Parametric Analysis of Heat Transfer through Inclined Elliptical Cylinder

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***Abstract*- Natural convection is the most important phenomenon regarding the heat transfer. An experiment is conducted here for an elliptical cylinder to find an equation for Nusselt number by which we can easily find out the amount of heat transfer. In this research, the inclinations observed at 00, 300, 450, 600, 900 at the axis ratio of 1:4. The cylindrical is cooled naturally and analysis is done on it. The equation of Nusselt number is obtained experimentally. This results are validated using CFD simulations. There is + 10% of error is detected between experimental and CFD simulation.**

***Index terms*- Convection, Nusselt number, Ellitical cylinder, CFD, inclination**

I.INTRODUCTION

Natural convection is the phenomenon obtained when the fluid motion is not generated by any external source like pump, fan, suction devices etc. This natural convection is done due to gravity force. Generally the convective heat transfer is obtained with the help of Nusselt number equation. So there are too many researches are done to find the heat transfer equation from the various type of geometries and they found different heat transfer equations for different phenomenon.

This study is mainly focused on finding the various parameters regarding heat transfer through elliptical tube. As we know that there is an effect of inclinations of geometries on heat transfer. There are too many researches are done to find heat transfer through cylindrical tube for various inclinations. And they found different results of heat transfers as they use different methods [1, 2]. But we are focusing on the study of elliptical tube heat transfer because there is very less research is done on this geometry. As per a study on the elliptical body, the amount of heat transfer is increased. For example, there is experimental investigation of Terukazu Ota et.al [3] found that the amount of heat transfer for elliptical bodies increases when it is tilted at angle of $60^0 – 90^0$ and it should be minimum at an angle of 0^0 - 30^0 at an axis ratio of 1:3 and the value of Raynolds Number increases from 8000 to 79000. Also according to the study of Amr O. Elsayed et.al [4] found that the amount of heat transfer should be maximum when the elliptical tube is placed as a major axis in the vertical direction. Also, some numerical study is done on that, for example, a mathematical modeling of Hyun Woo Chu et.al [5] found that the surface average Nusselt Number is increased by 3.9 % for two elliptical cylinders with aspect ratio of upper elliptical cylinder at 0.5 and lower elliptical cylinder at 2 with the Rayleigh number in the range of 10^4 to 10^6.

Natural convective heat transfer in cylindrical geometry has been widely studied for its applications in heat loss from piping, heat exchangers, HVAC systems, refrigerators, nuclear reactors fuel elements, dry cooling towers, etc. The cooling techniques commonly used in electronic equipment’s are as follows-

1. Natural convection cooling
2. Forced convection cooling with air
3. Immersion cooling with natural convection
4. Immersion cooling with boiling
5. Forced circulation of water
6. Heat pipe.

Here we are using natural convective cooling because there is a vast area of research are needed. Since most of the research are done with the help of mixed convection or forced convection.

The heat transfer from a surface at temperature T_s to a fluid at temperature T_{fluid} by convection is expressed as,

$Q_{conv} = h_{conv} A_s (T_s – T_{fluid})$

Where, h_{conv} = convection heat transfer coefficient

A_s = heat transfer surface area

Nomenclature

Nu	Nusselt Number (hd/k)
Ra	Rayleigh's Number (gβΔTD^3/αϑ)
Gr	Grashoff's Number(gβΔTD^3/ϑ^2)
Pr	Prandtl number (ϑ/α)
Re	Reynolds Number (ρvd/μ)
h	Heat Transfer Coefficient(W/m2K)
C	Circumference (m)
dh	Hydraulic Diameter (m)
D	Diameter (m)
R	Radius (m)
ε	Axis Ratio
s	Fin spacing (m)
H	Dimensional metric coefficient (m)
e	Eccentricity
ϑ	Kinematic Viscocity (m^2/s)
U	Velocity (m/s)
T	Top wall temperature (^{0}C)
T_1	Outer wall temperature (^{0}C)
T_2	Inner wall temperature (^{0}C)
α	Inclination angle (^{0})
η	direction of inclination in A. Bouras et.al
θ_N	Elliptical tube final (^{0})
θ_i	Elliptical tube initial (^{0})

D1 = Major Diameter

D2 = Minor Diameter

L = Length of pipe.

L_P = Channel width.

θ = Inclination of cylinder from horizontal.

H = Height of vertical plates.

Y = Elevation of cylinder from base plate.

S = Aspect ratio (L/L_P)

Suffix :

X	Local
Avg	Average
max	Maximum
∞	Atmospheric

II.LITERATURE SURVEY

1.1 Experimental Research on elliptical surfaces

The study on the elliptical surface has been done by various methods so that to find out various correlations for Nusselt Number to find the amount of heat transfer. The experimental study of Sebastian Ungera et.al [6] found a correlation for natural heat transfer. In this, the study on the oval tube has been done at various tilt angles (0-40^0) with fins on it.

$$Nu = -9.94 + Ra^{0.196} - 30.77\left(\frac{s}{d_h}\right) + \frac{s}{d_h}\,(32.47 - 2.76\,sin\alpha)$$

From this research, it is found that as the tube is tilt from 0^0 to 40^0 the Nu reduces by 11.1% and the volumetric flux density reduces by 9.6 %.

The variations of different tilt angles (0^0 – 40^0) at different fin spacing i.e. at s= 6 mm, s= 11 mm and s= 16 mm and different values of Rayleigh's Number is shown in the graph.

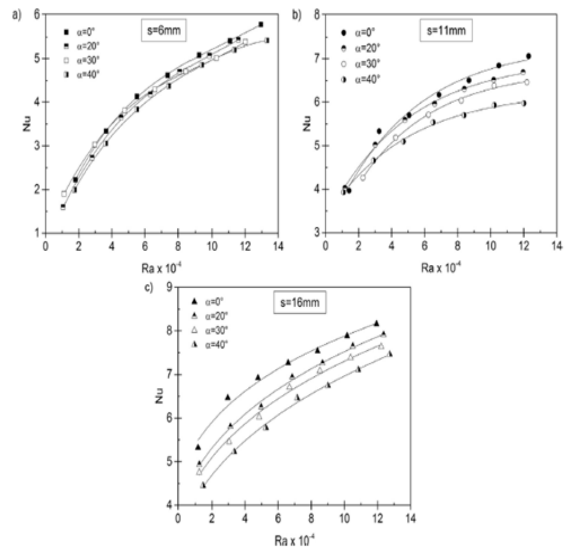

Fig. 1 : Variation of tilt angle at different fin spacing at various Rayleigh's Number.

M. Ashjaee et.al [7] the heat transfer Nusselt Number equation for different axis ratios By using Mach-Zehnder Interferometery (MZI) technique.. The axis ratios should be taken to be ε = 0.53, 0.67, 0.8 and 1. In this apparatus, a light source having 10mW is used. A He-Ne laser beam with its wavelength of 632.8 mm.

From the uncertainty analysis, the modified Nusselt Number obtained from the experiment as,

$$Nu_\infty = 0.711 - 0.136\,\varepsilon$$

The relation for maximum Nusselt Number at the optimum wall spacing can be obtained as,

$$Nu_{max} = 0.206 + Nu_\infty$$

In an experimental study done by K Kamajaya et.al [8] works on the same concept but here water-Al_2O_3 a nanofluid is used as a working fluid. This working fluid is compared with water-ZrO_2. In this setup, the diameter ratio is taken to be 1:16. The setup is held vertically with triangular geometry over it. The Nusselt Number equation is found to be –

$$Nu = 15.97\left(Ra\ \frac{D_h}{x}\right)^{0.2778}$$

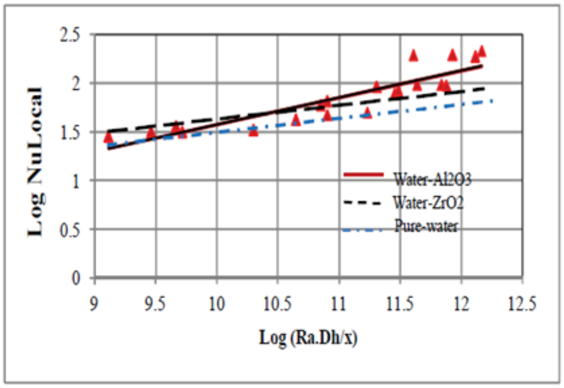

Fig. 2: Variations of water-Al_2O_3, water-ZrO_2 nanofluid and pure-water with nussel Number.

The result found to be the heat transfer coefficient was increased by 5-10 % for the working fluid than the pure water.

1.2. Numerical study on elliptical surfaces:

There is also some numerical study done for the elliptical cylinder is done for the different inclination of the tube [9-11]. A numerical approach is done by Young min seo et.al [9] to find the effects on heat transfer for various inclinations. In This Immersed Boundry Method (IBM) was used to capture the virtual wall boundary of the inner cylinder which is based on the Finite Volume Method (FVM).

This study concludes that the value of Nusselt Number increase monotonically from 0^0 to 45^0 for all mean radius and rapidly increase from 45^0 to 90^0.

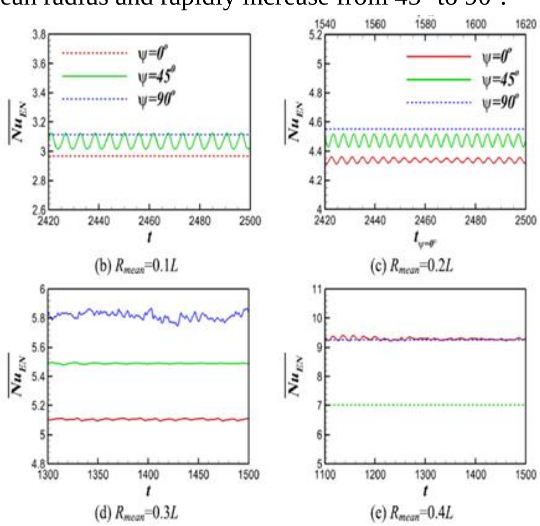

Fig. 3: Nusselt Number variation for different value of mean radius

There is another numerical study done for natural convection between two elliptical cylinders by A. Bouras et.al [10]. This study works on Boussineq Square approximation and the Vorticity-Stream function formulation, the flow is modeled by a differential equation of partial differential for continuity and momentum equation for the elliptical body.

The average Nusselt Number obtained for various inclinations is obtained as,

$$Nu_{avg} = \frac{1}{\theta_N - \theta_1}\int_{\theta_1}^{\theta_N} Nu\, d\theta$$

Where $T^+ = \frac{T-T_2}{T_1 - T_2}$, T is the top wall temperature and $T_1 > T_2$

Also in the study of mohamed Issam Elkhazen et.al [11], works for different eccentricities ranges from 0.4 to 1. The value of Rayleigh Number ranges from 10^2 to 10^5. From this study one should choose the value of eccentricity between 0.4 to 1 for getting the best effect on heat transfer and fluid flow.

III. EXPERIMENTAL SETUP

The experimental set up consists of a copper elliptical cylinder and it is placed between two mild steel vertical plates whose dimensions are major diameter of 80 mm, minor diameter of 20 mm and the length of 300 mm. The cylinder is coated with aluminum foil in order to prevent from short circuit. The outside surface of the vertical plate is insulated using Jute cord (Asbestos) and from outside thin sheet of aluminum material. The inclined cylinder is heated using nichrome wire which is wounded around the outer surface of the cylinder as shown in figure given below. The elliptical cylinder surface is of neither uniform heat flux nor isotherm. These conditions are most practical. The heat flux supplied was varied from $25.13 w/m^2$ – $2067.03 w/m^2$.The thermocouples were placed along the circumference of inclined cylinder. Some copper tubes are made to hold the thermocouple. For varying inclination, a screw arrangement is made which is connected to inclined cylinder, so as to ease to set a desired inclination of cylinder.

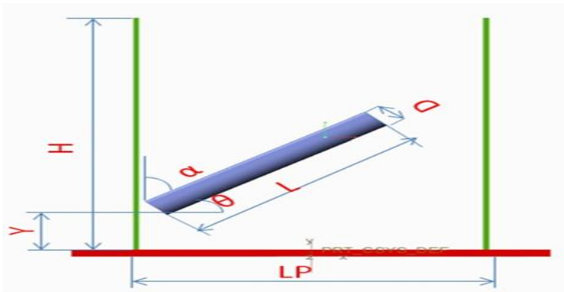

Fig. 4 - Proposed experimental setup

The heat input is supplied with the help of dimmer stat (0 – 270 Volt AC supply). The corresponding voltage and current are recorded with the help of pre-calibrated voltmeter and ammeter with the accuracy of ± 2% in the range of interest. All the temperatures were measured by means of K-type thermometers (copper constantan thermocouple sensors) since it is used in all the research papers of literature view hence it is selected. The thermocouples measuring cylinder surface temperature were checked by taking readings of all the thermocouples without supplying power to the heater. It was found that all the thermocouples were indicating the same temperature which was equal to the room temperature.

In order to identify the specific test section in terms of cylinder inclination, aspect ratio and elevation of cylinder from bottom a code is defined as follows.

XX-YY-ZZ

Where XX indicates cylinder inclination, YY indicates aspect ratio; ZZ indicates elevation of cylinder from bottom.

IV. OPERATING PROCEDURE

- The cylinder was adjusted for the desired inclination, aspect ratio and elevation from the bottom.
- The heater was switched ON and the heat flux was adjusted with the help of a calibrated dimmer-stat.
- The heat supplied was measured with a pre-calibrated voltmeter and ammeter.
- The entire system was run till steady state conditions were reached i.e. (when the temperatures indicated by the thermocouples read more or less the same value for two or more successive observations).
- The steady state data obtained and calculations done.

V.ANSYS SIMULATION

The experiment was conducted for 0^0, 30^0, 45^0, 60^0 and 90^0 and the value of voltage increased from 5V to 50V in the interval of 5V. An ANSYS simulation is done to know the percentage of error obtain experimentally and during computer analysis. There is a good agreement between simulated data and available experimental data. The graphs for heat transfer are given below:

Case 5.1.1: 0-0.88-7.5 (Heat flux Q = 18.15 W/m^2)

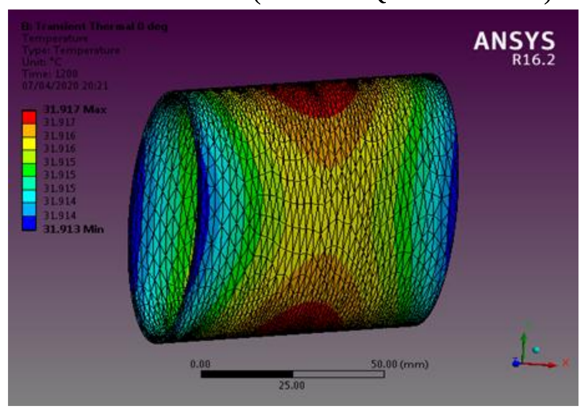

Fig. 5.: Heat flux at 0 degree at low heat input

Case 5.1.2:0-0.88-7.5 (Heat flux Q = 532.25 W/m^2)

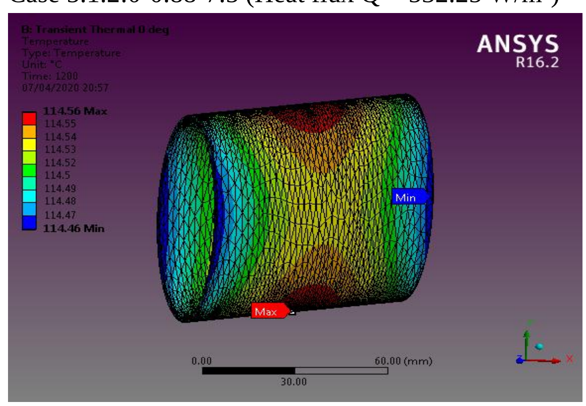

Fig. 6 : Heat flux at 0 degree at high heat input

Case 5.2.1:30-0.88-7.5 (Heat flux Q = 18.15 W/m^2)

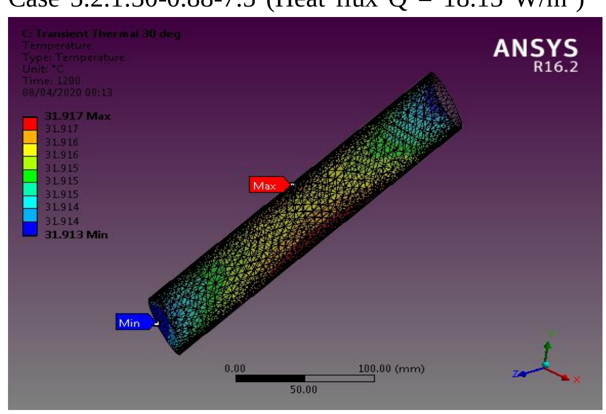

Fig. 7: Heat flux at 30 degree at low heat input

Case5.2.2 :30-0.88-7.5(Heat flux Q= 532.25 W/m^2)

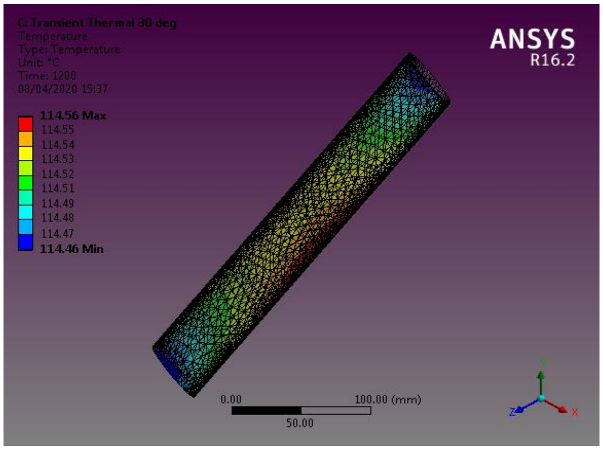

Fig. 8 : Heat flux at 30 degree at high heat input

Case 5.3.1: 45-0.88-7.5(Heat flux Q = 18.15 W/m^2)

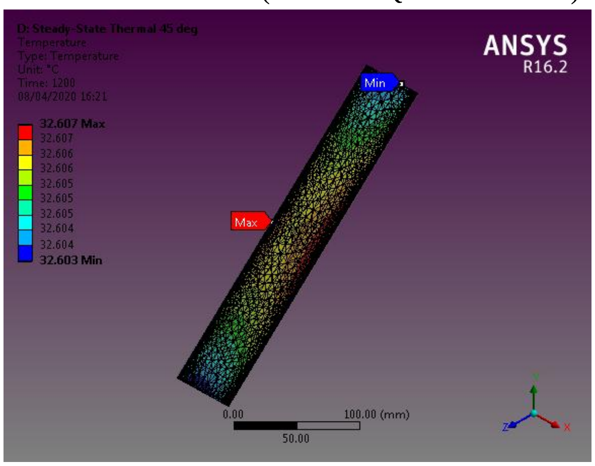

Fig. 9 : Heat flux at 45 degree at low heat input

Case 5.3.2:– 45-0.88-7.5 (Heat flux Q = 532.25 W/m^2)

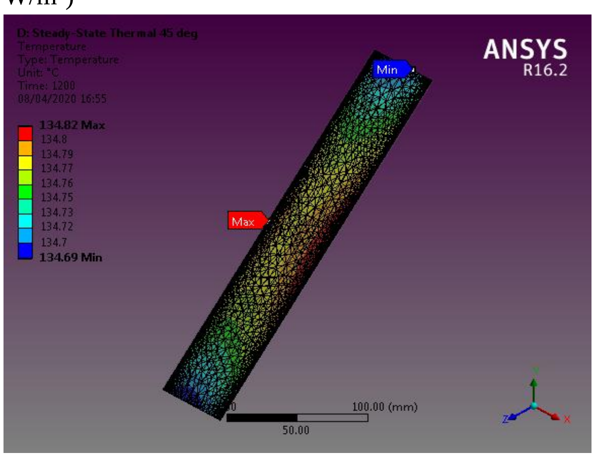

Fig. 10 : Heat flux at 45 degree at high heat input

Case 5.4.1:– 60-0.88-7.5 (Heat flux Q = 18.15 W/m^2)

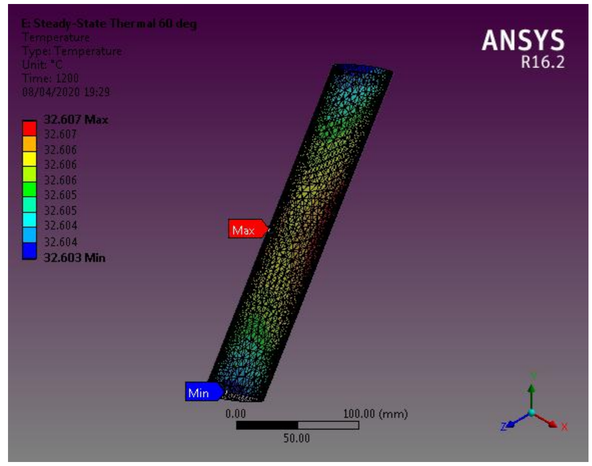

Fig. 11 : Heat flux at 60 degree at low heat input

Case 5.4.2: 60-0.88-7.5 (Heat flux Q = 532.25 W/m^2)

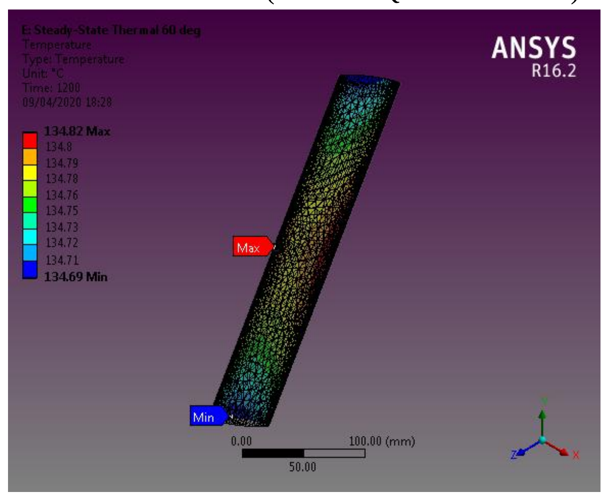

Fig. 12 : Heat flux at 60 degree at high heat input

Case 5.5.1:– 90-0.88-7.5 (Heat flux Q = 18.15 W/m^2)

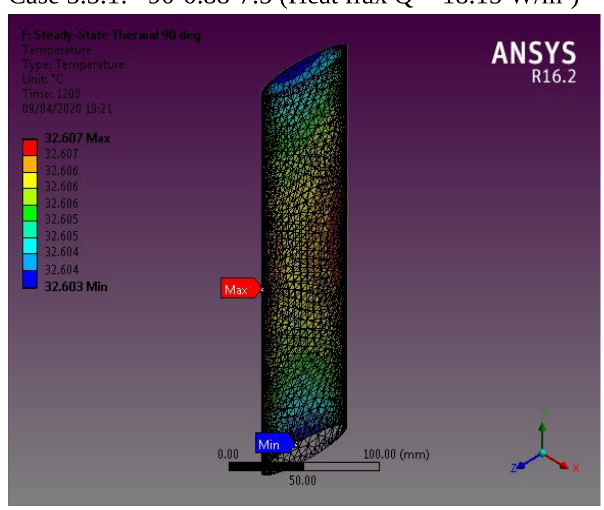

Fig. 13 : Heat flux at 90 degree at low heat input

Case 5.5.2:– 90-0.88-7.5 (Heat flux Q = 532.25 W/m^2)

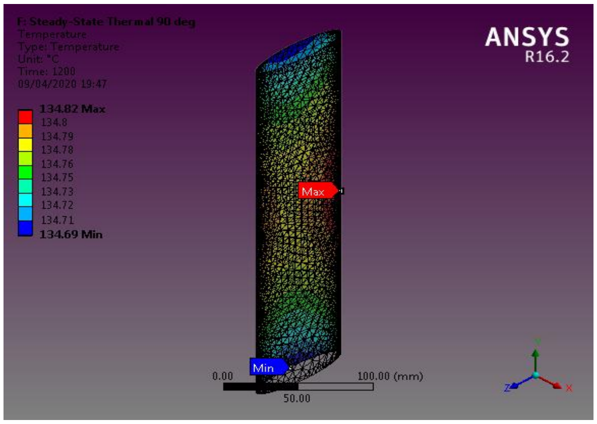

Fig. 14 : Heat flux at 90 degree at high heat input

The above graphs are shown for lower and high heat input which shows that heat transfer occurs maximum at the middle and minimum at the corners of the elliptical cylinder. Also it shows the minimum and maximum temperature at different heat inputs and at various inclinations of the elliptical cylinder.

VI.CONCLUSION

Form the above experiment, it is conclude that,

- Heat transfer coefficient is strongly influenced by the heat flux. As the heat flux increases the heat transfer is also increases and as the value of Nusselt number too.
- The inclinations of Elliptical cylinder also affects the heat transfer coefficient, it was obtained experimentally and also by CFD analysis that the value of heat transfer coefficient increases gradually from 0^0 to 45^0 but its value reduced after 45^0 upto 90^0.
- From the findings a correlation of heat transfer is obtained and it is given as,

$Nu = 170.8 \; Ra^{-0.006}$

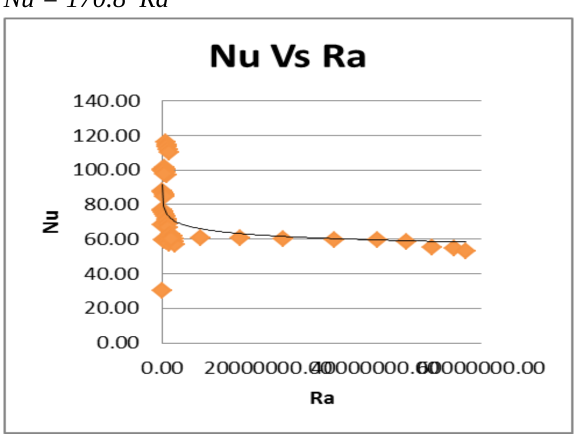

Fig. 15 : Experimental graph between Nu and Ra

Further, the validation of experimental results with CFD simulation is found to be in close agreement. i.e. (±10%) for all configurations

VII. SCOPE FOR FUTURE WORK

The present study needs to be extended further as suggested below.

1. The similar experimental data should be generated for air operating under Forced convection mode.
2. The horizontal cylinder of different shapes such as square, triangular can be used to predict the heat transfer characteristics.
3. Cylinder with internal fins can also be used to predict the heat transfer characteristics.
4. The variations in results can be studied by varying aspect ratio and height of the cylinder to be placed from bottom.

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