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Distribution of Wall Static Pressure on Flat Plate by Impenjing Air Jet from Orifice for Turbulent Flow

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Abstract: Wall static pressure distribution on any test section is one of the important factor which influences the local heat transfer coefficient, in the present work an attempt is made to know the effect of jet to test section spacing and Reynolds Number(Re) on coefficient of wall static pressure (C_p & C_{po}) distribution on the smooth flat surface due to impingement of air jet from circular orifice unconfined flow is studied in details for different flow and geometric parameters such as orifice diameter, Plat inclination angle ($\theta=0^0$ to 30^0), jet to test section spacing and Reynolds number of flow (Re=50000 to 25000). From experimental results different graphs of C_p v/s Θ, C_p v/s Z/d_h, C_{po} v/s Z/dh for various Reynolds number are plotted and it is observed that co-efficient of static pressure $C_p=\Delta p/0.5\rho AVj2$ is independent of Reynolds number, the high value of C_p are observed upto $\Theta=5^0$ to 10^0 at lower Z/d_h later it decrease gradually and higher value of C_{po} are observed for lower Z/d_h. It is also observed that C_p and C_{po} values are high for circular orifice compared to other orifice

Keywords: Smooth flat Surface, Jet Impingement, Inclination angle, Static Pressure, Unconfined.

I. INTRODUCTION

Jet impingement is an attractive cooling mechanism because of its higher heat transfer rate of cooling. Because of this, jet impingement has been widely used in many industrial applications. Impingement of air jet to study the heat transfer rate is a new development for cooling in industry. Jet impingement method is the least expensive method to achieve the desired results. Due to this more prior research has been given to understand the heat transfer characteristics. Cooling of electronic equipment is helpful in computer chip. Computer chip will generate much heat. Due to this, jet impingement has been developed in recent years. Jet impingement gives higher heat transfer rate over a small area so it is widely used in different industrial applications but it gives high heat transfer rate for a short flow path. In this air is used as medium for cooling. Many researchers investigated fluid flow and heat transfer characteristics by impinging jet on smooth and flat surface.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.

In recent years researches in these topics have put on a spurt because of its high potential local heat transfer enhancement. There have been indefinite works and developments in jet impingement technique over last few decades by research scholars on V. A. Smirnov et al., [1] studied about the heat transfer for flat plate. They studied for the different h/d ratios and obtained rated formula. They concluded that rated formulae includes angle of attack. They compared their results with Goldstein. C. J. Hoogendoorn [2] studied the effect of turbulence and found that due to the presence of turbulence heat transfer has been increased. The main effect of turbulence was found at the stagnation point. B. N. Pamadi [3] studied and concluded that for small nozzle to plate distance secondary peak will be observed around the stagnation point. R. J. Goldstein et al. [4] studied about radial distribution of the recovery factor and also about local heat transfer for axisymmetric impinging air jet for a smooth nozzle. D. Lytle and B. W. Webb [5] studied about the local heat transfer characteristics for small nozzle to plate spacing. To study this they used infrared thermal imaging technique.

A. Hanchinal et al in 2017[6] found that the value of Cp and Cpo at lower Z/d are high for higher D/d they also carried study on effect of curvature diameter by using different orifice diameter of 10-16mm on semicircular concave surface[7] and also extend their work for further analysis and study on this topic.[8] D.W. Zhou, C.F. Ma [9] studied about submerged circular jet for different Reynolds number from 691-43567.They correlated relation for local heat transfer rate for different nozzle to plate distance and for fixed radial locations. Quan Liu et al., [10] performed experiment on the target plate for different Z/d ratio ranging from 1.5 to 12

and for different Reynolds number ranging from 10000 to 60000. From that they concluded that secondary peak will be observed for Z/d =1.5.As Z/d crosses potential core length secondary peak will disappear.
The present work is mainly concentrated on the effect of jet to test section surface on distribution of wall static pressure on smooth flat surface due to air jet impingement from an orifice of 16mm diameter. The work is carried out for various geometrical and flow parameters such as Reynolds number (50000 to 25000), Z/d (1 to 4) and influence of test section inclination θ (0^0 to 30^0). The results obtained from experiments could find a significant role in the improvement of design of gas turbine blades for better blade efficiency and blade life.

II. NOMENCLATURE

SYMBOL	DESCRIPTION	UNIT
h	Test section height	mm
l	Test section length	mm
t	Thickness of test section	mm
d	Diameter of the orifice	mm
d_h	Hydraulic diameter of the orifice	mm
Re	Mean jet Reynolds Number	
H_w	Manometer head	mm
Z	Distance between curved surface plane and nozzle exit plane (mm)	mm
T_j	Jet air temperature	°C
C_d	Co-efficient of discharge of venturimeter	
V_j	Velocity of jet	m/s
θ	Circumferential angle	
C_p	Static pressure coefficient	
C_{po}	Stagnation pressure coefficient	
m	Mass of air	kg/s
ΔP	Pressure difference between wall static pressure and atmospheric pressure	
Greek Symbols		
ρ_a	Density of atmospheric air	kg/m^3
ρ	Density of air at nozzle exit	kg/m^3
μ	Absolute viscosity of air	kg/ms
Abbreviations		
Z/d_h	Non dimensional distance between nozzle exit plane and curved surface plane	
D/d_h	Curvature ratio	

III. EXPERIMENTAL SETUP AND PROCEDURE

The Schematic layout of experimental set up for the present work is shown in the Fig.1. The Air Blower with free air delivery of the blower is 2.3 m3/min and air pressure on 400mm of water is used for impingement of air through orifice and Venturimeter is used to adjust the Reynolds number and is calibrated whose Cd was found to be 0.92 ± 2%. To measure the jet temperature and ambient temperature is measured with help of calibrated K-Type thermocouples which uses a 4 ½ digital panel meter for mili voltmeter indication and this mili voltmeter reading is converted into degree Celsius by thermocouple equation. In addition to all experiment is performed under a steady state.

A. The Below Mentioned Parameters Are Varying Below Parameters During Experiment

1) Test Section : Smooth flat Surface
2) Diameter of the orifice d = 16mm
3) Reynolds Number (Re) in the range of 50000 to 25000
4) Z/d_h Ratio $1 \leq Z/d_h \leq 4$
5) Circumferential angles (θ = 0°- 30°)

6) Confinement : No

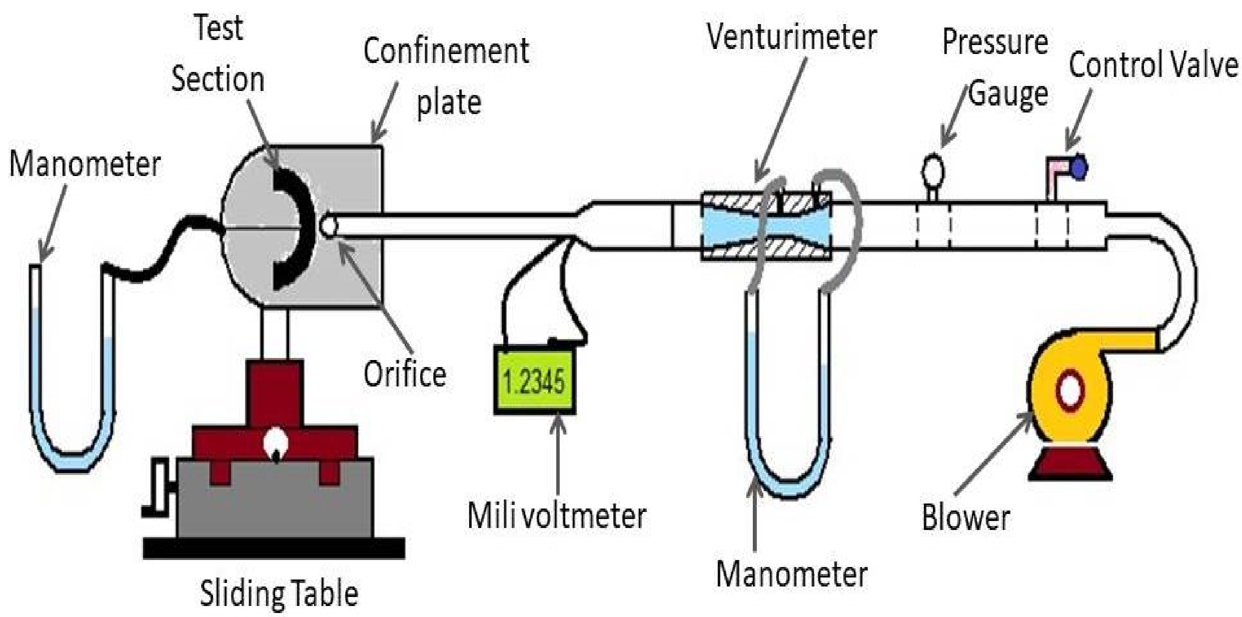

Fig.1 Schematic layout of the complete experimental.

The test section or target surface is a smooth flat surface made from acrylic material which is Crystal clear, UV stabilized, Tough and Impact Resistant and Chemical Resistant. The dimension of test section is width 50mm and thickness of 5mmwith total length 300mm which is shown in figure 2 and 3. A small hole of 0.5mm diameter at the center of test section used as pressure tap to measure stagnation pressure along the surface. The target surface is give free movement for inclination to measure the pressure at different plate inclination angles (θ=0-30°), the movement of test section along circumferentially must be smooth. The care has to be taken to maintain the smooth flat surface throughout the experiment.

The air is blown through 16mm diameter orifice at a particular Reynolds number. The static pressure difference is measured by manometer and it uses water as manometer fluids. The experiment is performed under a steady state for various flow parameters and results are tabulated to draw different graphs for further study. The present experiment is done by varying the mentioned parameters

IV. DATA REDUCTION

The following are the some of the important formulas for calculations used in the present experiments which are reduced to its simplest forms

The jet Reynolds number (Re)

$$\mathrm{Re} = \frac{4 \times m^{\cdot}}{\Pi \times d \times \mu}$$

Temperature of jet at exit of orifice in (°C)

$$T_j(^0C) = 23.188 \times v + 3.843$$

Density of Air from jet in (kg/m^3)

$$\rho = \frac{P_{atm}}{0.287 * (T_J + 273)}$$

Co-efficient of Pressure

$$C_p = \frac{\Delta P}{0.5 \times \rho_a \times V_j^{\,2}}$$

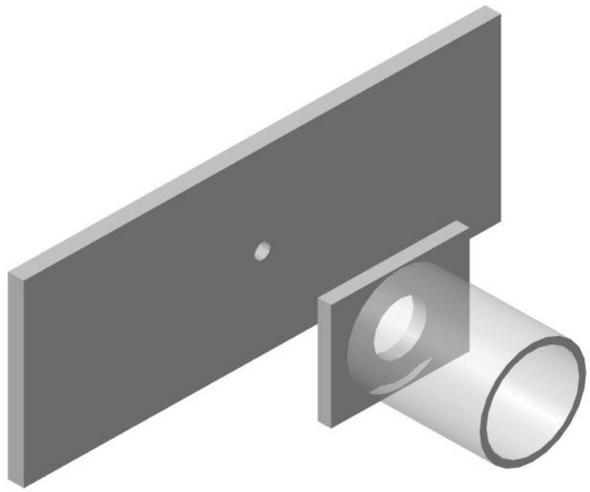

Fig.2 An Isometric view of Target surface along with orifice.

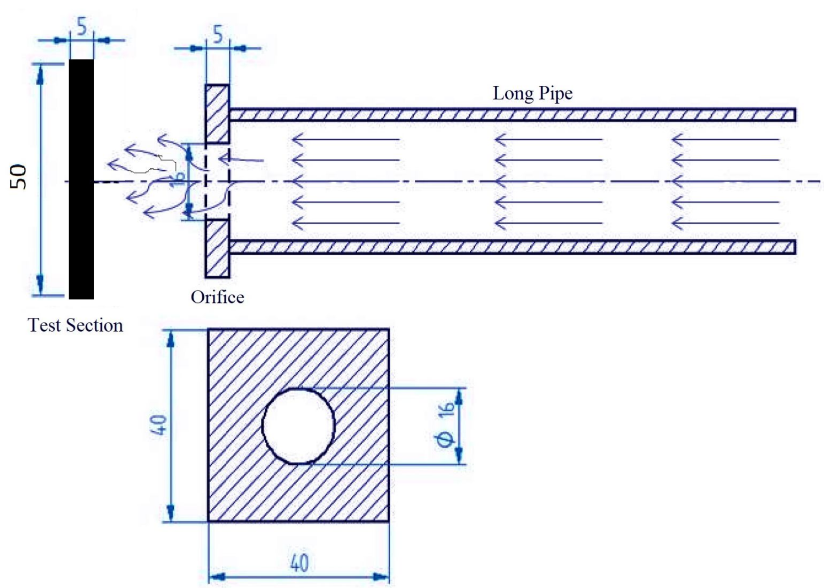

Fig. 3 Geometry of the orifice and test section.

V. RESULTS AND DISCUSSION

An experiment is conducted for various flow and geometric parameters to analyze the fluid flow Characteristics on a smooth flat surface by impinging turbulent air jet from an orifice and also to know the effect of jet to test section spacing on coefficient of static pressure distribution (Cp=Δp/0.5ρAVj2) by impinging jet of air through an orifice for free flow at steady state.

A. Influence of Reynolds Number on Wall Static Pressure

Figure 4 and 5 shows variation of wall static pressure with respect to circumferential angle at various Reynolds number of flow for two different Z/d_h, it can be seen clearly that lines representing different Reynolds number almost follow the same path and are seen to be collapsing throughout except for stagnation point for all dimensionless distance from jet to target plate (Z/d_h).

From the results and observations it can be concluded that Jet Reynolds number does not have any influence in wall static pressure coefficient variation. Static pressure coefficient is independent of Reynolds number for a smooth flat surface. The same trend is seen for all Z/dh Hence further analysis is carried out for any one representative Reynolds number (Re).

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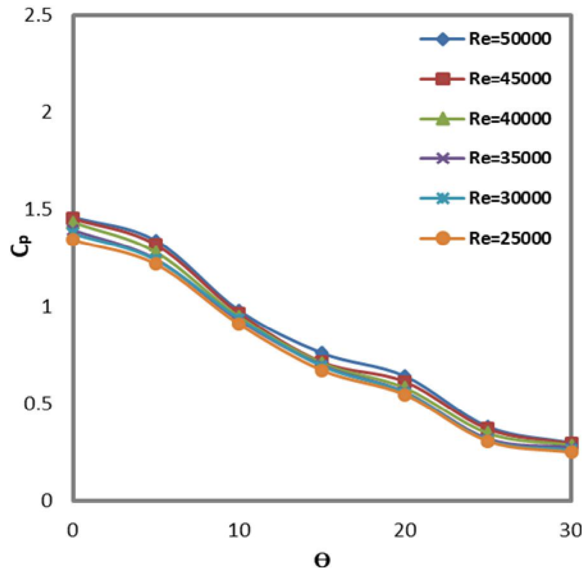

Fig.4 Variation of C_p for various Re at Z/d_h = 1

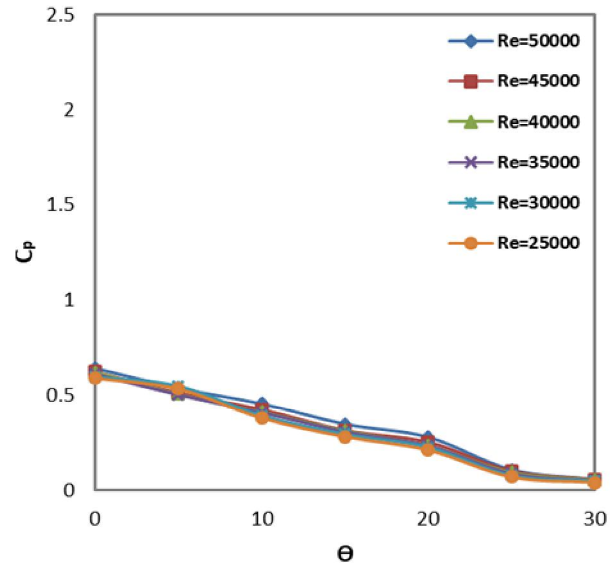

Fig.5 Variation of C_p for various Re at Z/d_h = 3

B. Effect Of Jet To Test Section Spacing And Plat Inclination On Wall Static Pressure

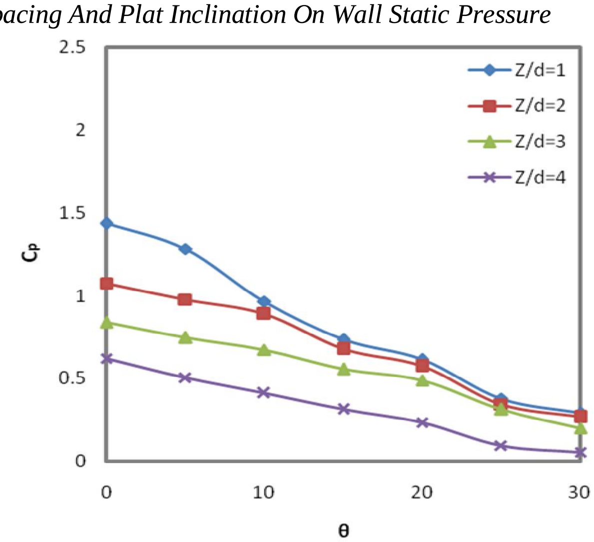

Fig .6 C_P v/s θ at *Re*=40000 for various *Z/d* with Curvature ratio 3.125

From figure 7.5 a and b, it is observed that with increase in the angle inclination the value of static pressure decreases. When the angle of pressure tap (Test section) is changed the intensity of jet on pressure tap also varies as change in the angle offset's the position of stream line of flow jet thus the value of C_p decreases as θ changes to higher angle and vies versa . From graph it also observed that the higher of C_p are seen at lower Z/dh as jet remains in the potential core zone for lower Z/dh, in this region the centerline velocity of the jet remains constant and is equal to the orifice exit velocity thus higher value of C_p are observed at lower Z/d_h and vies versa.

Thus it is clear that when plat inclination angle increases the wall static pressure decreases and the same trend is seen for all Reynolds number. With increase in the jet test section spacing the decrease in the wall static pressure is seen which is same for all Reynolds number of flow

C. The Effect Of Jet To Test Section Spacing On Stagnation Pressure

Figure 7 C_{po} v/s Z/d_h, gives variation of Stagnation pressure co-efficient with respect to Non dimensional distance between nozzle exit plane and curved surface plane (Z/d_h) for various Reynolds number (Re), from graph we can observe that the value of C_{po} are high at lower Z/d_h =1 and C_{po} value are low at higher Z/d_h = 4 because the velocity of jet is high at centerline when this high

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centerline of jet axis matches with the center of pressure tap that is at θ=0° we get higher value of pressure and this also may happen due to the vena contraction effect of jet.

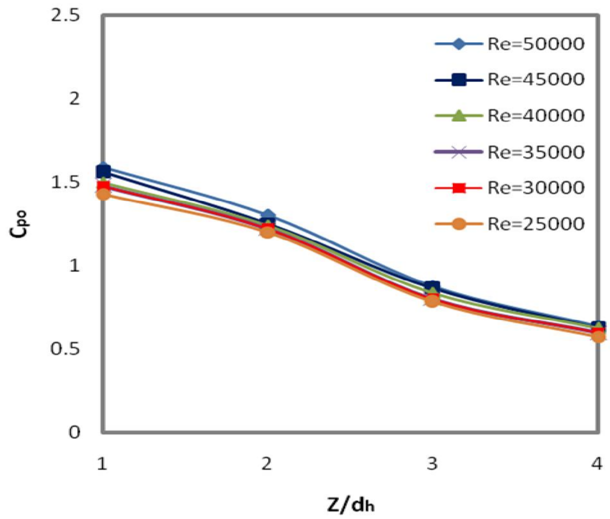

Fig.7 C_{po} v/s Z/d for various Reynolds Number

Thus it is clear that stagnation pressure co-efficient decrease with increases in the jet to test spacing as target surface moves out from the potential core region of free jet with increase in the jet to test spacing. And the same trend is seen for all Reynolds number.

VI. CONCLUSION

The Experimental determinations of effect of jet to test section spacing and Reynolds number on wall static pressure distribution on convex curved surface due to an air jet impingement from an orifice for unconfined flow for different geometrical and flow parameters are studied. After number of experiments at steady state condition.

A. The Following Are The Conclusions Drawn From The Fluid Flow Study

1) The static pressure distribution is independent of Reynolds Number of flow on impingement of air jet from circular orifice on smooth flat surface.

2) The value of wall static pressure C_P on the smooth flat surface are almost uniform up to θ=10^0 & decreases considerably for higher value of θ.

3) For the same Reynolds number the wall static pressure C_p is high for Lower Z/d_h compared to higher Z/d_h.

4) The Stagnation pressure co-efficient C_{po} is higher for lower Z/d_h and decreases with increase in the Z/d_h.

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