Experimental Determination of Coefficient of Static Pressure for Turbulent Flow on Smooth Convex Surface by Airjet Impingement from an Orifice for Open Flow

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Abstract

Jet impingement is a well-known method of heating and cooling of surfaces. This type of impingement allows small distance with high heat transfer rate. This heat transfer coefficient depends up on static pressure therefore in our project we are involving in a determining a distribution of static pressure over a convex surface made of acrylic with a opened flow. This experiment is conducted by varying Reynolds number from 6000 to 40000, and orifice to target plate distance (z/d)1 to 4, varying the circumferential angle(Ɵ) from 0° to 30° and also varying the stagnation point distance from the orifice i.e, (x/d) from 0 to 3.And from the study we can conclude that there is no influence of Reynolds number on Cp, value of Cp is always maximum at the stagnation point and the uniform value of Cp is observed in the potential core region of the jet.

KEY WORDS Static pressure distribution, Jet impingement, Vena Contacta, Stagnation Point, Curvature angle, Convex Surface, Potential core region.

1. INTRODUCTION

Jet impingement is an attractive method for cooling, heating and drying of the surfaces. Because of this jet impingement has been widely used in any industrial applications. Impingement of air jet through orifice to study the heat transfer and static pressure distribution is an new development to the industry. Since the local heat transfer coefficient and stagnation point is mainly depends on the flow of characteristic and the vena contacta between the orifice diameters to the target surface. Static pressure distribution depends on various parameters like Reynolds number, jet-to-tube spacing, radial distance from stagnation point, Prandtl number, target plate inclination, confinement of the jet, nozzle geometry, curvature of target plate, roughness of the target plate and turbulence intensity at the nozzle exit. Therefore the present work is to determine experimentally the static pressure coefficients on convex surface due to impingement of air jet from the orifice nozzle for free flow.

In 1969, Raymond E Chupp experimentally investigated static pressure coefficient by proposing correlation for stagnation strip by resistance heater by varying parameters like Reynolds number, jet to target surface distance, nozzle to target distance [1]

In 1969, R.E.Chupp modifies the previous work by using aluminium target plate acts as a sensor its transient resistance measured by thermocouple parameters varied are Reynolds number,jet to jet distance ,nozzle to plate distance.

In 1994,D. Lytle and B. W. Webb., “Air jet impingement heat transfer at low nozzle-plate spacings” studied about radial distribution of the recovery factor and also about local heat transfer for axisymmetric impinging air jet for a smooth nozzle.

In 2006 -2007, Ramkumar and Prasad conducted same experiment by using one row of jet and five row of jet (multiple jet) by varying a parameter like nozzle to plate distance, Reynolds number, and jet to target distance. The static pressure taps and micro manometers are used to find static pressure developed and local pressure, and heat transfer coefficient distribution showed presence of secondary peaks corresponding up to wash due to jet interactions.[6]

In 2013, Dr. Vadiraj katti have done experiment on the pressure distribution due to the rows of jet impingement on a concave surface and study the various parameters like jet to jet distance, Reynolds number, nozzle to target distance and they found there is a decreasing in wall static pressure coefficient with higher jet to jet distance and secondary peaks are found on adjacent sides [7]

In 2016, Mr.Karthik.N.R.et.al has done experimental investigation of Static pressure distribution on concave target surface for both confined and unconfined flow by varying Reynolds number for various jet diameters and found that the static pressure is more for confined flow when compared unconfined.[8]

In 2018, Prof.A M Hanchinal Experimentally determined the 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.[9]

Hence, the present work is focused on coefficient of static pressure distribution on free flow of ribbed flat plate surface due to the impingement of orifice. The works is processed by varying the various parameters like Reynolds Number (Re=10000 to 40000), Z/d (1 to 4), Ɵ (0° to 30°), and also x/d(0 to 3) with free flow . The conclusion from this work plays very important role while designing the blades of the turbines, deciding of air craft systems.

2. NOMENCLATURE

Symbols	Description	Units
X/d	Ratio of longitudinal distance to the orifice diameter	m
Z/d	Ratio of target plate distance from orifice to the orifice diameter	m
Re	Reynolds Number	-
Vj	Velocity of the jet	m3/Sec
ρ	Density	m3/Kg
Cp	Static pressure coefficient	-
Tj	Temperature of the jet	°C

Patm	Atmospheric Pressure	Pa
m	Mass Flow rate	Kg/Sec
V	Voltage	mV
d	Diameter of orifice	M
Q	Discharge	m3/Sec
Hw	Manometer Head	m
Δp	Pressure	Pa
Ɵ	Curvature angle	Degrees

3. EXPERIMENTAL SETUP AND PROCEDURE

3.1 Specifications of experimental setup

Blower capacity	3.0 m^3/min
Venturimeter C_d	0.92±2%
Orifice diameter	14mm
Pipe Used	PVC
Pressure gauge range	0-2.1 bar
Valve type	Ball Valves
Stand Supports	MS

3.2 Description of Target Plate

Target type	Convex surface
Material of target	Acrylic
Length	220mm
Inner and Outer diameters	50mm×60mm
Thickness	5mm
Hole diameter	2mm

The complete experimental procedure setup is as shown in fig (2) The blower with capacity of 3.0 m^3/min and maximum supply of power 240 W used for the supply of air jet. And the calibrated Venturimeter with coefficient of discharge C_d of 0.92±2% is used, & Calibrated K type thermocouple is used to measure the jet temperature with jet temperature connected with the milli voltmeter and mercury setup arrangement. And the other parameters are taken as per the steady state conditions.

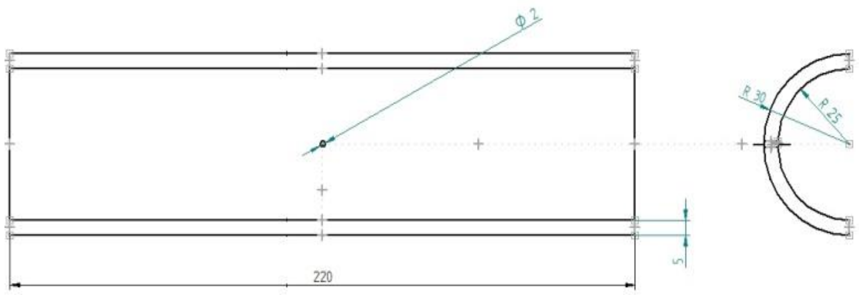

Figure 1 Description of Target Surface

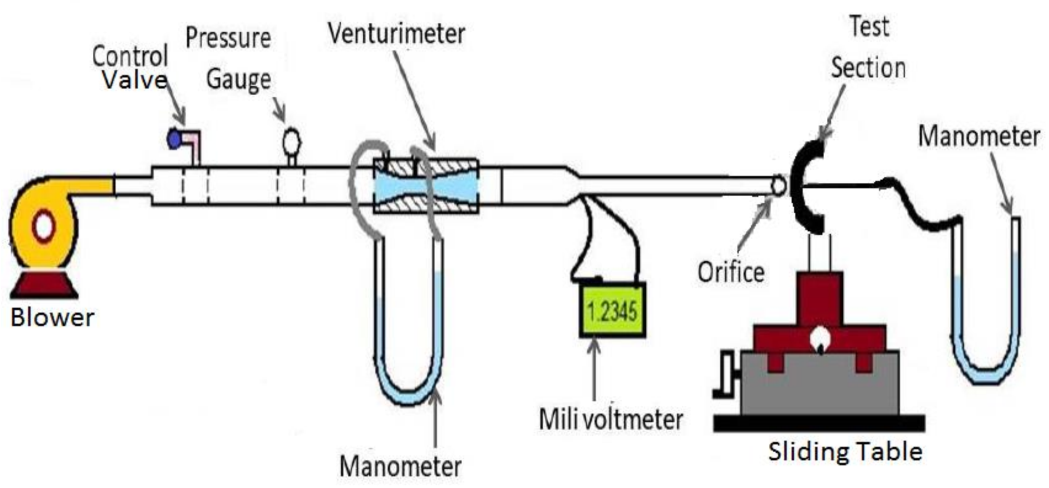

Figure 2 Schematic Layout of the Experiment

The target surface i.e convex surface with I.D and O.D 50mm and 60mm respectively with thickness of 5mm and length 220mm, with a hole of 2mm at the centre . Target surface is mounted in a square box which is placed on a sliding table. The parameters varied are z/d i.e the ratio of distance of target from the orifice to the orifice diameter is varied by changing the pipe length between z/d=1 to z/d=4. Other parameter varied is circumferential angle i.e, ϴ is varied between ϴ=0 to ϴ =30 degree. Another parameter varied is x/d i.e ratio of longitudinal distance from the orifice to the orifice diameter.(x/d=0 to x/d=3)

The blower which has a motor of power 1hp and has a speed of 13000rpm blows the air with a very high velocity to the venturimeter through a ball type control valve. The control valve helps in setting up of the Reynolds number by regulating the control valve. The air with higher velocity and at the desired Reynolds number hits the target surface that is placed at particular distance through the orifice of diameter 14mm. The flow of jet is confined to required length. The target surface may be placed at a distance i.e, z/d=1,2,3,or 4. Target surface is connected with a pressure tap which in turn connected to one of the ends of the manometer and other end of the manometer is open to atmosphere.

4. DATA REDUCTION

- **Reynolds number is defined on the basis of orifice diameter and is estimated using the following equation.**

$$\boldsymbol{Re} = \frac{\mathbf{4\ x\ m}}{\boldsymbol{\pi}\ \mathbf{x\ d\ x\ \mu}}$$

- **Temperature of the jet at the exit of orifice**

$$\boldsymbol{T_j(°C)} = (\mathbf{23.188\ x\ \upsilon}) + \mathbf{3.843} \text{.............. (°C)}$$

- **Density of air jet**

$$\rho = \frac{\text{Patm}}{0.287 \text{ x } (T_j + 273)} \text{.....................kg/m}^3$$

- **Static Pressure and Atmospheric pressure**

$$\Delta P = 1000 \text{ x } 9.81 \text{ x } H_w \text{..................Pa}$$

- **Coefficient of Pressure**

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

5. RESULTS AND DISCUSSIONS

5.1 Influence of Reynolds Number on Static Pressure

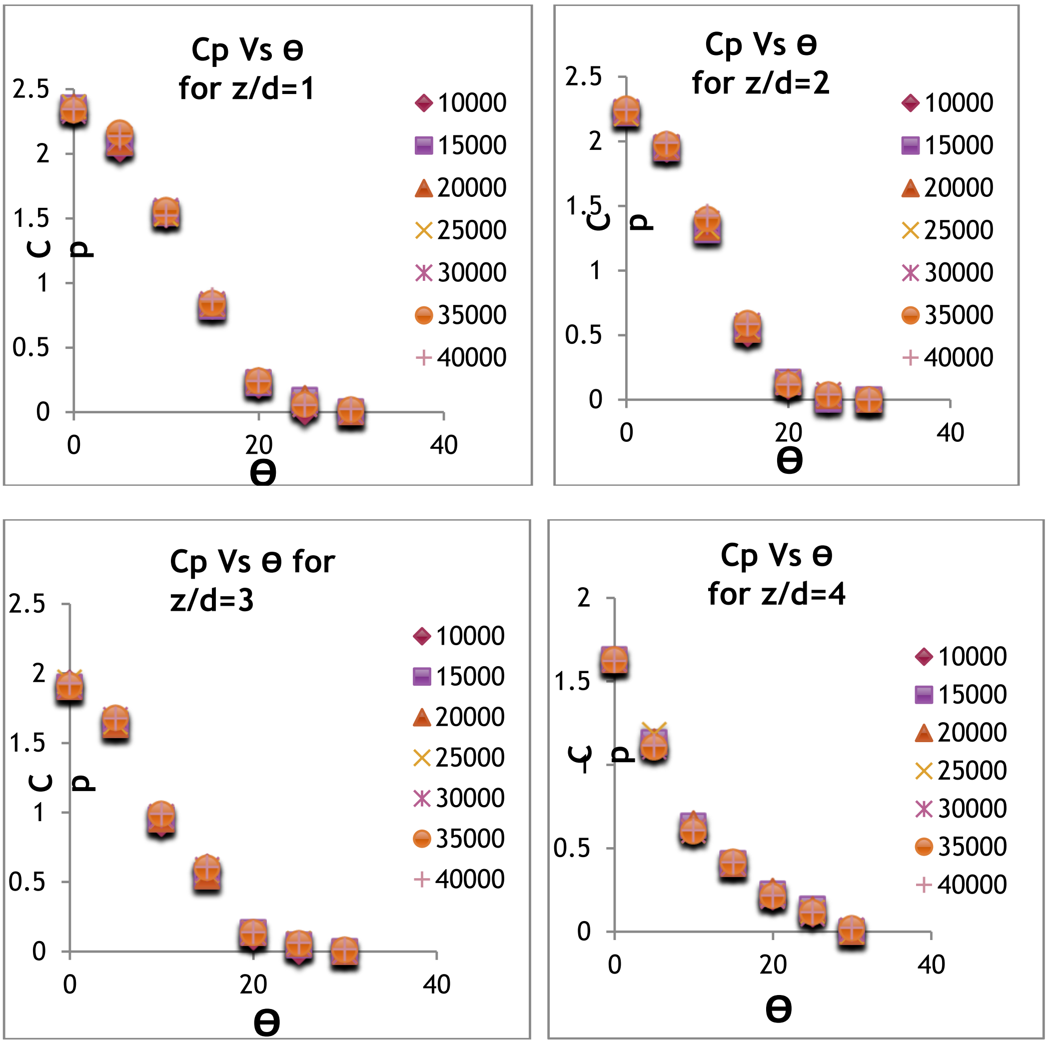

Figure 3 Influence of Reynolds number

The above figure shows the variation of the static pressure Cp with the circumferential angle Θ and the z/d ratio being 1,2,3 and 4. The figure reveals that the static pressure is maximum at the stagnation point i.e, at Ɵ= 0^0 because of high axial velocity of the jet. The value of Cp goes on decreasing as the circumferential angle is increased. From the above figure we can see that the trend of Cp with Ɵ is almost similar and are also getting merged with each other for all the Reynolds numbers i.e, from 10000 to 40000. The trend is same for all the z/d ratios(i.e, z/d=1,2,3,4). Therefore, it clears that the Reynolds number does not have any influence on the static pressure(Cp). Hence, the further analysis will be carried out for the representative Reynolds number i.e, Re=25000.

5.2 Effect of z/d ratio on static pressure

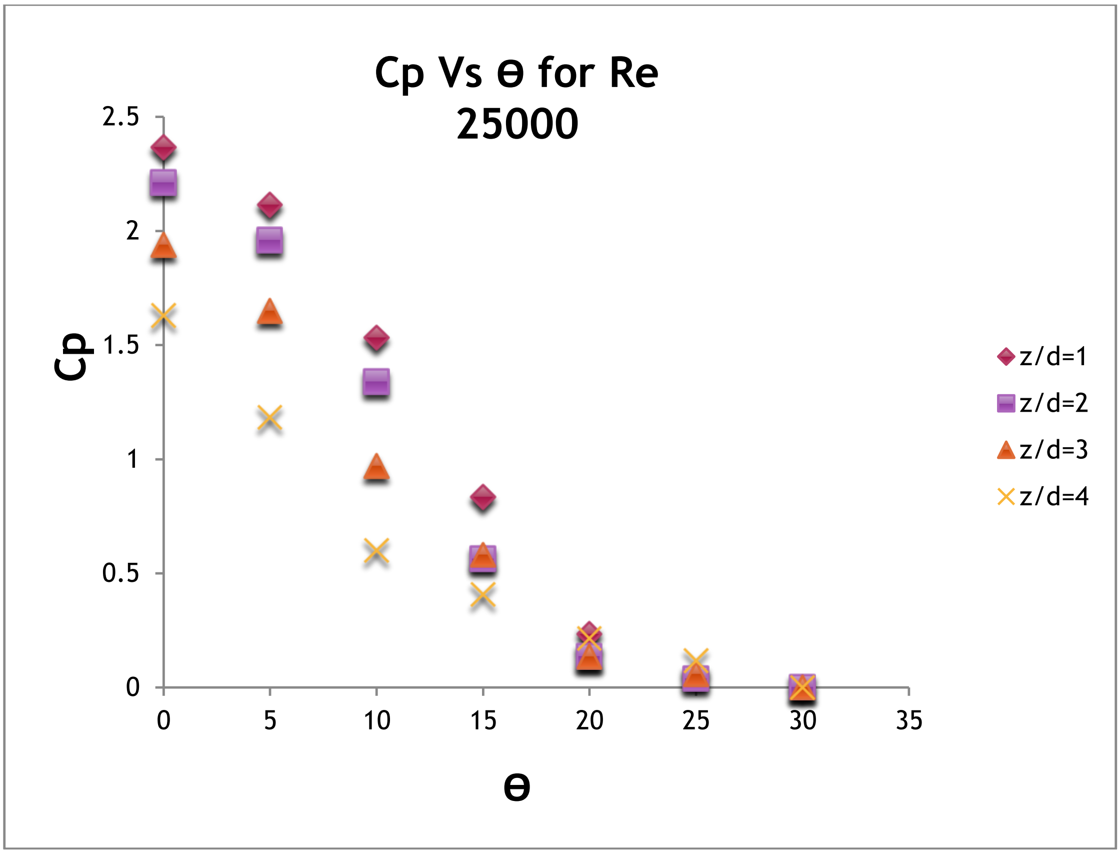

Figure 4 Variation of Cp with Ɵ

The above figure reveals the variation of the static pressure Cp with the curvature angle Ɵ at various z/d ratio. From the figure, it is seen that the static pressure Cp is maximum at the stagnation point i.e, at 0° since the jet and the pressure tap are co axial, hence the velocity of the jet is completely converted into the pressure energy. The value of Cp at stagnation point and z/d=1 is 2.405072. The value of Cp is uniform from 0 to 5° since the curvature angle is low and there is no much spread of the jet over the circumference of the target surface. From 5° to 10°, there is a gradual decrease in the value of Cp because of the higher curvature angle. From 10° to 20°, there is an appreciable decrease in the value of Cp. Atmospheric condition is reached on the convex surface at an angle higher than 25° from the point of impingement. From this data it can be concluded that the value of Cp decreases as the circumferential angle is increased.

5.3 Effect of x/d ratio on static pressure

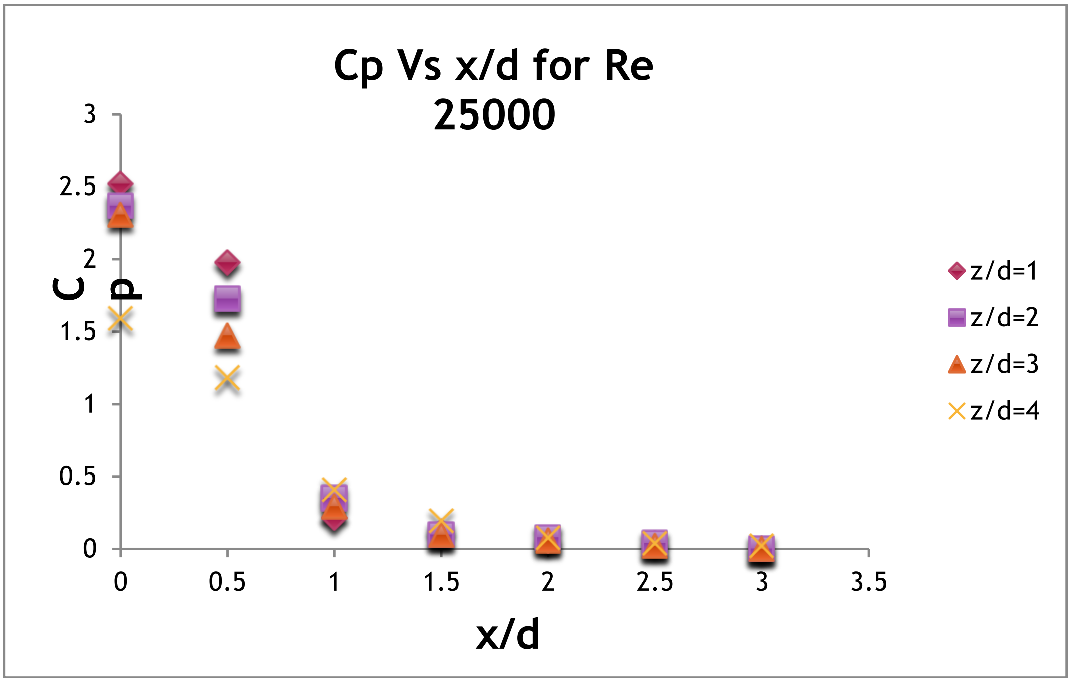

Figure 5 Variation of Cp with x/d

From the graph of Cp vs x/d, the value of Cp are higher for low x/d ratio due to the high axial velocity of the jet. They decrease gradually from x/d=0 to x/d=0.5, because of the lesser spread of the jet and then the jet will spread more with further increase of x/d distance and hence there is an appreciable decrease in the value of Cp is observed for the ratio x/d=1.0. The atmospheric pressure is reached on the convex surface due to jet impingement at a longitudinal distance equal to diameter of the jet.

5.4 Effect on z/d ratio on the static pressure at stagnation point

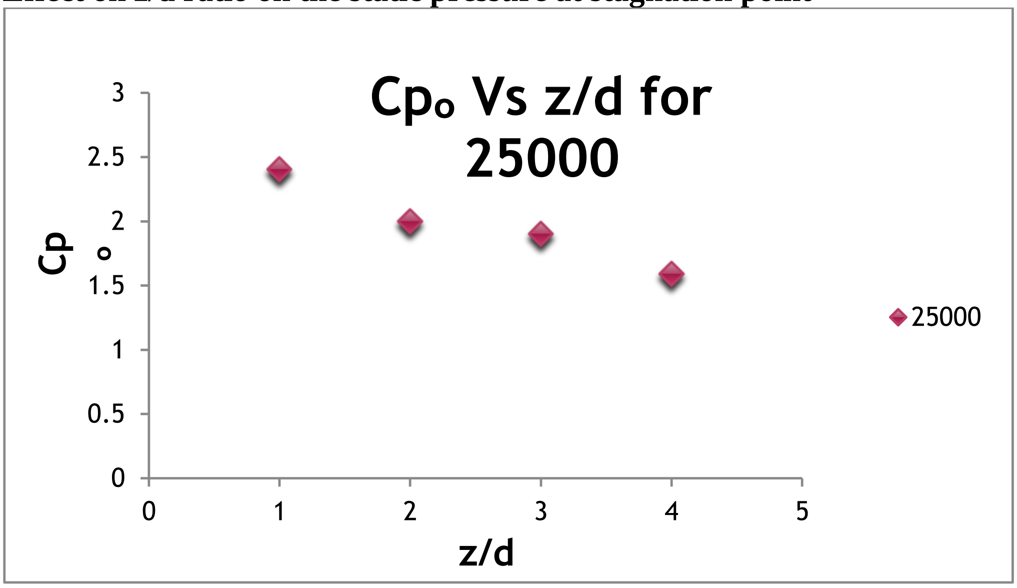

Figure 6 variation of Cp_o with z/d

The above figure shows the variation of the static pressure at stagnation point with the orifice to the target surface distance ratio i.e z/d. The value of Cp_o is maximum when z/d=1. The value of Cp_o remains more or less uniform in the range of z/d=2 to z/d=3. This may be because of target surface located within the potential core region of free jet. Then, the appreciable decrease of Cp_o is observed for further increase of z/d ratio. As distance from the orifice increase, the velocity goes on decreasing monotonically due to spreading of the jet.

6. CONCLUSIONS

- There is no influence of Reynold number on the static pressure (Cp).
- The value of static pressure is always maximum at the stagnation point due to the high axial velocity of the jet and goes on decreasing as the curvature angle (Ɵ) increases.
- Value of static pressure goes on deceasing as the ratio of longitudinal distance from the orifice to the orifice diameter increases.
- The Cp value is maximum at the stagnation point and the target surface located at the distance z/d=1, between z/d=2 and z/d=3, the Cp_o vale is almost uniform due to the potentiocore region of the free jet, and for z/d=4 there is an appreciable decrease in the value of Cp_o.

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