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Parametric Studies on Heat Transfer by Natural Convection from Inclined Cylinder Placed Between Vertical Insulated Plates

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Abstract: Natural Convection flow in a vertical channel with internal objects is encountered in several technological applications of particular interest of heat dissipation from electronic circuits, refrigerators, heat exchangers, nuclear reactors fuel elements, dry cooling towers, and home ventilation etc. Experiments were carried out to investigate natural convection heat transfer in an inclined uniformly heated circular cylinder. The effects of surface heat flux, angle of inclination, aspect ratio (the ratio of length of inclined cylinder to the spacing between vertical plates) and elevation of inclined cylinder from bottom plate on the heat transfer coefficient are discussed. The parameters varied during the experimentation are heat flux ranges from 25.13 W/m² to 2067.03 W/m², inclination of cylinder between 30° to 70° measured from vertical position, aspect ratio for 0.88, 0.78 and 0.71 and elevation from bottom is 7.5cm, 10cm and 15cm. An empirical correlation is presented in the form Nu =C Ra*n and valid for Rayliegh number between 9.4x103 - 2.4x105 and Prandtl number 0.7. The experimental results will also be validated with CFD simulation within ±10% (ANSYS SOFTWARE).

Keywords: **Natural convection, inclined cylinder, Vertical plate, Aspect ratio, CFD simulation.**

I. INTRODUCTION

Free convection is the process of heat transfer which occurs due to movement of the fluid particles by density changes associated with temperature difference in fluid. Natural convection heat transfer phenomena are two dimensional on vertical and horizontal cylinders but are three dimensional on inclined cylinders due to the circumferential and axial developments of the boundary layers making the flow as well as heat transfer behaviour complex. A number of correlations are available in literature for the estimation of natural convection heat transfer from vertical as well as horizontal cylinders, but little work has been reported on the effect of cylinder inclination on the mean heat transfer coefficient. Inclination of containers filled with fluid, inside which convective heat or mass transfer occur, may have either desirable or undesirable effects depending on the application.

Natural convection from cylindrical surface is given much attention in recent days due to its easy and cheap manufacturing capability and its practical utility in many applications. Its application is found generally in heat pipe, refrigeration system, solar energy, extended surfaces, thermal design of the buildings and power generation application. In the present scenario the electricity generation is costly and electricity generation method causes harmful effect on the environment. Other important reason for the study of natural convection is that if the system is cooled by forced convection and power failure occurs in such a situation natural convection phenomena becomes very important for the equipment safety.

II. LITERATURE REVIEW

A. Natural Convection from Cylinder

Your Samane Hamzekhan, Amir Akbari, Majedeh Maniavi Falahieh, Mohammad Rasoul Kamalizadeh and Mohammadreza Fardinpouron [1] conducted experimental studies on free convection heat transfer from the outside surface of an inclined cylinder for water and glycerol was experimentally investigated at different heat flux. For all test fluids, experimental results show that average Nusselt number decreases with increasing inclination of the cylinder to the horizontal at constant heat flux. A new model for the prediction of average Nusselt number, in free convection from the outside surface of an inclined cylinder is proposed, which predicts the experimental data with a satisfactory accuracy.

Dr.Akeel A. Mohammed, Dr. Mahmoud A. Mashkour and Raad Shehab Ahmed [2] research on natural convection heat transfer in an inclined circular cylinder. In this the effects of surface heat flux and angle of inclination on the temperature and local Nusselt number variations along the cylinder surface are discussed. The investigation covers heat flux range from 92 W/m² to 487 W/m², and angles of inclination 0° (horizontal) , 30°, 60° and 90° (vertical) . Results show an increase in the natural convection as heat flux increases and as angle of inclination moves from vertical to horizontal position. An empirical equation of average Nusselt number is as a function of Rayliegh number was deduced for each angle of inclination.

In another study M. Al-Arabi and Y. K. Salman [3] research on laminar natural convection heat transfer from an inclined cylinder. In this research work laminar natural convection heat transfer from the outside surface of a uniformly heated cylinder (constant heat flux condition) was investigated experimentally at different angles of inclination of the cylinder. General equations for the effect of inclination were determined for both the local and the average heat transfer. From the above work it is concluded that for the same flux both the local and the average heat-transfer coefficients increase with the angle of inclination of the cylinder. The minimum value occurs in the vertical position and the maximum value in the horizontal position. Moreover, the end of the laminar region, expressed as Gr, Pr increases with the angle of inclination.

Neetu Rani, Hema Setia, Marut Dutt and R.K.Wanchoo [4] conducted research work on natural convection heat transfer from inclined cylinders: a unified correlation. This work stipulates an empirical correlation for predicting the heat transfer coefficient for a cylinder under free convection, inclined at any arbitrary angle with the horizontal has been developed in terms of Nusselt number, Prandtl number and Grashoff number. The proposed correlation predicts the available data well within ±10%, for Prandtl number in the range 0.68-0.72 and Grashoff number in the range 1.4×104–1.2×1010. It is further concluded that from the above discussion that present correlation is a unified equation which can be applied to predict the natural convection heat transfer from all horizontal, vertical and inclined cylinders.

T.V.S.M.R.Bhushan and K.Vijaya Kumar Reddy [5] experimentally investigated the natural convection heat transfer from inclined square ducts. Experiments have been conducted in still air with duct oriented at an angle of 45O. In the present study two ducts having different area ratio are considered and uniform heat flux conditions are maintained. Variable heat inputs are applied to the centrally located resistance heating element in order to understand convection phenomenon in laminar and transition regions. Experimental data have been reduced in terms of Nusselt and modified Rayleigh numbers, Local values are evaluated by considering axial distance and average values by using square side length. Correlations were proposed in terms of local and modified Nusselt and modified Rayleigh numbers. Comparison of Experimental results with those reported in the literature pertaining to vertical cylinders is observed to be in close conformity.Furthermore, it is concluded convective heat transfer coefficients are on the lower side in the mid portion of the duct while they are on the higher side at the entrance ends that is heat transfer coefficient decreases from the end to the center of the duct. Moreover modified Rayleigh number is calculated by considering the tangential component of the gravitational component and the correlations were proposed between local Nusselt number and modified Rayleigh number with a power law fit.

Manmatha K. Roul and Ramesh Chandra Nayak [6] performed experimental investigation of natural convection heat transfer through heated vertical tubes. In their experimental work it was interpreted that the effects of L/D ratio and wall heating condition on local steady-state heat transfer phenomena are studied. The effects of ring thickness and ring spacing on heat transfer behavior are observed. The present experimental data is compared with the existing theoretical and experimental results for the cases of vertical smooth tubes and also for tubes with discrete rings. The natural convection heat transfer in heated vertical ducts dissipating heat from the internal surface is presented. From the experimental Investigation it was conclude that average heat transfer rate from the internal surfaces of a heated vertical pipe increases with providing discrete rings. Moreover average heat transfer rate increases with increasing the thickness of the rings up to a certain limits, beyond which it decreases. Finally, average heat transfer rate increases with increasing the number of rings i.e. reducing the spacing between the rings up to a certain value of spacing, but further reduction in spacing, reduces the heat transfer rate from the internal wall to air.

Ali F. Hasobee and Yasin K. Salman [7] investigate natural convention heat transfer inside inclined open cylinder. In this work natural convection is investigated experimentally in an inclined open cylindrical passage heated under constant heat flux condition to study the effect of angle of inclination and heat flux on heat transfer. Heat transfer results are given for inclination angles of 0o (horizontal), 30o, 60o and 90o (vertical).Using cylinder diameter of 4.8 cm, cylinder length 50 cm and heat flux from 70 W/m2 to 600 W/m2. Empirical correlations are given for the average Nusselt number as a function of the Rayleigh number. The results show that the local and average Nusselt number increase as the heat flux increase and when angle of inclination changed from 0o (horizontal) to 90o (vertical). An empirical correlation of average Nusselt number is as functions of Rayleigh number were obtained.

Sparrow and Lee [8] considered the problem of mixed convection boundary layer flow about a horizontal circular cylinder. They obtained a similarity solution for the aiding flow by expanding velocity and temperature profiles using power-law type expressions

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of the distance from the lowest point of the cylinder. The local Nusselt number distribution was only obtained in the region upstream of the point of separation.

Mohammed and Salman [9] performed an experiment to study the local and average heat transfer by mixed convection for hydro dynamically fully developed, thermally developing and thermally fully developed laminar air flow in an inclined circular cylinder. The investigation covered Reynolds number range from 400 to 1600, heat flux was varied from 70 W/m2 to 400 W/m2 and cylinder angles of inclination including 30o, 45o and 60o.The results presented the surface temperature distribution along the cylinder length, the local and average Nusselt number distribution with the dimensionless axial distance. For all entrance sections, the results showed an increase in the Nusselt number values as the heat flux increased and as the angle of cylinder inclination moved from (θ = 60o) inclined cylinder to (θ = 0o) horizontal cylinder. Also, the average Nusselt numbers have been correlated with the (Rayleigh numbers/Reynolds numbers) in empirical correlations.

Mohammed and Salman [10] experimentally studied combined convection heat transfer in a vertical circular cylinder for assisting, thermally developing and thermally fully developed laminar air flows under constant wall heat flux boundary conditions. They examined the cylinder inclination angle effect on the mixed convection heat transfer process. The experimental setup consisted of aluminum cylinder with (30 mm) inside diameter and (900 mm) heated length (L/D=30).They concluded that for the same heat flux and low Reynolds number, the local Nusselt number increased as the cylinder angle of inclination moved toward horizontal cylinder. It was found also that the lower value of local Nusselt number occurred at (θ = 90°) vertical cylinder and the higher value occurred at (θ = 0°) horizontal cylinder when the free convection was the dominating factor on the heat transfer process.

B. Natural Convection from Cylinder in Vertical Channel

The problem of natural convection heat transfer in a vertical channel with a single obstruction was investigated both experimentally and analytically by Said and Krane [11]. Optical techniques were used to obtain measurement of both quantitative data (heat flux and temperature) and qualitative data (flow visualization), with uniform wall temperature boundary conditions in experimental investigation. In the numerical study, finite element computer code NACHOS was used with the two thermal boundary conditions of uniform wall temperature and uniform heat flux. It concludes that the location of the obstruction along the wall affects the rate of heat transfer. Moving the obstruction away from the entrance towards the exit was found to reduce the net heat transfer rate from the channel.

Kihm [12] investigated natural convection heat transfer characteristics in converging vertical channels flows by measuring the wall temperature gradients using a laser speckle gram technique. The local and average heat transfer coefficients were obtained for forty different configurations, including five different inclination angles from the vertical (θ= 00, 150, 300, 450 and 600) with eight different channel exit openings for each inclination angle. Correlations were obtained for local and average heat transfer coefficients in the range of Grashoff numbers up to 7.16×106; however the flow regimes for all considered cases were laminar. It reported that as the top opening of channel decreased, both local and average Nusselt number values started decreasing below that of a single plate. In low Rayleigh number range, neither the single plate limit nor the fully developed limit could properly describe the heat transfer characteristics in the converging channel.

Ghalib Y. Kahwaji, Abbas S. Hussien & Omar M. Ali [13] experimentally investigate the natural convection heat transfer from horizontal cylinder with square cross section situated in a square enclosure, vented symmetrically from the top and the bottom .The work includes temperature measurements of the cylinder surface and the environment during transient state to determine Nu for the unbound and the bound cylinder. The studied variable ranges were: 107 ≤ Ra ≤ 6.6×107,2 ≤ W/D ≤ 4, 0.25 ≤ O/D ≤ 4.The result observed an Increment in Nu with Increasing Ra. The maximum percentage of the enhancement is more than 20% for bounded square cylinder as compared with unbounded square cylinder.

Mahmoud S. Ahmed, Hany A. Mohamed, Mohamed A. Omara and Mohamed F. Abdeenon [14] conducted experimental study of natural convection heat transfer inside smooth and rough surfaces of vertical and inclined equilateral triangular channels of different inclination angles with a uniformly heated surface are performed. The inclination angle is changed from 15o to 90o. Smooth and rough surface of average roughness (0.02mm) are used and their effect on the heat transfer characteristics are studied. The local and average heat transfer coefficients and Nusselt number are obtained for smooth and rough channels at different heat flux values, different inclination angles and different Rayleigh numbers (Ra) 6.48 × 105 ≤ Ra ≤ 4.78 × 106. The results show that the local Nusselt number decreases with increase of axial distance from the lower end of the triangular channel to a point near the upper end of channel, and then, it slightly increases. Higher values of local Nusselt number for rough channel along the axial distance compared with the smooth channel. The average Nusselt number of rough channel is higher than that of smooth channel by about

8.1% for inclined case at θ = 45o and 10% for vertical case. The results obtained are correlated using dimensionless groups for both rough and smooth surfaces of the inclined and vertical triangular channels.

A. La Pica [15] studied experimentally the free convection of air in a vertical channel in a laboratory model of height (H) = 2.6m and rectangular cross section b × S; with b = 1.2m and the channel width S variable. One of the channel walls is heated with a uniform heat flux. Tests are made with different values of channel gap and heating power (s = 7.5, 12.5, 17cm and qc = 48 to 317 w/m2). The following correlations are developed and the geometrical parameter S/H;

Nu = 0.9282Ra0.2035 (S/H) 0.8972

Re = 0.5014Ra0.3148 (S/H) 0.418.

Shahin and Floryan [16] studied the heat transfer enhancement generated by the chimney effect in a system of vertical channels. The increase in heat transfer with adiabatic chimneys was studied numerically and a heat transfer correlation was presented.

M. Sadegh Sadeghipour, Yazdan Pedram Razi [17] investigates the laminar natural convection from an isothermal horizontal cylinder confined between vertical walls, at low Rayleigh numbers. The height of the walls is kept constant; however, their distance is changed to study its effect on the rate of the heat transfer. Results are incorporated into a single equation which gives the Nusselt number as a function of the ratio of the wall distance to cylinder diameter, t/D, and the Rayleigh number. There is an optimum distance between the walls for which heat transfer is maximum.

Mohamed A. Atmane, Victor S.S. Chan, Darina B. Murray [18] investigates the effect of vertical confinement on the natural convection flow and heat transfer around a horizontal heated cylinder. The flow characteristics and the time-resolved heat transfer have been measured respectively above and around the cylinder. It is shown that the primary effect of the vertical confinement is an increase in heat flux on the upper part of the cylinder for given separation distances between the cylinder and the fluid boundary. This increase is shown to be related to the large-scale oscillation of the thermal plume. The relationship between the flow pattern and the heat transfer characteristics at the cylinder surface is studied and the origin of the oscillation discussed. However, for a very small cylinder to free surface separation (case where H/D =1/5), the Nusselt number around the cylinder is dramatically reduced. This work shows that, for a Rayleigh number of the order of 6x106, the natural convection flow around a heated cylinder, vertically bounded by a free surface, can undergo a transition from stable to unstable when the distance between the free surface and the cylinder is roughly equal to the diameter of the cylinder. This instability seems to disappear for low and large distances as the heat transfer results for H/D = 1/5 and H/D = 3 suggest.

F.J. Higuera, Yu.S. Ryazantsev [19] performed analysis of the laminar natural convection flow due to a localized heat source on the centerline of a long vertical channel or pipe whose walls are kept at a constant temperature. Stationary solutions are obtained for infinitely long and finite length channels, the asymptotic limit of infinite Rayleigh numbers is discussed, and an optimal height of the channel is found leading to maximum mass flux and minimum temperature for a given heat release rate or Rayleigh number.

Ameni Mokni, Hatem Mhiri, Georges Le Palec, Philippe Bournot [20] conducted numerical investigation of mixed convection in a vertical heated channel. This flow results from the mixing of the up-going fluid along walls of the channel with the one issued from a flat nozzle located in its entry section. The fluid dynamic and heat-transfer characteristics of vented vertical channels are investigated for constant heat-flux boundary conditions, a Rayleigh number equal to 2.57x 1010, for two jet Reynolds number Re=3x103 and 2x104 and the aspect ratio in the 8-20 range. The obtained results show that the turbulence and the jet-wall interaction activate the heat transfer, as does the drive of ambient air by the jet. For low Reynolds number Re=3x103, the increase of the aspect Ratio enhances the heat transfer of about 3%, however; for Re=2x104, the heat transfer enhancement is of about 12%.It also show that an increase in the flow supports an effective cooling of the walls. The maximum heat transfer is reached at the entry area. We found that the Nusselt number decreases by increasing the aspect; this trend is due to the greater mass flow rate that circulates close to the channel walls, bringing along a better heat transfer activity. Correlations for dimensionless mass flow rate and average Nusselt numbers, in terms of Rayleigh number and dimensionless geometrical parameters, were proposed.

C. CFD Analysis of Natural Convection from Cylinder

Arularasan Rand Velraj R. [21] performed CFD analysis in a heat sink for cooling of electronic devices. In this the optimal design of the heat sink have been carried out on a parallel plate heat sink considering the geometric parameters such as fin height , fin thickness, base height and fin pitch with a constant length and width of a heat sink using computational fluid dynamics study. The simulation is carried out with the Commercial software provided by fluent Inc. Experimental studies have been carried out with a parallel plate heat sink to validate the heat sink model. The results obtained in the experimental studies have been compared with the simulation results and found to be in good agreement.

Rupesh G.Telrandhe, R.E.Thombre [22] studied the effect of different system parameters on the heat transfer and buoyancy induced flow inside circular tubes using CFD. They include tube length, tube diameter, tube inclination and heat supplied. Constant heat flux boundary condition is created on the tube surface. The heat transfer coefficient and the induced flow rate both were found increasing with increase in the heat supplied and the angle of inclination with the horizontal. Also the temperature and Velocity both increases with increases in the heat supplied and length of the tube. The flow rate of water is found to be independent of the tube length if the tube length is more than 1m.The Experimental results are to be Compare with the CFD results. Boundary condition, Geometry is created in GAMBIT and Solver; Boundary conditions are provided to the pipe in fluent software.
Rupesh G. Telrandhe, T.S.Karhale and B.B.Deshmukh [23] thermal analysis of circular inclined pipe subjected to natural convection using CFD is studied. The temperature is found more in large diameter pipe. It reduces with decrease in pipe diameter. The change in temperature was found about 20 % with increase in pipe diameter from 12 mm and 24 mm. additionally, as the heat supply increases it will effect on the output temperature and it also increases. Hence it is concluded that the temperature is strongly influenced by heat flux, diameter of the pipe and its inclination.

III. PROPOSED WORK

The aim of the present work is to investigate experimentally the natural convection heat transfer inside inclined cylinder placed in vertical channel. The details of the experimental set- up are as follows.

TABLE1. Details of experimental set-up

Sr. No.	Description	Dimensions/Range
1	Cylinder (Copper) 1no.	D=38mm L=300mm
2	Vertical plate (Mild Steel) 2 no.	500×450×6mm
3	Heat input	25.13–2067.03 W/m^2

The parameters varied during the experimentation are heat input, aspect ratio and elevation of cylinder from bottom. The temperatures at various locations of cylinder are measured with the help of calibrated PT-100 thermocouples. Heat input is supplied by the use of dimmer stat. The two vertical plates are kept as adiabatic walls and only heat is supplied to the inclined cylinder.

IV. EXPERIMENTAL SET-UP

A. The Experimental Set-Up consists of Following Instrumentation

1) Dimmer stat (0-260 Volt AC Supply)
2) Voltmeter (0 – 460 Volt)
3) Ammeter (0 – 5 Ampere)
4) Digital Temperature Indicator (DTI) of 12 port (Range 0 – 400^{O}C)
5) Calibrated Thermocouples used PT-100 type – 12nos.

B. The Parameters Varied during the Experimentation are

1) Heat input (25-2067.03watt/m^2).
2) Inclination of cylinder measured from vertical (30^0,50^0 &70^0).
3) Aspect ratio (the ratio of length of inclined cylinder to the spacing between vertical plates are 0.88, 0.78 &0.71).
4) Elevation of inclined cylinder from bottom (7.5cm, 10cm &15cm).

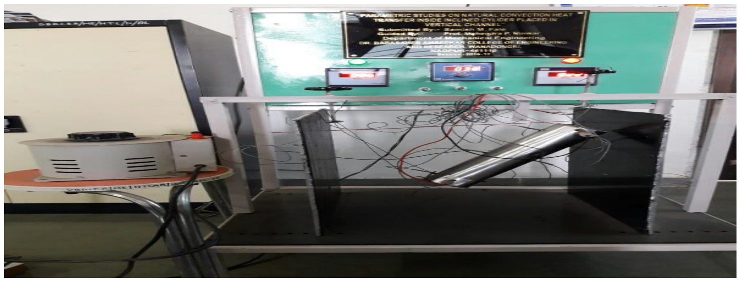

Fig.1 Experimental Set-up

D. Experimental Procedure

1) The cylinder was adjusted for the desired inclination, aspect ratio and elevation from the bottom.
2) The heater was switched ON and the heat flux was adjusted with the help of a calibrated dimmer-stat.
3) The heat supplied was measured with a pre-calibrated voltmeter and ammeter.
4) 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).
5) The steady state data is taken.
6) The same experiment procedure was performed for various parameters.

The rate of heat transfer for natural convection in inclined cylinder in vertical channel strongly depends upon Nusslet number (Nu), Rayleigh number (Ra), Aspect ratio (S), Cylinder inclination (α) and Elevation of cylinder from bottom (y). For this reason data is presented in the form of

a) Heat Transfer Coefficient: The heat transfer coefficient was calculated by the following equation

$$h = Qconv/(As\,\Delta T)$$

Where A_s = Surface area, ΔT ($T_m - T_a$) = Temperature difference between mean film temperature and ambient temperature of air.

b) The Dimensionless Parameters:

Nusselt number ($Nu = \frac{h\,Lc}{K}$),

Grashof number ($Gr = \frac{g\,\beta\,\Delta T Lc^3}{\nu^2} \cos\alpha\,(S)$) and

Prandtl number($Pr = \frac{\mu\,Cp}{K}$), are evaluated at mean film temperature.

V. CONCLUSIONS

The extensive experimentation was carried out. The effect of various parameters on the heat transfer coefficient is as follows.

A. Effect of Heat Supplied

The heat transfer coefficient is strongly influenced by heat flux. It can be observed that, with the increase in the value of heat flux supplied the heat transfer coefficient tends to increase (25). This is due to the fact that with increase in heat flux supplied the buoyancy force tends to increase.

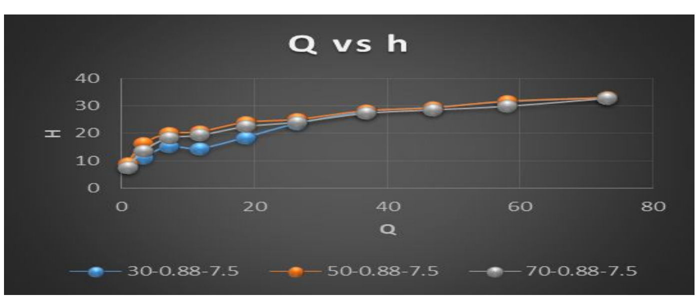

Fig.2 Effect of heat supplied

B. Effect of Inclination

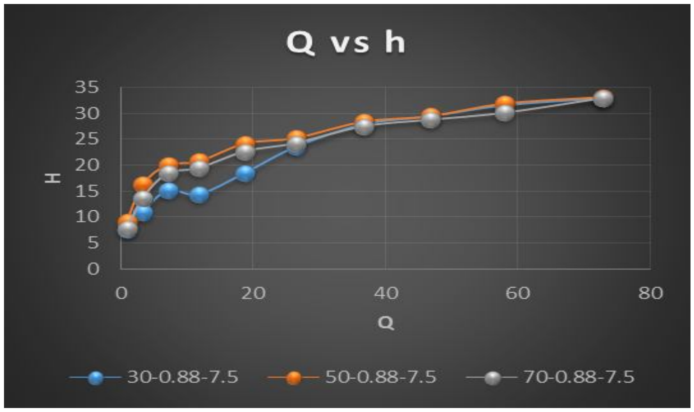

Fig.3 Effect of inclination

With the increase in inclination, the buoyancy force component (F_x) increases and it assists the motion moreover for the upper surface the force component (F_y) initiates upward motion in addition to the parallel motion along the plate. This tends to increase the heat transfer rate (26).

C. Effect of Aspect Ratio

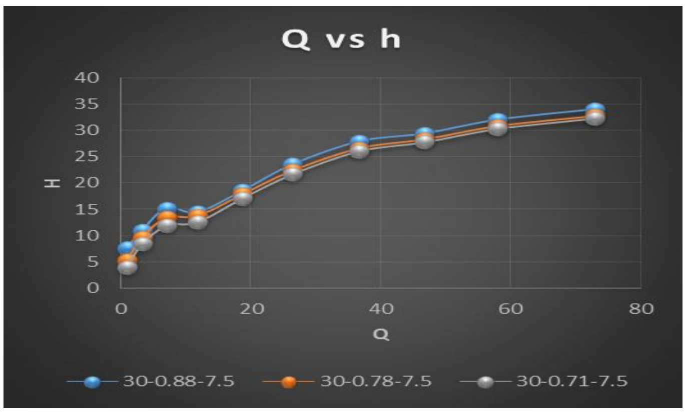

Fig.4 Effect of aspect ratio

With the increase in aspect ratio, the heat transfer rate increases i.e. higher the aspect ratio, higher the heat transfer rate. The heat transfer enhancement is attributed to the chimney effect caused by the presence of vertical walls than the free space positioning (17).

D. Effect of Elevation

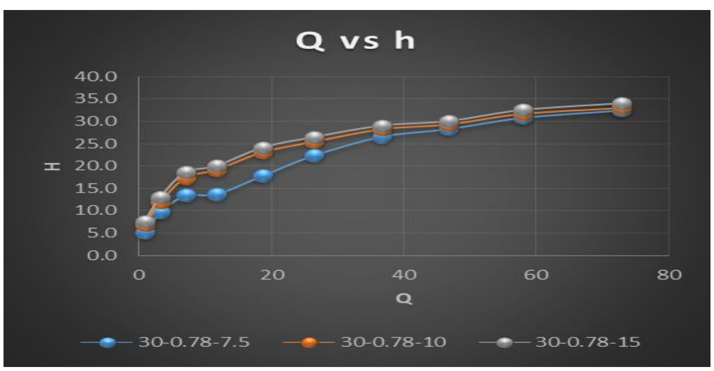

Fig.5 Effect of elevation

When elevation of the inclined cylinder is equal to 15cm from bottom, the flow tends to stabilize here and hence the heat transfer coefficient tends to increase. The central positioning of the plate is observed to be the best from the heat transfer point of view (24).

The extensive experimentation has been carried out to generate the data. The following correlation is obtained from experimental results by using best fit curve method.

$$\mathbf{Nu = 1.1689 \times Ra^{*0.3121}}$$

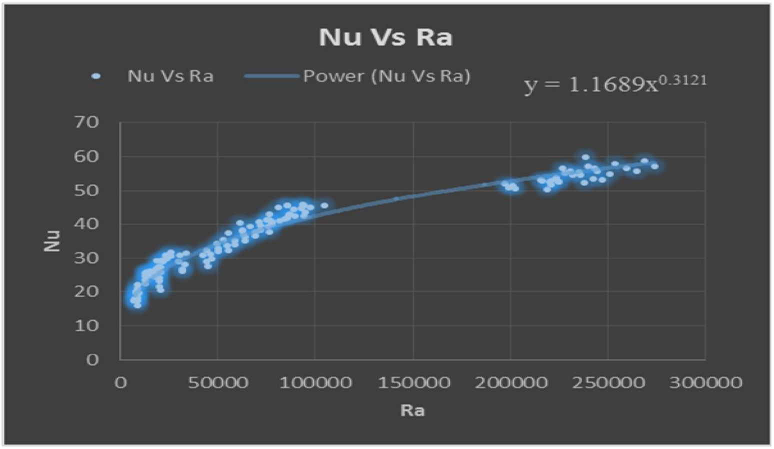

Fig.6 Nu Vs Ra

E. Conclusions

The present study deals with the heat transfer characteristics of inclined cylinder placed in vertical confining walls which will give maximum heat transfer rate when the gap between inclined cylinder and vertical plate is minimum, as the flow of air will be more steady and continuous. Also this increase in heat transfer rate is contributed to chimney effect i.e. due to presence of vertical confining walls the rate of heat transfer is more. This study is particularly useful in design of cooling of various electrical and electronic components mounted on printed circuit boards, heat dissipation from electronic circuits, refrigerators, heat exchangers, nuclear reactors fuel elements, dry cooling towers, and home ventilation etc.

The correlation obtained is as given under:

$$\mathbf{Nu = 1.1689 \times Ra^{*0.3121}} \qquad \textbf{(1)}$$

The experimentation is valid for the cylinder inclination from 30^0 to 70^0 measured from vertical, aspect ratio from 0.71 to 0.88, elevation of cylinder from bottom between 7.5 to 15cm and Rayleigh number range from $9.4x10^3$ - $2.4x10^5$.

VI. NOMENCLATURE

A. g Gravitational acceleration [m/s^2]
B. Gr* Modified Grashof number
C. L_p Length of a inclined cylinder[m]
D. L Channel width[m]
E. Nu Average Nusselt number
F. Pr Prandtl number
G. q Average wall heat flux (Q_{con}/A_s) [W/m^2]
H. Ra* Rayleigh number, Gr*.Pr;
I. T_s Surface wall temperature [^{0}C]
J. T_a Ambient temperature [^{0}C]
K. T_m Mean film temperature [^{0}C]
L. h Average heat transfer coefficient [W/m^2K]
M. k Thermal conductivity[W/mK]
N. S Aspect ratio [Lp/L]
O. y Elevation of inclined cylinder from bottom [m]
P. C_p Specific heat at constant pressure [kJ/kgK]
Q. L_c Characteristic length [m]

R. Greek Symbols

1) β Average volumetric thermal expansion Coefficient [1/K]
2) ρ Fluid density [Kg/m^3]
3) α Angle of inclination of plate with the vertical
4) ν Kinematic viscosity[m^2/s]
5) μ Dynamic viscosity [$N\text{-}s/m^2$]

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