

# A Review on Parametric Investigation of Heat Transfer through Inclined Elliptical Geometry

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**Abstract:** Natural convection has been broadly studied for different engineering applications. The cylindrical and rectangular objects are already estimated and it is implemented in the practical use of heat transfer but there are again too many shapes are available from which more amount of heat transfer is obtained than circular surfaces. The work on the elliptical surface needs to enhance because it receives great results than circular surfaces. From the study, For elliptical tube the best heat transfer obtained at an inclination of  $40^\circ$  and for the axis ratio of 1:4. The tube is cooled naturally and the analysis is done on it. From various results, a Nusselt Number equation is obtained, from which the amount of heat transfer is attained for natural convection. Nusselt Number equation is to obtain experimentally or by mathematical modeling. The variation in the result is compared by CFD simulations.

**Keywords:** Natural Convection, Heat transfer, Elliptical surfaces, axis ratio, inclinations.

## I. INTRODUCTION :

Convection is a source of heat transfer that transmits heat from hot surfaces to cold surfaces. The convection broadly classified in Natural Convection and Forced Convection. Many pieces of research have been done on this convection phenomenon. Researchers mainly interested to find out the amount of heat transfer through convection medium. For that mathematical equation of Nusselt Number are made by some experimental research. This study is for finding such a mathematical equation of heat transfer for various geometries.

Generally, the equation of Nusselt Numbers for cylindrical, spherical, Rectangular shape is done and that is for only at the inclination of  $0^\circ$  and  $90^\circ$  in natural as well as forced convection. But the question arises what should be changed in heat transfer when these objects are taking at different inclinations? There are some researches are done where experimental or Numerical Modeling are done for the cylindrical surface at different inclinations [1], [2]. By this research, they conclude various equations of Nusselt Number so that to find the amount of heat transfer easily.

As some researchers studied natural convection phenomenon on cylindrical geometries and they got some positive results and found the amount of heat transfer through cylindrical geometries by making a Nusselt Number equation [1], [2]. But there are again some more geometry is available other than this. In this study, there is mainly focus on heat transfer through elliptical bodies. 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  $60^\circ - 90^\circ$  and it should be minimum at an angle of  $0^\circ - 30^\circ$  at an axis ratio of 1:3 and the value of Reynolds 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  $10^6$ .

### Nomenclature :

Nu	Nusselt Number ( $hd/k$ )	T	Top wall temperature ( $^\circ\text{C}$ )
Ra	Rayleigh's Number ( $g\beta\Delta TD^3/\alpha\theta$ )	$T_1$	Outer wall temperature ( $^\circ\text{C}$ )
Gr	Grashoff's Number ( $g\beta\Delta TD^3/\theta^2$ )	$T_2$	Inner wall temperature ( $^\circ\text{C}$ )
Pr	Prandtl number ( $\theta/\alpha$ )	$\alpha$	Inclination angle ( $^\circ$ )
Re	Reynolds Number ( $\rho vd/\mu$ )	$\eta$	direction of inclination in A. Bouras
h	Heat Transfer Coefficient ( $\text{W}/\text{m}^2\text{K}$ )	et.al	
C	Circumference (m)	$\theta_N$	Elliptical tube final ( $^\circ$ )
dh	Hydraulic Diameter (m)	$\theta_i$	Elliptical tube initial ( $^\circ$ )
D	Diameter (m)		
R	Radius (m)	<b>Suffix :</b>	
$\varepsilon$	Axis Ratio	X	Local
s	Fin spacing (m)	Avg	Average
H	Dimensional metric coefficient (m)	max	Maximum
e	Eccentricity	$\infty$	Atmospheric
$\theta$	Kinematic Viscosity ( $\text{m}^2/\text{s}$ )		
U	Velocity (m/s)		

### 1.1 Pre-research on cylindrical surfaces.

Before starting on the research on elliptical surfaces first research on cylindrical surfaces had been done. Samuel S. Goodrich et.al [1] done an experimental study find the effect of radius of curvature on heat transfer and boundary layer transition from laminar to turbulent flow on vertical heated cylinders with heat flux boundary. For this study they used five heaters having diameters ranging from 6.4 to 25.4 mm with a length of 762 mm at the beginning from the sealed tip and a total length of 914 mm. also K-type thermocouple inserted in the full length of the rod and withdrawn it with the use of the clamp. This study works on the value of Rayleigh Number ranges from  $10^{10}$  to  $10^{11}$ . They made an algorithm for finding the correlations. From this study, the local heat transfer coefficient found to be -

$$Nu_x = 0.408 \left( 1 + \frac{20.6}{Ra_D^{0.25}} \right) Ra_x^{0.207}$$

The experimental study on natural heat transfer was also done by T. Fujji et.al [2]. For this study, they used the 'Mirage Method'. The Mirage Method works on the phenomenon of, The light beam is curved more when it passes through nearer to the heated cylinder because the refractive index of the fluid in the boundary layer decreases with temperature rise.

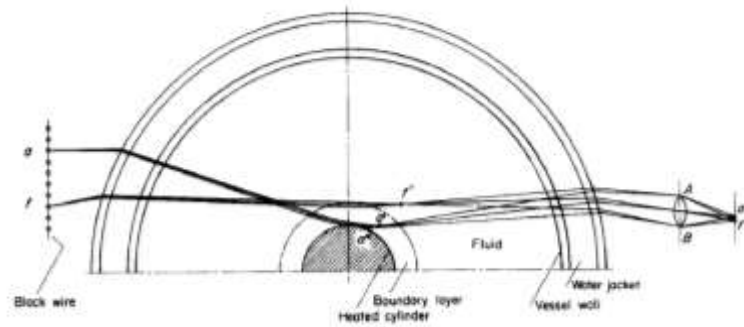


Fig 1 : Miraj Method.

In this, natural convection heat transfer study on vertical cylinder observed on water, Spindle Oil, Mobiltherm Oil. The Prandtl Number is taken in the range of 2-300,  $[Gr, Pr]_e = 5 \times 10^7$  to  $5 \times 10^{12}$  and  $[Gr, Pr]_\infty = 9 \times 10^6$  to  $2 \times 10^{12}$ . From this experiment, the result for the equation for Nusselt Number for natural convection is found to be –

For water,

$$Nu_{x,e} = 0.130 [Gr_x, Pr]_e^{\frac{1}{3}} \quad - (4 - 8) \times 10^{10} \leq [Gr_x, Pr]_e$$

$$Nu_{x,e} = 0.215 [Gr_x, Pr]_e^{\frac{1}{4}} \quad - (1 - 7) \times 10^{13} \leq [Gr_x, Pr]_e$$

For spindle Oil and Mobiletherm Oil, the equation are,

$$Nu_x = 0.87 [Gr_x, Pr]_e^{\frac{1}{4}}$$

For spindle oil,  $8 \times 10^{10} \leq [Gr_x, Pr]_e \leq 6 \times 10^{11}$

For Mobiletherm Oil,  $(2 - 4) \times 10^{11} \leq [Gr_x, Pr]_e$

Also ,

$$Nu_x = 0.90 [Gr_x, Pr]_e^{\frac{1}{3}}$$

For spindle oil,  $(4 - 8) \times 10^{13} \leq [Gr_x, Pr]_e \leq 5 \times 10^{14}$

For Mobiletherm Oil,  $(2 - 4) \times 10^{14} \leq [Gr_x, Pr]_e$

## 1.2 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 ( $0-40^\circ$ ) with fins on it. The fin spacing should be about 6 mm to 16 mm and Rayleigh Number should in the range of 11,000 – 130,000. The major axis of the oval tube is taken as 34 mm and the minor axis is 16 mm. the experiment is done at different tilt angles from  $0^\circ$  to  $40^\circ$  has been done at various fin spacing as  $S= 6$  mm,  $S= 11$  mm and  $S = 16$  mm. the oval tube takes in a cuboidal vacuum chamber with twelve K- type thermocouple installed on it. The input source of current  $I = \pm 0.014$  A and  $V = \pm 0.3$  V is supplied to the system. After the experiment, the correlation found to be -

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

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

The variations of different tilt angles ( $0^\circ - 40^\circ$ ) 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.

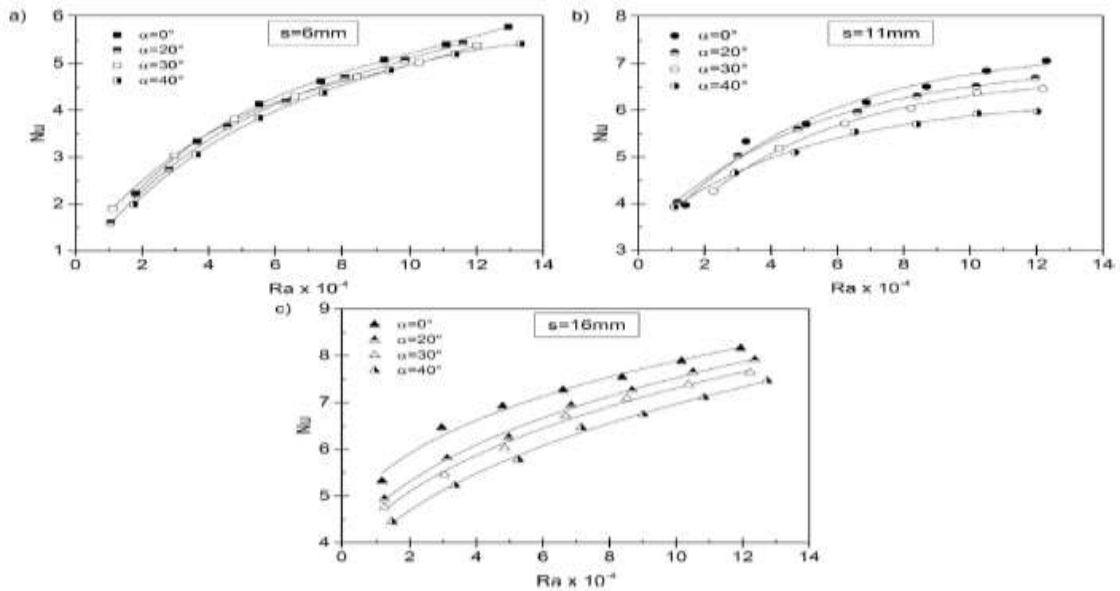


Fig. 2 : Variation of tilt angle at different fin spacing at various Rayleigh’s Number.

Before this study, in 1983, Terukazu OTA et.al [3] done an experimental analysis on an elliptical cylinder, where the correlation of Nusselt Number is obtained. The experimental apparatus consists of an elliptical cylinder that is taken at the axis ratio of 1:3. The major axis is 50 mm and the length of the tube is 150 mm. it was made up of Reinforced fiber Plastic material. The heating is done by a 0.05 mm thick and 29 mm wide Stainless Steel sheet which is wound helically and stuck on the elliptical surface. There are 41 copper constant thermocouples of 0.07 mm diameter were embedded in the cylinder. The value of Raynolds Number should be within the range of 8000 to 79000 and tilt should be taken as 0<sup>0</sup> - 90<sup>0</sup> from the horizontal surface. The outside velocity was to be in the range of 2 to 22 m/sec. The value of Raynolds number was estimated from the formula -  $Re = \frac{U_{\infty} C}{\nu}$ , where C is the circumference of the tube. An FFT analyzer is used to detect the Vortex shading frequency from the output voltage anemometer. The correlation was found to be after the result and it is given as –

$$Nu_{avg} = A Re^n$$

Here the value of n and A changes naturally with different tilt angles and its values are given in the table below –

Table 1: Value of n and A for different tilt angles.

$\alpha$	n	A
0	0.539	0.546
15	0.492	0.839
30	0.461	1.178
45	0.532	0.70
60	0.546	0.684
75	0.549	0.671
90	0.548	0.671

The result obtained as the value of Nusselt Number found to be maximum from the tilt angle of 60<sup>0</sup> to 90<sup>0</sup> and a minimum at a tilt angle of 0<sup>0</sup> to 30<sup>0</sup>.

The value of heat transfer is also estimated by experimental research of Amr O. Elsayed et.al [4], where an elliptical tube having a 90 mm major axis and 50 mm minor axis with a length of 1000 mm is used. A cylindrical heater with a 10 mm diameter is placed inside the tube at its center as a heating element. The gap between the heater and the cylinder is filled with fine sand. Eight Copper constantan thermocouple of 0.5 mm diameter is used at its periphery. The tube is rotated with an increment of 45<sup>0</sup> from the horizontal surface. The tube is rotated up to 180<sup>0</sup>.

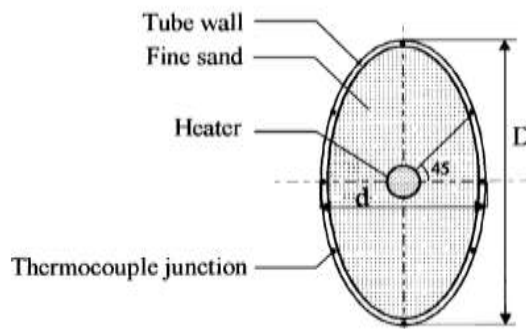


Fig. 3 : Elliptical tube with different thermocouple.

The tube is heated and kept for 3 to 4 hrs. the maximum variation of thermocouple recorded as 0.2°C. also, ambient room temperature is recorded. After the experimental study, the result obtained as the value of heat transfer is minimum at an angle of 0° and maximum at 180°. The value of minimum heat transfer is 0.054 KW/m² with a temperature difference of 1.5°C and maximum heat transfer is 1.2 KW/m² with a temperature difference of 18.50C. the value of average Nusselt number is found to be

$$Nu_{avg} = 0.47 Ra^{0.2} \quad 1.1 \times 10^7 \leq Ra \leq 8 \times 10^7$$

This equation is fitted in Nusselt Rayleigh Correlation as-

$$Nu_{avg} = 0.394 Ra^{0.25} \quad 9 \times 10^5 \leq Ra \leq 4 \times 10^6$$

M. Ashjaee et.al [7] the heat transfer Nusselt Number equation for different axis ratios. By using Mach-Zehnder Interferometry (MZI) technique the local and average Nusselt numbers were determined for several tube axis ratios. The axis ratios should be taken to be ε = 0.53, 0.67, 0.8 and 1. The value of Rayleighs Number should be in the range of 1000-2750 and wall spacing from 1.25 to infinite. In this apparatus, a light source having 10mW is used. A He-Ne laser beam with its wavelength of 632.8 mm.

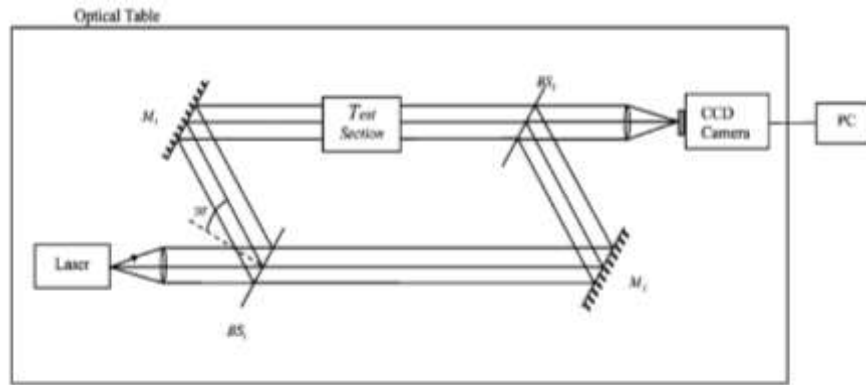


Fig. 4 : Plan view of apparatus setup by Mach-Zehnder Interferometry (MZI) technique .

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

$$Nu_{\infty} = 0.711 - 0.136 \epsilon$$

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

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

There is again an experimental study done by K Kamajaya et.al [8] works on the same concept but here water-Al<sub>2</sub>O<sub>3</sub> a nanofluid is used as a working fluid. This working fluid is compared with water-ZrO<sub>2</sub>. In this setup, the diameter ratio is taken to be 1:16. The setup is held vertically with triangular geometry over it. The heating power should be varied in the range of 250 W, 350 W, 500 W, 650 W, 750 W, 850 W. After the experiment the Nusselt Number equation is found to be –

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

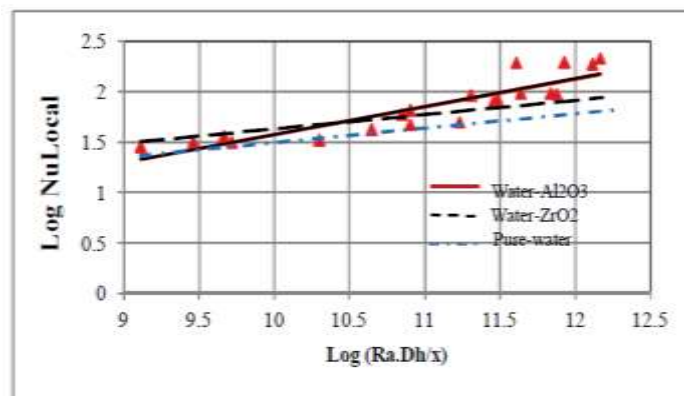


Fig. 5 : Variations of water-Al<sub>2</sub>O<sub>3</sub>, water-ZrO<sub>2</sub> nanofluid and pure-water with nussel Number.

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

### 1.3. 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. A numerical approach is done by Young min seo et.al [9] to find the effects on heat transfer for various inclinations. In this 3-D numerical simulations is done for the natural convection where a hot elliptical tube is enclosed in a long rectangular enclose. 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).

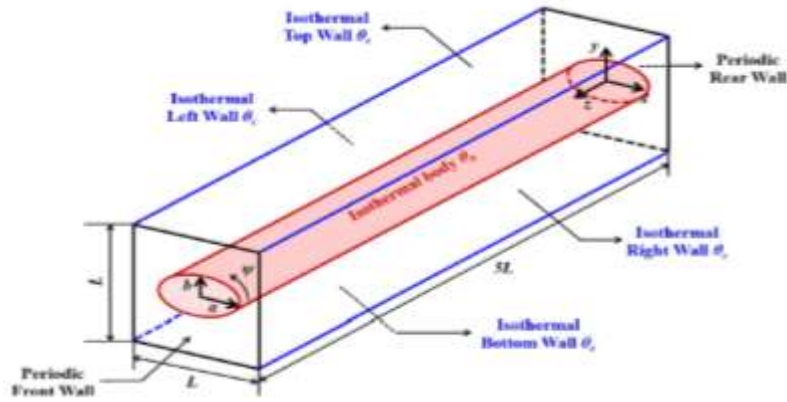


Fig. 6 : computational domain model for the study

The study is done for various mean radius as 0.1L, 0.2L, 0.3L, 0.4L. The value of Rayleigh’s Number varies from the range of  $10^4$  to  $10^6$  and for the value of Prandtl Number to be 0.7. The tube is inclined from  $0^\circ$  to  $90^\circ$  in the anticlockwise direction from the horizontal surface. This study concludes that the value of Nusselt Number increase monotonically from  $0^\circ$  to  $45^\circ$  for all mean radius and rapidly increase from  $45^\circ$  to  $90^\circ$ .

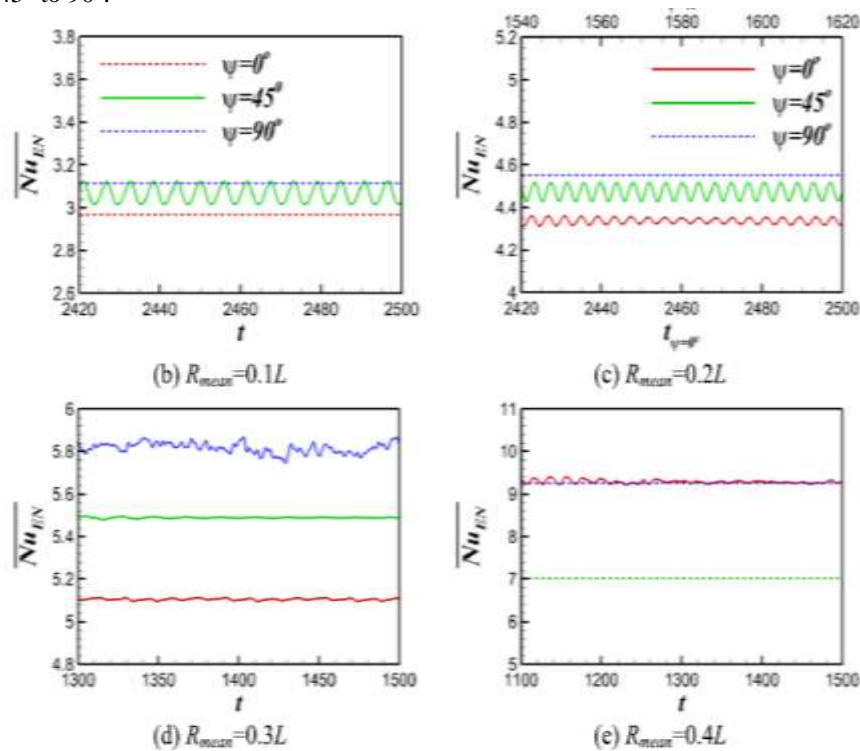


Fig. 7 : Nusselt Number variation for different value of mean radius

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.

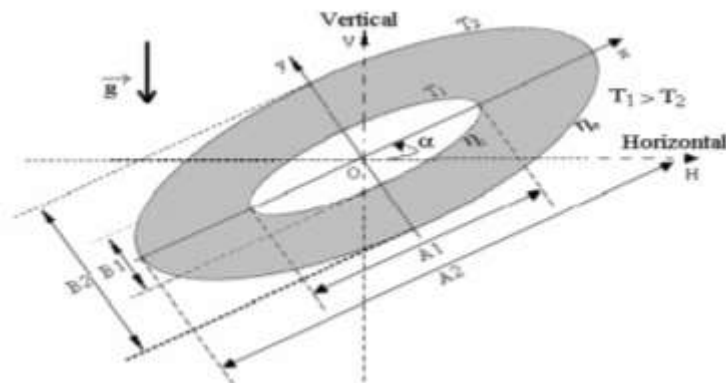


Fig. 8 : cross section of the model.

In this, the study is done for two directions i.e.  $\eta$  and  $\theta$  direction where the elliptical tube is heated externally so that the outer temperature is greater than inner as shown in fig.  $T_1 > T_2$ . A mathematical equation obtained for various inclinations of the elliptical tube is given as,

$$Nu = -\frac{1}{H} \frac{\partial T^+}{\partial \eta}$$

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 H is the Dimensional Metric Coefficient (m) and  $T^+ = \frac{T - T_2}{T_1 - T_2}$ , T is the top wall temperature.

The results obtained from the study is showing in the following table –

Table 2 : Result for various inclinations with different Ra

Eccentricity $e_1$	Eccentricity $e_2$	Angle $\alpha$	Ra	Nu (inner)	Nu (outer)
0.86	0.4	90 <sup>0</sup>	10 <sup>4</sup>	3.72	1.37
0.86	0.4	90 <sup>0</sup>	4.10 <sup>4</sup>	4.86	1.80

Again a 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 102 to 105. From this study the effect of eccentricity on the heat transfer obtained. It is found that the eccentricity affects the parameters on heat and fluid flow. The mean Nusselt Number increases with increasing Rayleigh Number. Hence once should choose the value of eccentricity between 0.4 to 1 for getting the best effect on heat transfer and fluid flow.

## II. PROPOSED METHODOLOGY :

A method is to be implemented to find the correlation for Nusselt Number to obtain the heat transfer. A proper experimental setup with low cost is to be maintained. A method to be employed for the obtaining correlation is explained as –

- A setup is needed to make for heating of the elliptical tube which is confined between two walls.
- This elliptical tube is well insulated so that the heating of the tube does not disturb.
- This tube is tilted for various inclinations from 0<sup>0</sup> to 180<sup>0</sup> at a short interval of time so that proper heat transfer at various inclinations is observed properly.
- The surface temperature is measured through various K-type thermocouple also the atmospheric temperature is also measured.
- By using different values of heat transfer the equation for Nusselt Number is to be estimated.
- This equation is then verified by CFD simulation.
- The error in the equation need to be observed.

## III. PROPOSED CONCLUSION :

The review observed from the above discussion conclusion obtain are given as follows –

- The axis ratio of the elliptical tube is to maintain up to 3.5mm to 4mm to obtain a proper heat transfer ratio than a circular tube. As the axis ratio is maintained in this range then the average Nusselt Number is increased up to 11%.
- The tube made is properly insulated by proper insulating material so that the heating of the tube should be proper and its topmost layer is to be cover by proper material.
- Different thermocouples at proper inclinations are to be provided on the elliptical tube so that the minute variations in the temperature on the surface of the tube are found out easily.
- The proper natural convection needs to occur so that uniform heat transfer is to be obtained.
- From the various above analyses, it is observed that at an angle of 45<sup>0</sup> the average Nusselt Number should be obtained maximum. The heat transfer increases monotonically from 0<sup>0</sup> to 45<sup>0</sup> and rapidly increases after 45<sup>0</sup>.
- The tube is heated for different heating powers then different values of Nusselt Numbers are obtained. For Water-Al<sub>2</sub>O<sub>3</sub> nanofluid, a working substance obtains the best result than pure water. For Water-Al<sub>2</sub>O<sub>3</sub> nanofluid the heat transfer coefficient increase by 5-10% than of pure water.

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