingement. The objective of the work is to study the variation of Nusselt number for various distances (*Z/D*) between nozzle exit and plate. It is found that the Nusselt number increases with increasing in Reynolds numbers for all distances (*Z/D*) between nozzle exit and plate at radial direction for using the different shape and size of pipe nozzle. From the experimental study following conclusion is observed.

1. The heat transfer rate on the impinging plate increases with increase of Reynolds number for all nozzle exits to impinging plate distance (*Z/D*) and also for 10 mm circular and square nozzle. The velocity increases the heat caring capacity of air increase and also Nusselt number increases.

ISSN: 2278 – 7798

2. At the stagnation point (*r/D* = 0) Nusselt number is very high for all 10 mm circular and square nozzle at different impinging plate distance (*Z/D*) with different Reynolds numbers. The reason is at the stagnation point velocity is very low because of fluctuation near the stagnation point. A computational result shows that it is the one of the heat transfer characteristics of jet impingement.

3. For *Z/D* = 6 the highest Nusselt number is obtained for all shape and size of nozzle. The Nusselt variation increases up to *Z/D* = 6 after that it continuously decreases for 10 mm circular and square nozzle for all different Reynolds numbers. For *Z/D* = 12 lowest Nusselt number obtained because the distance is more and velocity flow not reaches properly on impinging plate.
4. Radial direction (r/D) Nusselt number decreases with increase the radial distances. For r/D = 10 lowest Nusselt number value observed for 10 mm circular and square nozzle at all nozzle exit to impinging plate distance (*Z/D*).
5. Comparison of nozzles the square nozzle gives high Nusselt number and the 10 mm circular and square nozzle Nusselt number variation difference is very less may be the same area of cross section. From comparison one thing observed that nozzle geometry also effect on the jet impingement heat transfer characteristics. If nozzle geometry shape changes but area of cross section is same the it is not that much effect on heat transfer rate.

ACKNOWLEDGMENT

The author wishes to thank Mr. Ravinarayana Bhat, Professor and HOD, Dept. of Mechanical engineering, SIT, Mangalore and Mr. Chandrajith E, Associate professor, SNGCET, Payyanur for their moral support throughout the work.

REFERENCES

[1] Peter Hrycak, David T. Lee, James,Gauntner and John N. B. Livingood, Experimental Flow Characteristics of a SingleTurbulent Jet Impinging On A Flat Plate" NASA TN D- 5690, JANUARY 1973.

[2] Peter Hrycak, "Heat Transfer from Round Impinging Jets to a Flat Plate" International Journals of Heat and Mass Transfer. Vol. 26. pp. 1857-1865. 1983.

[3] Tianshu Liu and J.P. Sullivan, Heat transfer and flow structures in an excited circular impinging jet.Journals of Heat and Mass Transfer vol. 39, 3695-3706, 1916.

[4] Jets. L. Huang and M. S. El-Genk1, Heat Transfer and Flow Visualization Experiments of Swirling, Multi-Channel, And Conventional Impinging jets. Journals of Heat and Mass TransferVol. 41, No. 3, pp. 583400, 1998.

[5] M. Angioletti, R.M. Di Tommaso, E. Nino, G. Ruocco,Simultaneous visualization of flow field and evaluationof local heat transfer by transitional impinging jets..International Journal of Heat and Mass Transfer 46 (2003) 1703–1713

[6] Jungho Lee, Sang-Joon Lee,The effect of nozzle configuration on stagnation region heat transfer enhancement of axisymmetric jet impingement.International Journal of Heat and Mass Transfer 43 (2000) 349.

[7] C. Cornaro, A.S. Fleischer, R.J. Goldstein.Flow visualization of a round jet impinging on cylindrical surfaces. International Journal of Thermal and Fluid Science 20 (1999) .

[8] VadirajKatti, S.V.Prabhu, Experimental study and theoretical analysis of local heat transfer distribution between smooth flat surface and impinging air jet from a circular straight pipe nozzle. International Journal of Heat and Mass Transfer 51 (2008) 4480–4495.

[9] Matt Goodro, Jongmyung Park, Phil Ligrani, Mike Fox, Hee-Koo Moon, Effects of Mach number and Reynolds number on jet array impingement heat

transfer. International Journal of Heat and Mass Transfer 50 (2007) 367–380

[10] Tadhg S. O'Donovan, Darina B. Murray,Jet impingement heat transfer – Part I: Mean and root-mean-square heat transfer and velocity distributions. International Journal of Heat and Mass Transfer 50 (2007) 3291–3301.

[11] Tadhg S. O'Donovan, Darina B. Murray, Jet impingement heat transfer – Part II: A temporal investigation of heat transfer and local fluid velocities.International Journal of Heat and Mass Transfer 50 (2007) 3302–3314.

[12] M. F. Koseoglu, S. Baskaya, The effect of flow field and turbulence on heat transfer characteristics of confined circular and elliptic impinging jets. International Journal of Thermal Sciences 47 (2008) 1332–1346.

[13] M.Fenot, J.-J. Vullierme, E. Dorignac.Local heat transfer due to several configurations of circular air jets impinging on a flat plate with and without semi-confinement.International Journal of Thermal Sciences 44 (2005) 665–675.

[14] DaeHee Lee, Jeonghoon,The Effects of Nozzle Diameter on Impinging Jet Heat Transfer and Fluid Flow.journal of Heat Transfer AUGUST 2004, Vol. 126 Õ 557

[15] Luis A. Brignoni, Suresh V. Garimella, Effects of nozzle-inlet chamfering on pressure drop and heat transfer in confined air jet impingement. International Journal of Heat and Mass Transfer 43 (2000) 1133±1139.

[16] B. Sagot, G. Antonini, A. Christgen, F. Buron,Jet impingement heat transfer on a flat plate at a constant wall temperature.International Journal of Thermal Sciences 47 (2008) 1610–1619.

[17] PuneetGulati, VadirajKatti, S.V. Prabhu, Influence of the shape of the nozzle on local heat transfer distribution between smooth flat surface and impinging air jet. International Journal of Thermal Sciences 48 (2009) 602–617.

[18] Peter R. Voke, Numerical study of heat transfer from an impinging jet. International Journal of Heat and Mass Transfer Vol. 41, pp. 671-680, 1998.

[19] C. L. Huang , Y. R. Shieh and Y. H. Hung , Local Thermal Characteristics of a Confined Round Jet Impinging onto a Heated Disk. 1997 IEEVCPMT Electronic Packaging Technology Conference.

ISSN: 2278 – 7798