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Study on Impingement of Air Jet from Orifice on Convex Surface for Unconfined Flow

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***Abstract:** Jet impingement methods create a small flow path which is efficient process for heating or drying and cooling of any surfaces. The wall static pressure distribution on any test section is one of the important factor which influences the local heat transfer coefficient, thus the present work is experiments 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 convex curved surface due to impingement of air jet from a 16mm circular orifice for free flow is studied in details for different flow and geometric parameters such as orifice diameter, Circumferential angle ($\theta=0^0$ to 30^0), jet to test section spacing, Curvature ratio (D/d=3.125) and Reynolds number of flow (Re=50000 to 25000). The experimental results revels that the value of C_p is independent of Reynolds number of air flow and for any Reynolds Number value of C_P decreases along the circumferential angle with increase in the Z/d_h, The value of C_{po} decrease with increase in the Z/d_h as the decay of jet is low at this point.*
***Keywords:** Convex Curved Surface, Jet Impingement, Curvature Ratio, Static Pressure, Unconfined.*

I. INTRODUCTION

Jet impingement is the fluid stream that is extracted from the different nozzle geometries with high velocity to the target surface which can be flat or curved. Jet impinging cooling is one of the coherent solutions of cooling hot object in industrial processes as it produces very high heat transfer rate through the force convection. Jet impinging is widely used for cooling, heating and drying in several industrial applications due to their high heat removal rates with low pressure drop. There is large class of industrial processes such as cooling of turbine blades, the quench of product in the glass or steel industry and enhancement of cooling efficiency in the electronic industries. Jet impingement provide high 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 Curved surfaces, whereas on confined flow impingement very less number of works is done. In the year 1972 Tabakoff W. and Clevenger W[1] done experiment on this topic by impingement of slot jet on the curved surface and they concluded that at higher flow rate the wall static pressure decrease along the curvature at lower ratios of diameter of curved surface to slot. Bunker [2] the curvature effect is greater at larger Reynolds numbers. reports about many and mostly unattended major thermal issues of turbine cooling as advanced engine design has allowed surpassing normal material temperature limits. One of the key issues includes uniformity of internal cooling of turbine blade passages.

In 2001 C. Cornaro et al[7], found that the heat transfer increases with Reynolds number and also it increased with increasing curvature for all situations studied by impinging single jet on convex surface. Lee et al. [5] done experiments on convex surface with low relative curvature (d/D = 0.034–0.089) for Re = 11000–50000 using liquid crystals to measure the local surface temperature. They came to conclusion that the Nusselt number increases with increasing values of curvature at stagnation point. Kornblum and Goldstein [6] did work to study the local heat transfer and recovery factors for jets impinging on both concave and convex surfaces. The high Reynolds number, contoured-nozzle jets impinged on surfaces with small relative curvature (d/D = 0.019–0.038). It also includes flow visualization using entrained water droplets. Recently in 2014 Dr V.V. Katti and R.N. Patil [3] conducted experiment on static pressure distribution on curved surface target due to impingement of air jet they optioned result, at stagnation the values of C_p are higher due to higher centerline velocities and it is almost uniform up to curvature angle of 5°, and decrease appreciably along circumferential angle θ of a curved surface. A. Hanchinal et al in 2017[4] found that the value of C_p and C_{po} 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[9] and also extend their work for further analysis and study on this topic.[8]

The present work is mainly concentrated on the effect of jet to test section surface on distribution of wall static pressure on convex curved 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 curvature angle 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

D	Test Section diameter (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)
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 m^3/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 C_d 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.

The below mentioned parameters are varying below parameters during experiment

A. Test Section : Convex Surface
B. Diameter of the orifice d = 16mm
C. Reynolds Number (Re) in the range of 50000 to 25000
D. Z/d_h Ratio $1 \leq Z/d_h \leq 4$
E. Circumferential angles (θ = 0°- 30°)
F. Confinement : No

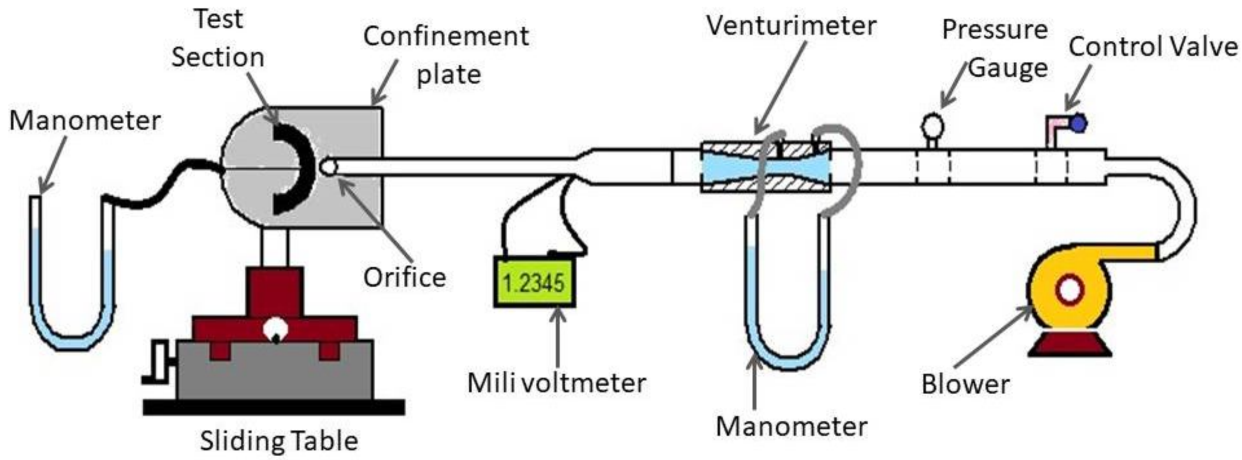

Fig.1 Schematic layout of the complete experimental.

The convex cylindrical tube of inner diameter 40mm and outer diameter of 50mm and length 300mm is used as the test surface; the care has to be taken to maintain the smooth convex surface which is shown in Figure.2. This target surface will be fixed on calibrated compound sliding table at particular Z/d_h position. To measure stagnation pressure, the Slider with 0.5mm diameter hole at the centre used as pressure tap, this slider is placed at the middle of the target surface to measure the static pressure at different Circumferential angles varying θ=0°-30° and the movement of slider along circumferentially must be smooth. 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

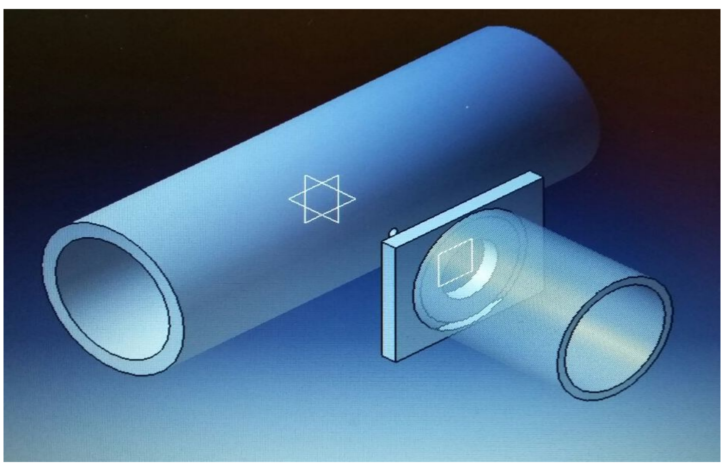

Fig.2 An Isometric view of Target surface along with orifice.

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

A. The jet Reynolds number (Re)

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

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

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

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

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

3) Co-efficient of Pressure

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

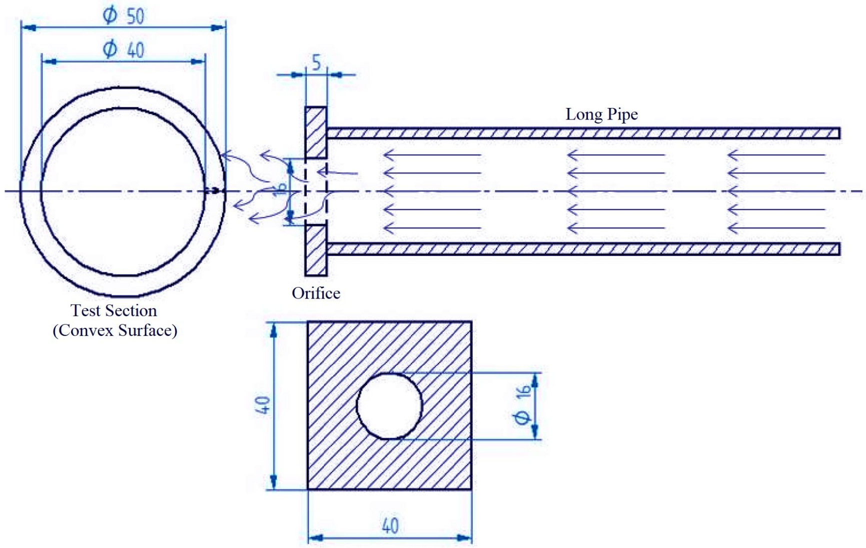

Fig. 3 Geometry of the impinging jet with orifice and test section.

V. RESULTS AND DISCUSSION

An experiment is conducted for various flow and geometric parameters on the convex curved surface to determine the effect of jet to test section spacing on coefficient of static pressure distribution ($C_p=\Delta p/0.5\rho AV_j^2$) by impinging jet of air through an orifice for free flow at steady state.

Influence of Reynolds number on wall static pressure

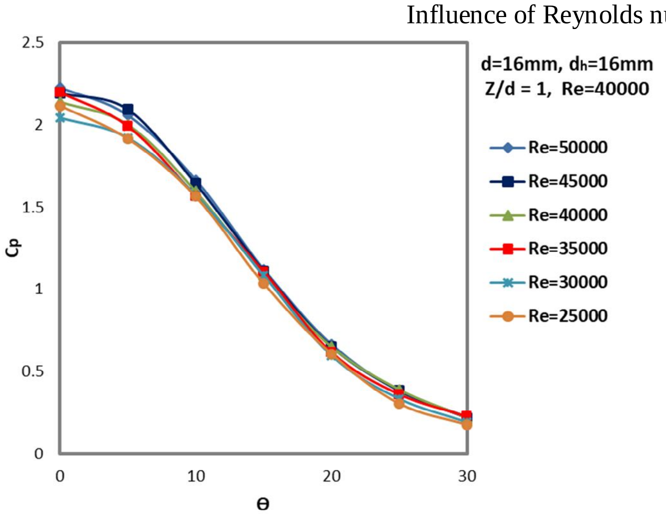

Fig.4 Variation of C_p for various Re at $Z/d_h = 1$

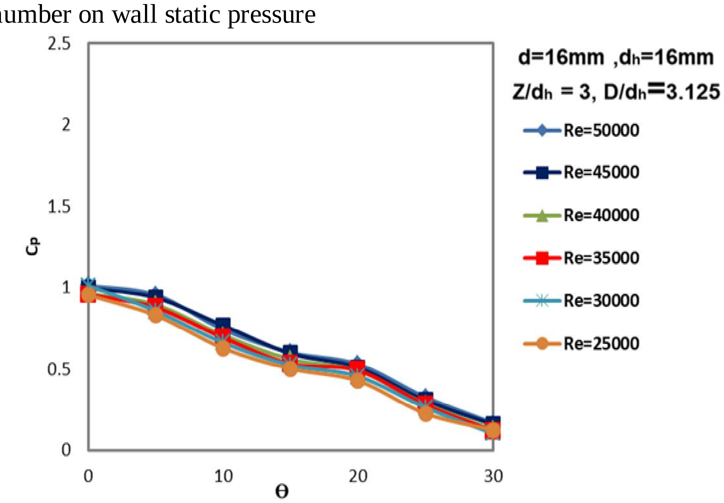

Fig.5 Variation of C_p for various Re at $Z/d_h = 3$

Figure 4 and 5 shows variation of wall static pressure with respect to circumferential angle at various Reynolds number of flow (50000-25000) for two different Z/d_h(1 and 4), it can be seen clearly that lines representing different Reynolds number almost

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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 cylindrical convex surface. The same trend is seen for all Z/d_h Hence further analysis is carried out for any one representative Reynolds number (Re).

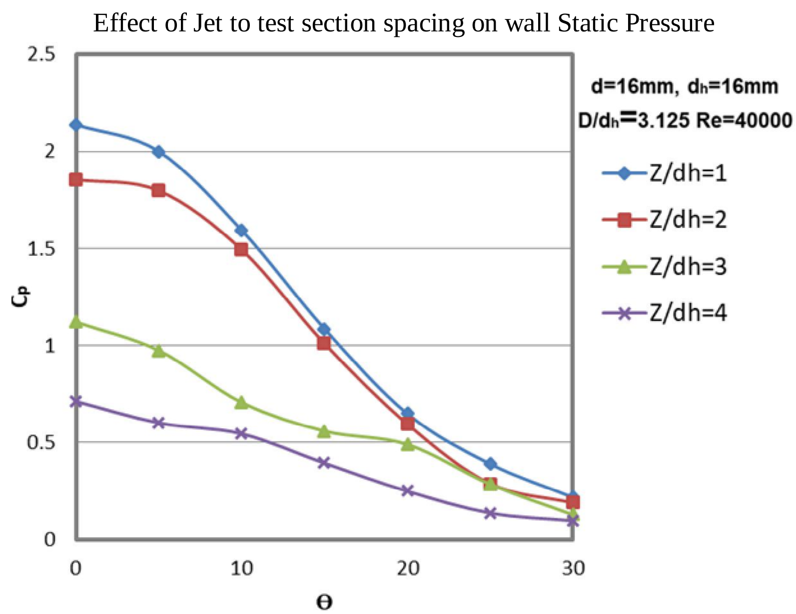

Fig .6 C_P v/s θ at *Re*=40000 for various *Z/d* with Curvature ratio 3.125

Figure 6 gives the variation of Static pressure co-efficient along circumferential angle at curvature ratio D/d=3.125, the higher values of C_p are obtained at *stagnation* point that is $\theta = 0^0$ because of higher center line velocity and also due to vena contraction effect which makes air to remain in the potential core region ($\theta = 0^0$ to5^0). The value of C_p decrease steadily up to $\theta = 15^0$ and decrease considerably for higher value of θ at 30^0.

Thus it is clear that when circumferential angle increases the drop in the wall static pressure is observed and the same trend is seen for all Reynolds number.

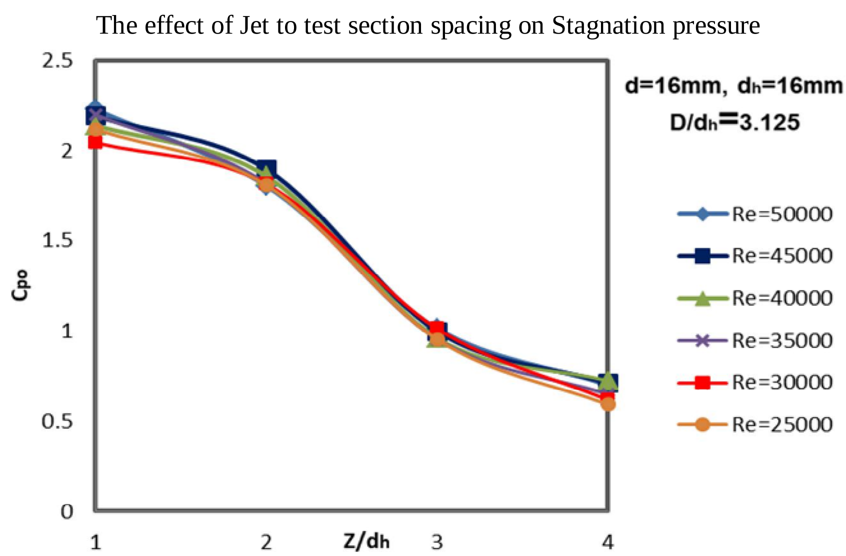

Fig.7 C_{po} v/s Z/d for various Reynolds Number

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) at curvature ratio (D/d_h) = 3.125 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.
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 the bellow conclusions are obtained.

A. The static pressure distribution is independent of Reynolds Number of flow on impingement of air jet from circular orifice on convex curved surface.
B. The value of wall static pressure C_P on the convex curved surface are almost uniform up to $\theta=10^0$ & decreases considerably for higher value of θ.
C. For the same Reynolds number the wall static pressure C_p is high for Lower Z/d_h compared to higher Z/d_h.
D. 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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