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Heat Transfer Analysis Using Swirl Jet Impingement

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ABSTRACT

Jet impingement methods are having numerous applications, which have been studied. The work focuses on Heat Transfer in Swirl Jet Impingement. Swirling jet is created by nozzle with insert having twist ratios=6.125, 12.5, 25, and 50 and the results compared with normal jet. The experiments are performed by locating jet at four different jet-to-plate spacing of H/d=0.83, 1.66, 2.5, 3.33, and 4.16. The nozzle diameter is selected as 12mm and Nozzle length is of 50d i.e. 600mm. Reynolds Number range is 9000 to 19000, to study effect of moderate Reynolds Number. The results revealed that at Re=15632 and H/d=1.66 and 4.16, insert with twist ratio = 6.125 gives highest average Nusselt Number.

Keywords— **Swirling Jet Impingement, Heat transfer enhancement,Electronic Cooling**

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I. INTRODUCTION

An impingement jet is a jet of high velocity fluid which is made to strike against a target surface. An impinging jet can be classified as a) Submerged Jet or b) Free Jet. If the fluid issuing from the nozzle is of the same density and nature as that of the surrounding fluid then the jet is called a Submerged Jet. If the fluid issuing from the nozzle is of a different density and nature than that of the surrounding fluid then the jet is called a Free Jet. [1]

Further distinction between jets can be made as a) Confined and b) Un-confined jets. In the case of confined jets, the jet remains bounded between the two surfaces during its flow. There is very less entrainment of air from the atmosphere. Un-confined jets are free to expand after they impinge on the target surface. [2]Circular jets and slot jets are two basic jet configurations other arrangements are nozzle geometry of square edge (no chamfered) and with chamfered edge, inclined jet, axially symmetric air jet, elliptic jet arrays. Swirling Jet the impinging jet is forced to swirl when exiting the jet orifice/nozzle, providing a flow commonly known as the swirling jet. [3]

The coolant fluids used in jet impingement are mainly air and water but some research has also been reported with kerosene, fluorocarbons (FC) and Freon etc. [4]

Jet impingement on smooth and non-smooth surfaces have been studied. [5]

The flow field of jet impingement is characterized by a) Jet zone, b) Stagnation zone, and c) Wall jet zone. [6]

Applications of impinging jets include drying of textiles, film, and paper; cooling of gas turbine components and the outer wall of combustors; freezing of tissue in cryosurgery, cooling of electronic equipment, for the cooling of a grinding process. Various Parameters which are studied in

Jet Impingement are Jet to plate spacing, Reynolds No., Jet Diameter, Prandtl number etc. [1-9].

Nuntadusit studied the flow and heat transfer characteristics of multiple swirling impinging jets (M-SIJs) with 3×3 in-line arrangement, on impinged surfaces. The jet to-jet distances (S/D=2, 4, 6 and 8).The nozzle-to-plate distance was kept constant H/d=4. The obtained results demonstrated that at the similar operating conditions, the multiple swirling impinging jets were more effective and consistently gave higher heat transfer rate on impinged surfaces than the multiple conventional impinging jets. [10]

Inairo studied the influence of the swirl number on the wall heat transfer distribution on a flat plate with a swirling air jet impinging. To create swirling effect Helical inserts were used. Measurements were performed at a fixed value of the Reynolds number Re (28,000), for five values of the swirl number is (0, 0.2, 0.4, 0.6 and 0.8) Swirl Number was calculated by relation

$$S = \frac{2}{3}\left[\frac{1-\left({}^{d}/_{D}\right)^3}{1-\left({}^{d}/_{D}\right)^2}\right]\tan\theta$$

Where D and dare nozzle and vane pack hub diameters and θ is swirling angle. Five values of nozzle-to-plate distance H/d (2, 4, 6, 8 and 10 diameters) were chosen, IR thermography and heated thin foil sensor was used to record temperatures. The study show that the multichannel jet induces a general enhancement in heat transfer with respect to the circular impinging jet, the swirl motion decreases the rate and increases the uniformity of heat transfer. [11]

Bakirki n bilen studied and visualized the temperature distribution. They evaluate heat transfer rate on the impingement surface. Constant wall temperature boundary condition for the swirling (SIJ), multi-channel (MCIJ) and conventional impinging jet (CIJ) using liquid crystal technique was used. Swirl Jet was created by using a housing tube and a solid swirl generator insert which had four narrow slots machined on its surface. The swirl angle, θ was 0^o, 22.5^o, 41^o, 50^o .Results revealed that the local Nusselt numbers of the MCIJ θ = 0^o were generally much higher than those of CIJ and SIJs. Increasing Reynolds number for swirler angle increase the heat transfer rate on the entire surface, and increase saddle shape heat transfer distribution on the surface, but had no significant effect on the position of the individual impingement regions, but increased saddle shape heat transfer distribution on the surface. The lower Reynolds number (Re = 10000) and the highest H/d = 14 gave much more uniform local and average heat transfer distribution on the surface, but decrease their values on the entire surface. [12]

Mao-Yu Wen discussed the results of an experimental investigation of the heat transfer between the constant-heat-flux test plate and the impinging jets. The round jets with and without swirling inserts were used. Smoke flow visualization was used to study the behavior of swirling-flow jet. The effects of flow Reynolds numbers (500<Re<27 000), the geometry of the nozzle used were tube without inserts (BR), longitudinal swirling-strip (LSS), and crossed swirling-strip (CSS)), and jet-to-test plate placement (36<=H/d<=16) were examined. The results revealed that flow visualizations brought good understanding of the flow field: air flow development after exiting the jet housing tube, flow mixing and formation of vortices on the impinged surface and entrainment of ambient air. The heat transfer rate increased as the jet spacing decreases. Simple correlations of the stagnation point Nusselt number as well as the average Nusselt number were derived for all the nozzle types and other variables. [13]

$$Nuavg = 0.442Re^{0.696}Pr^{1/3}\left(H/d\right)^{-.02}\left(r/d\right)^{-0.41} \text{ For BR}$$

$$Nuavg = 0.452Re^{0.702}Pr^{1/3}\left(H/d\right)^{-.02}\left(r/d\right)^{-0.41} \text{ For LSS}$$

J. Ortega-Casanova studied the Numerical simulations of the impingement of a swirling jet against a heated solid wall .The swirling jet is created by an experimental nozzle (whose exit diameter is D) and with the swirl given to the jet by moving swirl blades: different blade orientations give jets with different swirl intensities. The jet velocity components were measured by means of a LDA system just at the nozzle exit and their mathematical models were also presented for seven Reynolds numbers and each nozzle configuration. The LDA measurements showed the jet was axisymmetric and highly turbulent. The same seven Reynolds numbers and three nozzle-to-wall distances were simulated numerically. Correlations of the area-weighted average Nusselt number Nu avg and the stagnation point Nusselt number Nuo as a function of the dimensionless parameter Re (ranging from around 7000 to 20 000), Si (ranging from around 0.015 to 0.45), Iavg (ranging from around 10 to 40%), and H/d (=5, 10 and 30), were proposed. [14]

Proposed Correlation for Stagnation point Nusselt No.

When Si (0.015-0.1)

$$Nu_o = 0.772Re^{0.5644}Si^{0.0246}\left(\frac{H}{d}\right)^{-0.2770}(Iavg)^{-0.0230}$$

When Si (0.1-0.45)

$$Nu_o = 0.3246Re^{0.8598}Si^{0.2414}\left(\frac{H}{d}\right)^{-0.7079}(Iavg)^{-0.2844}$$

For Average Nusselt No Correlation is

$$\overline{Nu} = 0.1805Re^{0.6313}Si^{0.0407}\left(\frac{H}{d}\right)^{-0.3780}(Iavg)^{-0.1132}$$

II. EXPERIMENTAL FACILITY

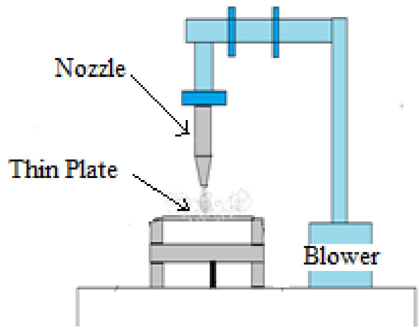


Figure 1 Experimental Setup Diagram

The schematic diagram of the vital components of experimental facility is demonstrated in Fig. 1. The facility consisted of a high pressure blower, a transformer, an anemometer, a nozzle, an impingement plate, a temperature measuring IR gun. In the experiment, air is supplied by a high pressure blower. The exit velocity of air is measured by anemometer.

The impinged plate consisted of the stainless sheet. The impinged plate is of width110 mm and a length of 270 mm. The steel plate is clamped tightly. Because the stainless steel plate is extremely thin, the lateral conduction is negligible and its surface is assumed to be under uniform heat flux condition. An AC electric current is conducted to the stainless sheet with a uniform heat generation rate. The power supplied to the steel sheet is measured by Multimeter. The circular nozzle had an inner diameter and a length of 12 mm (d) and 600 mm (50d) long located above the impinged plate at four jet-to-plate spacing of H/d=0.8333,1.66,2.5,3.333,4.16. During experimentation, power is supplied from power source. In the experiments, the swirl fluid motion is induced by the twisted inserts equipped in the nozzle. The inserts are made of aluminiumsheet with a width (W) of 12 mm, a thickness (δ) of 0.05mm and a length (l) of 600 mm. The inserts are prepared with four different twist ratios, y/d=6.125,12.5,25,50 where twist ratio is defined as twist length (y, 180^{o}/twist length) to tape width (d). The inserts are fabricated by twisting straight tapes, about their longitudinal axis, while being held under tension.

III.DATA REDUCTION

The heat transfer rate in term of the local Nusselt number and local convective heat transfer coefficients at the impingement plate are calculated by

$$Q = V \times I \quad (1)$$

$$q = Q/A \quad (2)$$

$$h = \frac{q}{(Tp - Tj)} \quad (3)$$

$$Nu = h \times \frac{d}{K_{air}} (4)$$

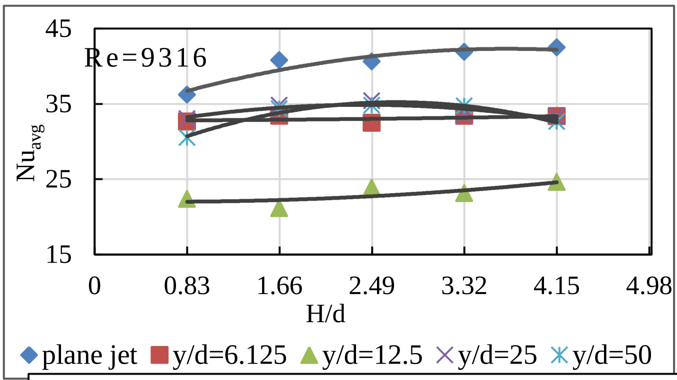
Where h is the heat transfer coefficient, d is the nozzle diameter, K_{air} is the conductivity of air, Tp is the impingement wall temperature and Tj is the jet air temperature. Where q is the heat flux obtained by power input from power supply to impinged wall, V is the voltage, I is the current and A is the surface area for smooth impingement surface. Reynolds number is calculated from

$$Re = \frac{\rho \times v \times d}{\mu} \quad (5)$$

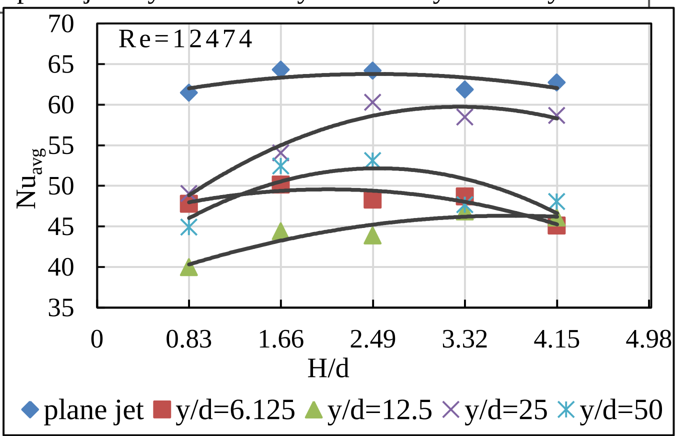
Where ρ is the density of air corresponding to the jet air temperature is the average velocity at the exit of the nozzle and μ is the viscosity of air.

IV.RESULT

1.1. a Effect of the twist ratio (y/d) on Average Nusselt number distribution



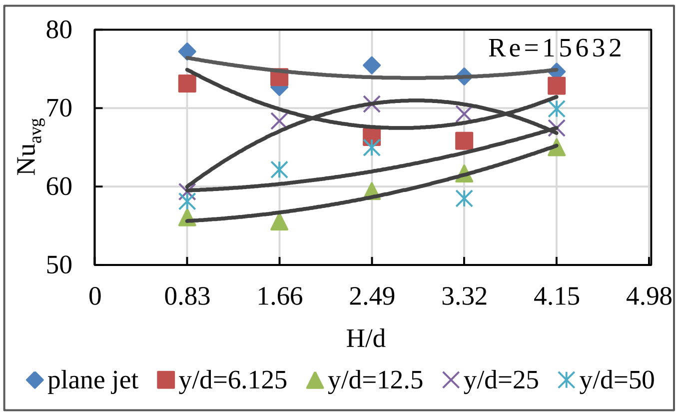
Graph 1: Nu_{avg} vs H/d for Re=9316



The above graph show that for Re=9316 for plane jet the average Nusselt no increases as the H/d increases. The lowest range of average Nusselt No is achieved in case of y/d=12.5.For Y/d 6.125 the average Nusselt number is found to be constant as the H/d increases.

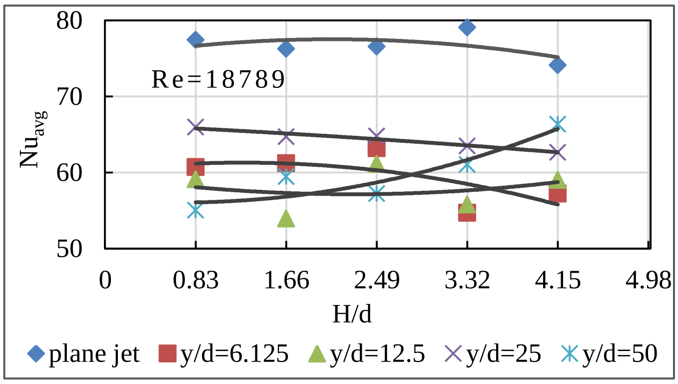
Graph2:Nu_{avg} vs H/d for Re=12474

The above graph show that for Re=12474 for plane jet the average Nusselt first increases and then decreases as the H/d increases. The lowest range of average Nusselt No is achieved in case of y/d=12.5.For Y/d 6.125 the average Nusselt number is found to be increasing as the H/d increases and at H/d=4.16 it is slightly less than plane jet for same H/d.



Graph3:Nu_{avg} vs H/d for Re=15632

The above graph show that for Re=15632 for plane jet the average Nusselt first increases and then decreases as the H/d increases. The lowest range of average Nusselt No is achieved in case of y/d=12.5 but it increases as H/d increases. For Y/d 6.125 the average Nusselt number is found to be decreasing as the H/d increases and after H/d=2.5 it increases and reach to slightly less than plane jet for H/d=4.15.



Graph4:Nu_{avg} vs H/d for Re=18789

The above graph show that for Re=18789 for plane jet the average Nusselt first decreases and then increases as the H/d increases. The lowest range of average Nusselt No is achieved in case of y/d=12.5 but it increases as H/d increases. For Y/d=50 the average Nusselt number is found to be increased along H/d.

V.CONCLUSION

The work focusses on Analysis of heat transfer by swirling jet impingement. Swirling jet is created by nozzle with insert having twist ratios=6.125, 12.5, 25, and 50 and the results compared with normal jet. The experiments are performed by locating jet at four different jet-to-plate spacing of H/d=0.83, 1.66, 2.5, 3.33, and 4.16. The nozzle diameter is selected as 12mm and Nozzle length is of 50d i.e. 600mm. Reynolds Number range is 9000 to 19000, to study effect of moderate Reynolds Number. The results Revealed that as Reynold number increases the Average Nusselt number increses.The plane jet was found to give more value of Nusselt number as compared with the swirling jets. The swirling jet with twist ratio 6.125 was found to give higher average Nusselt number at H/d=1.66 and Re=15632 as compared with insert results.

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