

4 METHODOLOGY AND EXPERIMENTAL SETUP

4.1 Introduction

In the view of analysis of parameters decided for investigation, experimentation is proposed. The experiment consists of a jet arrangement with air as the fluid. The detail heat transfer calculations and experimental setup are given below.

4.2 Heat transfer calculations

The target plate is to be heated by supplying electrical energy and recorded by measuring Voltage and Current. This energy is supplied to the target plate for heating, which is to be carried out by fluid flow of impinged jet.

Following assumptions are made during calculations and experimentation.

1. Heat supplied to target plate is constant.
2. Negligible heat loss by conduction through the target plate, as it is very thin.
3. Material of the target plate is homogenous.
4. Air is used as working fluid hence for analysis it is assumed that Pr is constant and assumed to be 1.

The heat energy can be passed out through heat transfer from bottom and top of the plate majority by convection, and also by conduction and radiation. The heat transfer through conduction by thin target is very small and hence to be neglected. The radiation heat loss by the thin foiled target from bottom and top side is calculated by using conventional methods. Correction factor is applied during analysis. The heat available for convection heat transfer by jet is calculated by deducting heat loss by radiation by foil (emissivity as 0.3) by both sides from heat supplied.

The energy coming out of plate is written as:

$$E_{out} = Q_{conv.jet} + Q_{conv.bottom} + Q_{rad(both\ surface)} + Q_{cond} \quad (4.1)$$

But the heat loss from bottom surface is unavoidable by applying insulation. Assuming heat transfer through bottom of target plate by Natural convection only, (Fig. 4.1)

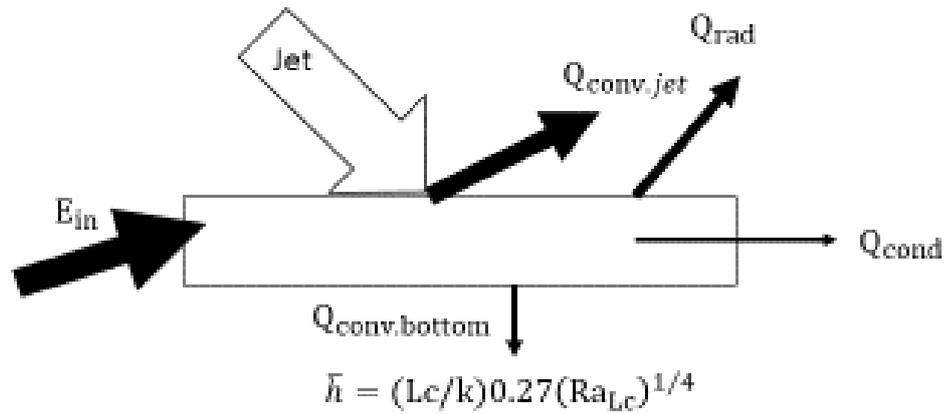


Fig. 4.1 : Heat balance for inclined jet impingement

$Q_{\text{conv.bottom}}$ = Natural convection

For lower Surface of hot plate, Average Nusselt Number is given by

$$Nu_{\text{avg,Lc}} = 0.27(Ra_{Lc})^{1/4} \quad (4.2)$$

Where, Ra_{Lc} is Rayleigh Number and for $(10^5 \leq Ra_{Lc} \leq 10^{10})$ [78]

And Characteristic length as, L (which is a function of surface area and perimeter)

$$Lc = \frac{A_s}{Pe} \quad (4.3)$$

$$Ra_{Lc} = \frac{g\beta(T_s - T_0)Lc^3}{\alpha \cdot v} \quad (4.4)$$

By calculating Lc , Ra_{Lc} is calculated. Which finally help in calculating h and Nu , as required to calculate $Q_{\text{conv.bottom}}$.

$$Q_{\text{conv.bottom}} = h \cdot A \cdot (\Delta T) \quad (4.5)$$

It is coming out up to 7 to 8 W; which is very less comparatively, hence correction factor is applied during calculation of heat supplied.

Actual energy supplied = Heat input – $Q_{\text{conv.bottom}}$

i.e. $(Q_{\text{actual}}) = (\text{Voltage} \cdot \text{Current}) - Q_{\text{conv.bottom}}$

But,

$$\text{Nu}_D = \frac{hL}{k}$$

In case of jet, diameter D is considered as the characteristic dimension, hence

$$\text{Nu}_D = \frac{hD}{k} \quad (4.6)$$

$$Q_{\text{act}} = h \cdot A_s \cdot \Delta T$$

$$h = \frac{Q_{\text{act}}}{A_s \cdot \Delta T}$$

Put value of h in above equation;

$$\text{Nu}_D = \frac{Q_{\text{act}}}{A_s \cdot \Delta T} \cdot \frac{D}{k} \quad (4.7)$$

$$\text{Nu}_D = \frac{(\text{Voltage} \cdot \text{Current} - Q_{\text{conv.bottom}})}{A_s \cdot \Delta T} \cdot \frac{D}{k} \quad (4.8)$$

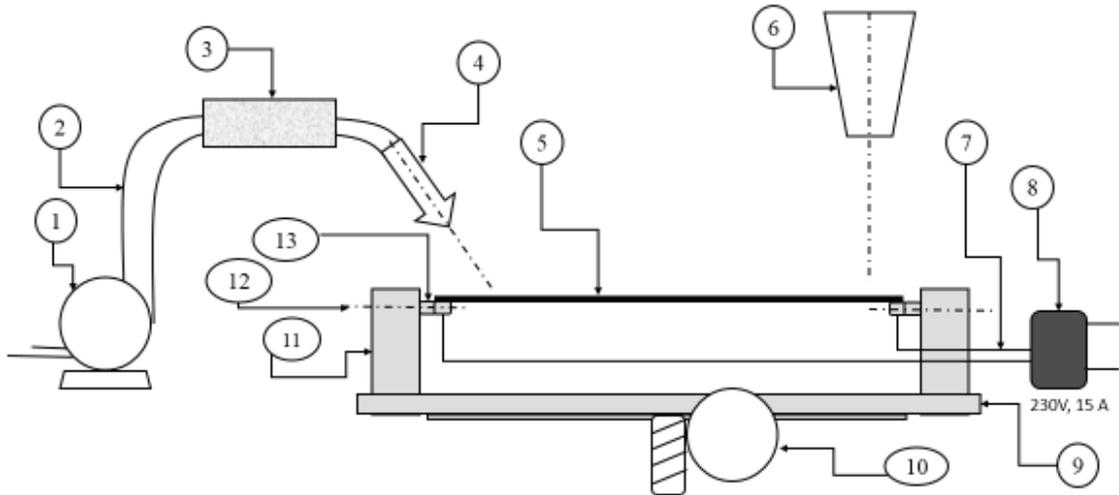
The Reynolds Number is calculated on the basis of diameter of jet that indicates –

$$\text{Re}_D = \frac{V \cdot D}{\nu} \quad (4.9)$$

By using this value, Local Nusselt Number and Average Nusselt Number is calculated at every location of the plate. For analysis purpose, the averages are also calculated as per requirements. The graphs are plotted accordingly and results are discussed in next topic.

4.3 Description of Experimental setup

The experimental setup is as shown in Fig. 4.2. The arrangement of production of air jet and its impingement on the target is made. The target surface is positioned as horizontal. (Appendix V)



1- Blower for air supply, 2 - Hose pipe, 3 – Air cooler, 4 – Inclined Replaceable Jet, 5 – Target Plate, 6 – Infrared Camera, 7 – Electrical cables, 8 – Transformer, 9 – Base Housing, 10 – Hand wheel for changing Height, 11 – Vertical support, 12 – Tightening Bolts, 13 – Bus Bars

Fig. 4.2 : Block diagram of experimental setup

The **test target** is hot, plane and smooth plate, made up of thin foil of **stainless steel** with thickness of 0.050 mm and heated by Joule effect. The area of target element selected is 264mm x 108mm. The heating element is placed in between two copper bus bars in tight horizontal position. It is observed that the target plate foil gets expanded during heating. To avoid buckling of target plate, the provision are made to tighten the foil using tightening arrangement available with housing of target plate as shown in Fig. 4.3. [79] [80]

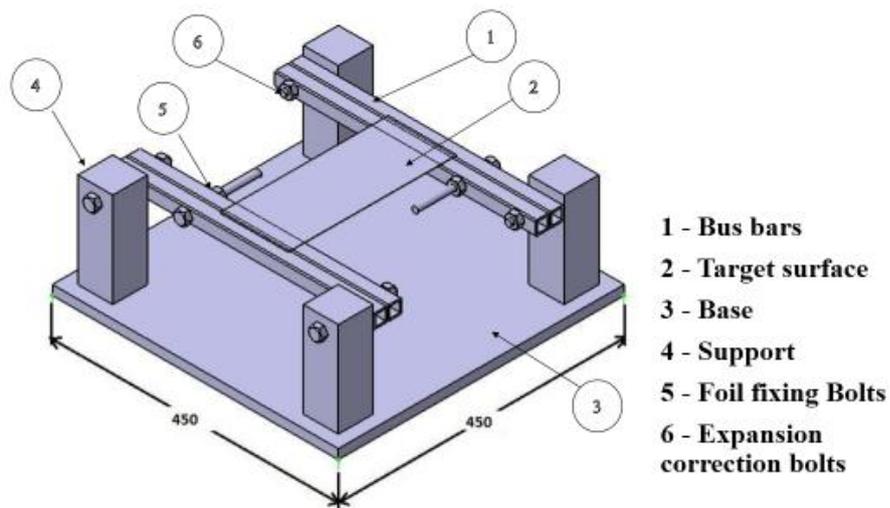


Fig. 4.3 : Housing of a target plate in 3D view

The **housing** is made with the intention of placing the target plate as per required position. The housing is made up of nonconductive material for avoiding heat loss through conduction from heater to housing. The aim of housing is also to fix foil heater with bus bars. Also it is easy to change distance of jet from target (H). This height 'H' is measured by using height blocks of slanted sizes.

Two copper **bus bars** are used in conjunction with heater plate foil. The bus bars are made up using 4mmx10mm rectangular cross-section. . Electric supply is given to target plate and tested without bus bars. It is observed that target plate gets uneven heated at junction of plate and cables. By referring arrangements made by [79] , bus bars are used which satisfying requirements of uniform are heating.

The supply of 230V, 5Amp is given to a **transformer** and converted to required ratings. The single phase electric supply is given to target plate through copper bus bars. The supply given to target is of 3 Volt and 50 Ampere AC.

This heated target plate is cooled by impinging air through **circular cross-section jet**. The circular jet is selected for simplicity in making them. Only **one jet** is used at a time in present study. The jet is made up of **wood / plastic**, again for simplicity in manufacturing. The plate is placed horizontal and jet will be impinged from top side in downward direction as shown in Fig. 2.1 (h). The bottom side of plate was not impinged with jet and it is allowed to cool by natural convection. The width of target plate (shorter side) is considered as the reference Y axis for locating the jet position. The jet is placed at the center position along the width of target surface. The longer side of target plate (length) is considered as X reference axis as shown in Fig. 4.4. Fig. is also showing the downhill side of target, defined by inclination and jet position. (Discussed in earlier topic.)

Jets of **different diameters** are investigated during experimentation with length of 400mm. To change jet diameter, the end jet assembly is changed directly which is

hinged to main horizontal plate near exit to jet. It is possible to use any diameter of jet by replacing end unit attachment up to maximum 25 mm diameter.

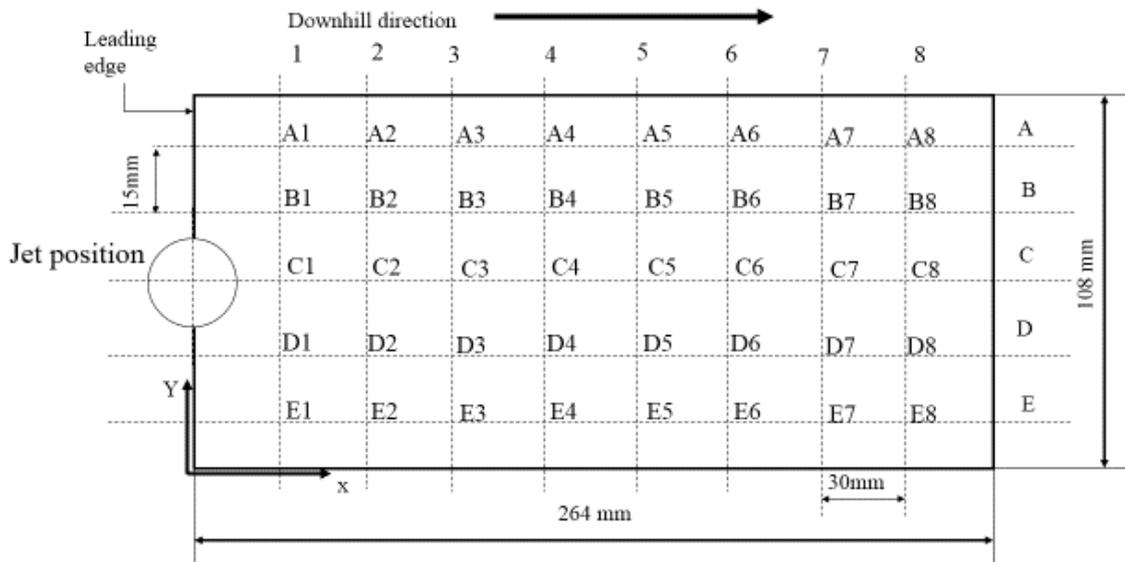


Fig. 4.4 : Target plate – specifications and nomenclature

For cooling of target plate, air is used as a fluid in present study. Air is supplied by a blower as specified in Table 4.1 for the experimentation. Air passes through a hose pipe of 25 mm diameter and its flow is controlled through a flow regulating valve. This will also satisfy requirements of air at Reynolds number varying from 2000 to 20000.

The wet cloth is wounded on the air supplying pipe, provides heat exchange from high temperature air developed due to blower effect. It is used to maintain the jet air temperature close to that of the ambient air. The air then passes through a straightened passage to convert it for streamline flow. After the straightened chamber, the air passes through a jet unit.

The **jet to target plate distance** is one of the important parameter to analyze. To understand the effect of change in height H, it is varied from 10 mm to 55 mm. To change this distance, the screw jack assembly is used in the setup, which makes it convenient to change height H, as per requirement. (Arrangement photograph is shown in Appendix)

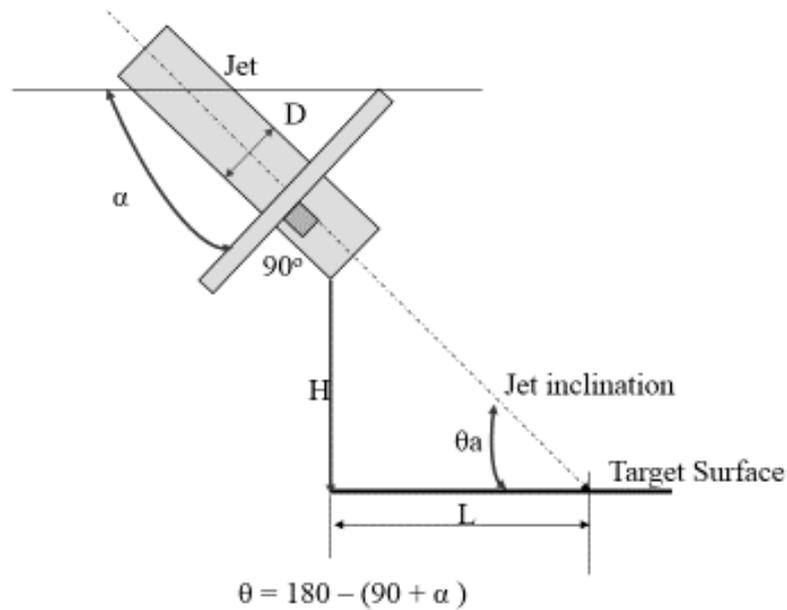
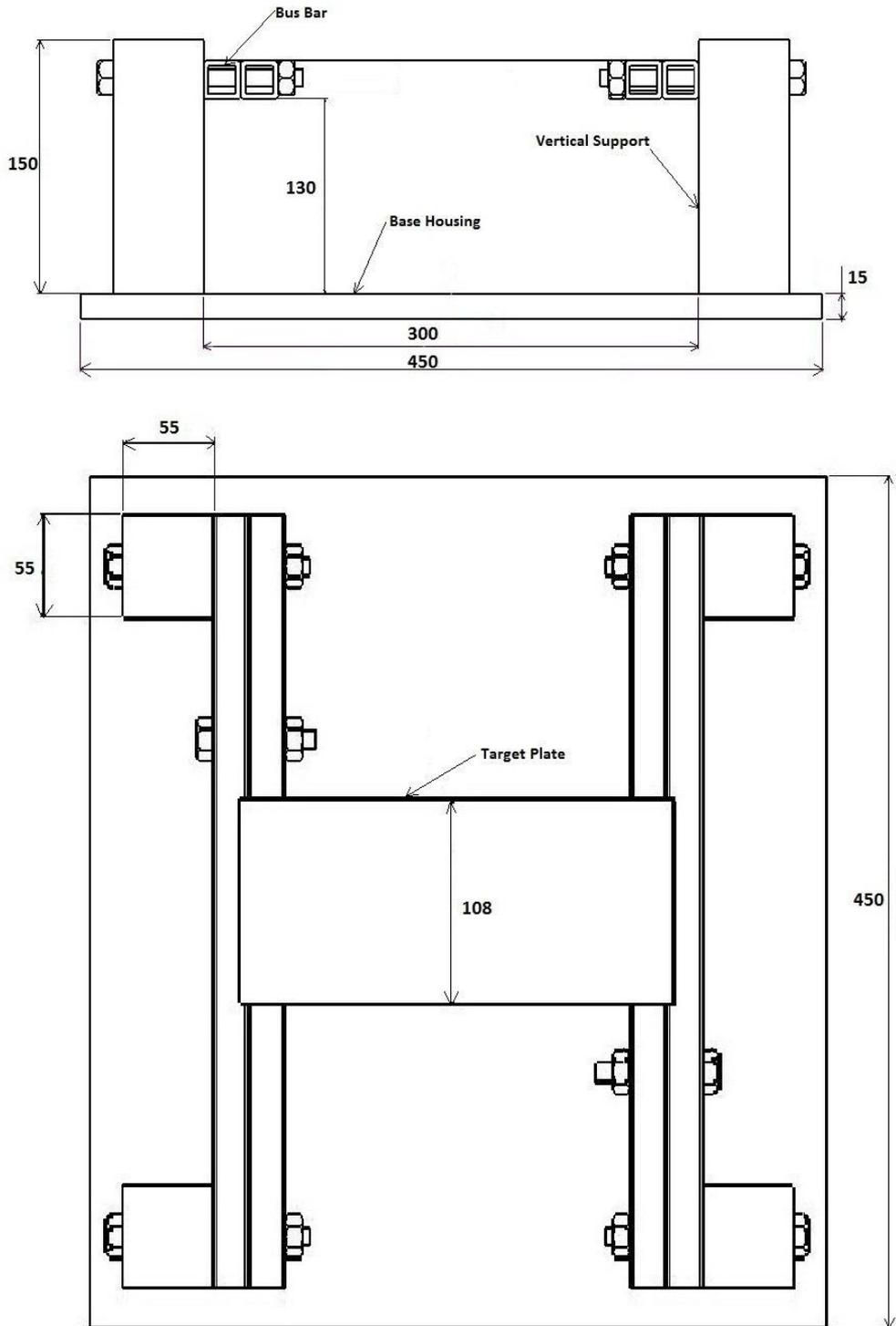


Fig. 4.5 : Jet inclination terminology

The axis of jet can make an **angle** of 0 to 90 Degree with horizontal target plate as shown in Fig. 4.5. The angle of impinged jet is measured by angle measuring unit which is placed at the exit end of the jet. A protractor is placed for measuring angle. It is assured that target plate is horizontal and it makes right angle to vertical jet by using Engineers square and spirit level.

An **infrared thermometer** is used to take temperature readings of the target plate. Its range is -30°C to 550°C , with accuracy of ± 0.02 . The target plate is divided into various fragments along X and Y axis as shown in Fig. 4.4. Every crossing of X and Y lines, is designated as A1, A2A8, B1, B2...E1, E2,...E8, and the temperature is measured at these cross lines. Total forty points are referred to measure temperature. Thermal images of heated target are shown in Appendix III

The **velocity** of air jet is measured in m/s by using anemometer. It is with range of 0 to 30 m/s and reading can be taken in the resolution of 0.01m/s. For accuracy in velocity measurement, average of readings at three/five different locations, immediately after jet plate is measured. All readings are taken at **steady state conditions**. It will be considered as jet exit velocity, and used as governing parameter for data reductions



All Dimensions are in mm

Fig. 4.6 : Housing and target plate (In two views)

further. Same velocity is used to calculate jet Reynolds number. Data tables are given in Appendix II. If also jet is getting impinged on the target surface, its velocity at each point on the target will be different, and also will be difficult to consider as characteristic parameter to study. Efforts are made to measure velocity by various experimental and numerical techniques. [81]. Jet diameter is considered as the characteristics dimension, which is comparatively simpler and widely accepted way of study. The careful observations are taken at steady state condition of experiment. Two views of detailed drawing of housing and target plate are shown in Fig. 4.6

Some important practical observations

Initially various heaters are tried as per availability and tested for uniformity in temperature. It is seen that highest temperatures are observed near cartridge, and decreases in surrounding region. Even oil bath heaters are thought, which are difficult to manufacture.

Scope

Scope of experiment is limited to parameters like Reynolds number up to 20000. Also diameters of jets can be installed maximum 25mm, by changing head assembly. Only ambient air can be used as fluid in jet system in this experiment.

4.4 Setup equipment specification

The Summary and specifications of experimental setup is as shown in Table 4.1.

Table 4.1 : Specifications of items used in experimental setup		
S. No.	Major items	Specifications
1	Blower	Make – Powerica Ltd., Centrifugal Type, Rated RPM 1500, 500 CFM, with motor 0.5 HP.
2	Target plate	Stainless Steel, 0.05mm thick, 108 x 264 mm ²
3	Transformer	Make – Super transformers, 2007, Input 440/230V, Max DC voltage 60

		V, 50 Hz, Insulation class – A, Max Current 300A
4	Anemometer	Make - TES Electrical Electronic Corp., Taiwan Triple Display, 4 Digit LCD, 0 – 30 m/s range with 0.01 m/s resolution. Accuracy +/- 3%, Response Time 2 seconds
5	Infrared Thermometer	Make – Kusam-Meco IRL900, range -30 to 550 ⁰ C, Accuracy +/- 0.02 C for up to 100 ⁰ C and 1% for greater than 100 ⁰ C, € = 0.1 to 1 adjustment
6	Jet Assembly	Made-up of wood/plastic, replaceable, Jets from 5mm to 25mm are possible to install.
7	Angle Measurement Unit	Jet inclination angle can be measured, Range from 0 to 90 Degree

4.5 Validation of experimental setup

The experimental setup is validated by using available equations for perpendicular circular jet. For this the equations used are: [82]

By Mohanty and Tawfek

$$Nu_0 = 0.388Re^{0.696}(H/D)^{-0.345} \quad (4.10)$$

For (H/D) 6 to 58 and Re 6900 to 24900.

By Lytle and Webb

$$Nu_0 = 0.726Re^{0.53}(H/D)^{-0.191} \quad (4.11)$$

For (H/D) < 0.1, Re from 3700 to 30000.

The comparison of results are shown in Fig. 4.7 . It is observed that stagnation Nusselt Number is matching with results from equations and experiments in $\pm 10\%$, as shown in Fig. 4.8.

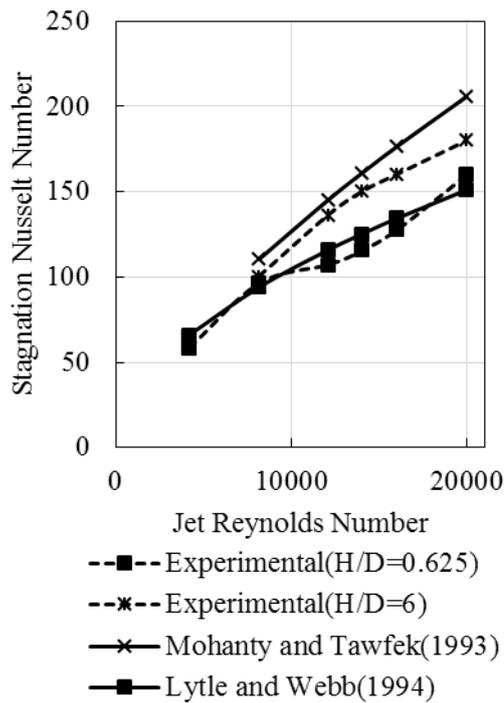


Fig. 4.7 : Validation of Nu_0 for perpendicular jet

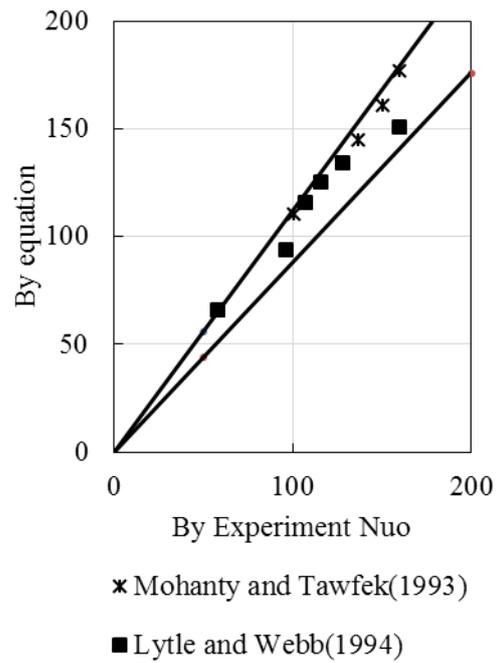


Fig. 4.8 : Comparison of experimental and equation results : Nu_0

Data analysis

The data generated by experimental reading is recorded in observation table recorded in Appendix VI. The analysis of data is performed by various approaches. Initially, the data is used to calculate local Nusselt number for the target plate. It is then plotted and observed that Y average can be taken, as jet is symmetrical along the C-C. Then Y average along the C-C are plotted and studied. With this average Nusselt Number are also calculated along the entire surface. The hot or cold point are playing important role for designing packaging electronics devices. With the aim to study this, maximum value of Nusselt number along C-C are obtained. Again the question of location of this coolest position is to be identified. It is then found by data analysis in terms of X_0 . With this entire target can be analyzed. In the entire data analysis, the local cold / hot spots are remaining untouched. To understand, centerline temperatures are taken from observation table, as it is. The aim of enhancement of jet cooling by comparison with

natural convection. For this natural convection heat transfer for a plate are calculated and data in terms of enhancement factor are generated. The uncertainty analysis is performed and found in the range as in Appendix IV. Photographs of experimental setup and all allied arrangements are shown in Appendix V. The observations and calculation tables are given in Appendix VI.

4.6 Conclusion

Experimental setup with instruments is framed and heat transfer calculations are made. By doing this the data available is then analyzed with relation to heat transfer.
