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Experimental Investigation of the Natural Convection from Inclined Heated Cylindrical Tube in Air Filled Cavity

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Abstract—*In this paper, the experimental analysis had been done for the natural convection inside a cavity (in still atmosphere) around the cylindrical tube at different θ at the steady state condition. θ of the tube varies from 90° to 45° with the step size of 15° for various Q (29.35 W, 35.00 W, 41.16 W and 48.29 W). The variation of the ΔT_s on the tube, heat transfer coefficient, Nu_x and Nu_m were studied at different heat flux inside the cavity around the axial length of the tube. The results shown for the variation of the surface temperature difference, local Nusselt number around the tube, and the variation of average Nusselt number with Rayleigh number. An empirical relation had been deducted for the variation of the average Nusselt number with Rayleigh number for different inclination based on power law of $Nu_m = Ra_m^n$. In the whole analysis of the free convection around the tube, the effect radiation was neglected.*

Keywords: *Heat transfer, Natural convection, inclined convection, closed cavity, still air.*

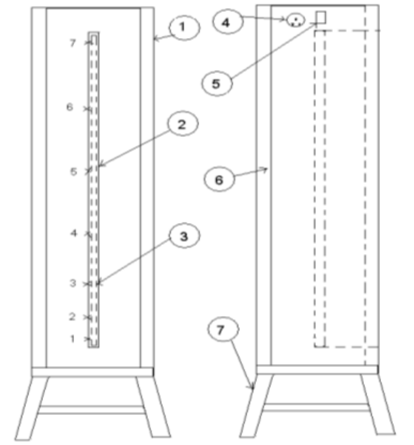
1. INTRODUCTION

Natural convection is occurs in various enclosure (here square enclosure is a particular interest) is an important of engineering application. Natural convection occurs whenever a density gradient exists, it is developed due to the temperature difference between two points. We need to understand the behavior of the free convection by that we can increase or reduce the heat transfer rate in an enclosure. Here we heat the tube with uniform heat flux rate to find the behavior of the natural convection in a closed square enclosure. Natural convection has many application such as heat transfer from a building, electronic chip, nuclear reactor etc.

When a hot body is placed in a still atmosphere or surroundings then only heat transfer from the body will occur due to the natural convection by the surroundings fluid. The fluid layer in contact with the body is gets heated, rises up due to decrease in the density and cold fluid comes in place of hot fluid. This process is continues and heat is transferred due to continuous motion of fluid around the hot body. Ahmed *et al.*[1] investigated the heat transfer by natural convection in an open channel for a triangular cross-section having rough and smooth surface for an inclined and vertical position. They detected Nu_m increases with increase of Ra. Nu_x decreases with increase of the x the lower end of the triangular channel up to near the top end of the cylinder and then gradually decreases. Arshad *et al.* [2] studied the natural convection heat transfer from an enclosed assembly of a thin vertical cylinder at high Ra. Roul *et al.*[3] carried out the experimental investigation of natural convection heat transfer through heated vertical tubes in the duct. The duct was open ended and circular in the cross section. They uses different aspect ratio and observe the variation of the different properties and drawn the graph between temperature versus axial length of the tube. Mallik *et al.*[4] had experimental study on the natural convection heat transfer over an array of staggered discrete vertical plates and observed that the use of discrete vertical plates in place of continuous plates gives the enhancement of natural convection heat transfer. Sankar[5] had the Numerical study of natural convection in a vertical porous annulus with discrete heating. Totala *et al.*[6] studied the Natural characteristics in vertical cylinder. Shiri *et al.*[7] conducted the experimental analysis of the natural convection near the wall region of vertical cylinder and measure the mean and turbulence quantities at the near wall region, where the varying thermal properties also affect the flow due to the strong temperature gradient. A new sets of boundary layer equations were established to represent the variable properties of the flow at this region. Rajamohan *et al.*[8] had experimental study on mixed convection heat transfer in a square duct with varying inclination angles. Nouanegue *et al.*[9] had studied on the conjugate heat transfer by natural convection, conduction and radiation in an inclined square enclosure bounded with the solid wall with it outer boundary at the constant temperature, while the opposite wall maintained at the constant heat flux and other two boundary were made adiabatic.

2. EXPERIMENTAL SETUP

The apparatus consist of a brass tube fitted in rectangular cavity in vertical position. The cavity was closed at top and bottom, and forms an enclosure and serves the purpose of undisturbed surrounding. One side of duct is made up of Perspex for visualization. An electrical heating element is kept in vertical tube which in turns heats the tube surface. The heat loss by tube to surrounding air is by natural convection. The temperature of vertical tube is measured by seven thermocouples which are fixed on the tube by drilling holes along the tube wall. The heat input to the heater is measured by an ammeter and voltmeter and is varied by a dimmer-stat. The tube surface is polished to minimize the radiation loss.



(1) Duct (2) Cylinder (3) Heater (4) Heater Socket (5) Thermocouple Socket (6) Acrylic Sheet (7) Stand (8) 1 to 8 Thermocouple Position

Fig. 1: Schematic diagram of natural convection apparatus

Specifications:

1. Outer Diameter of the tube (d) = 38 mm
2. Length of the tube (L) = 500 mm
3. Cavity size = 250mm × 250mm × 880mm
4. Number of the thermocouples = 8
5. Thermocouple number 8 reads the T_{∞} and is

kept in the cavity.

6. Temperature Indicator 0-300°C. Multi-channel type calibrated from Fe-Ca thermocouples with compensation of ambient from 0-50°C.
7. Ammeter
8. Voltmeter
9. Dimmerstat

3. EXPERIMENTAL PROCEDURE

In this paper following method was adopted to conduct the experiment of the Natural convection at the different θ at different Q, the procedure were followed by-

a.) Checked the all instrument in working condition or not.

b.)Fixed the required angle of the test cavity.

c.)Put on the supply and fixed the required heat input with the help of dimmer-stat and then leave for some time.

d.)Waited till(3-4 hours) the fairly reached up-to steady state which is confirmed from the temperature reading of T1 to T7 is not changing with time.

e.) After the experiment surface temperature and ambient temperature were taken out.

4. DATA REDUCTION

A definite power was supplied to the tube by adjusting the dimmer-stat. Waited up to the steady state and then temperature was measured along the tube at the seven points and a ambient temperature inside the cavity with the help of thermometer.

Heat supplied to the tube Q = V.I

Total heat transfer from the tubes

Q= $Q_{convection} + Q_{radiation}$

Net heat transfer through radiation

$$Q_{radiation} = \sigma\, A\, \varepsilon\, (T_f^4 - T_\infty^4)$$

Heat transfer through natural convection

$$Q_{convection} = hA(T_{f-}T_{\infty})$$

The local heat transfer coefficient along the tube inside the square cabinet is calculated by

$$h_x = \frac{q}{\Delta T_x}$$

The temperature difference from the local temperature of the tube to the ambient temperature inside the cavity is calculated by-

$$\Delta T_x = T_x - T_\infty$$

Local Nusselt Number-

$$Nu_x = \frac{h_x.L}{K}$$

Heat transfer coefficient

$$h_m = \frac{q}{\Delta T_{mx}}$$

The average inner temperature is calculated by

$$T_{mx} = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7}{7}$$

Bulk mean temperature

$$T_{mf} = \frac{T_{mx} + T_\infty}{2}$$

The average Nusselt number is calculated by

$$Nu_m = \frac{h_{mL}}{k}$$

Rayleigh number '*Ra*' is calculated by

$$Ra = Gr.Pr$$

5. RESULTS AND DISCUSSION

5.1 Temperature variation along the axial length of the tube:

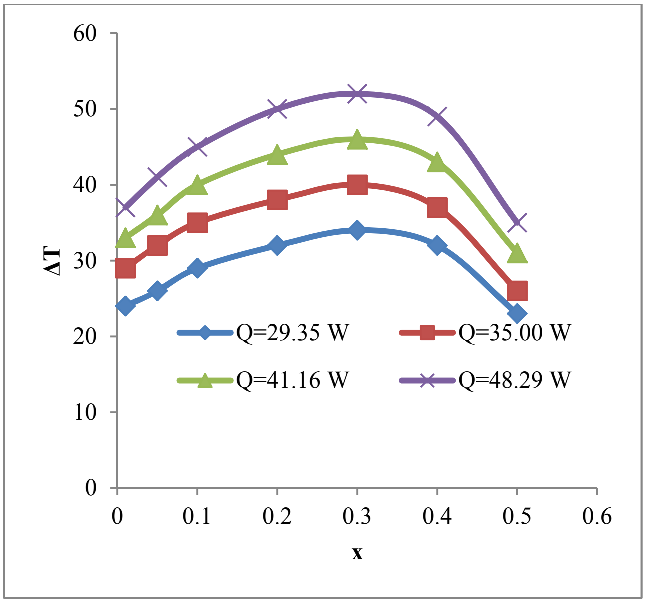


Fig. 2: ΔT *Vs* x For θ=90°

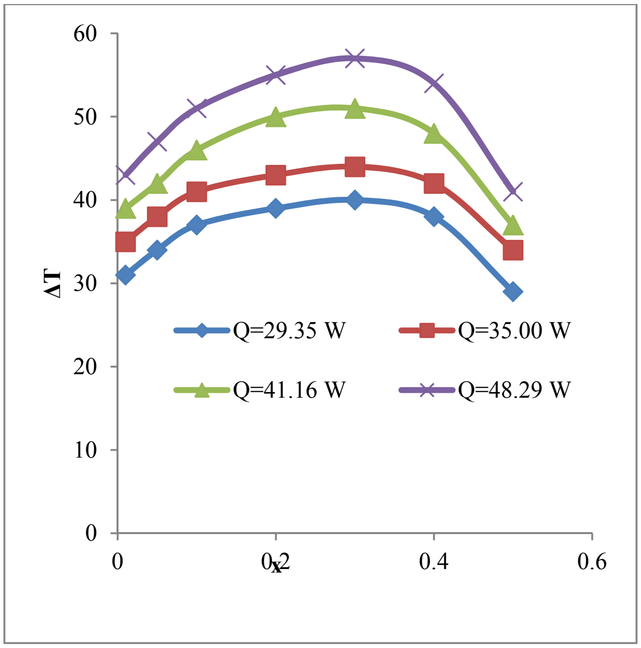


Fig. 3: ΔT *Vs* x for θ=75°

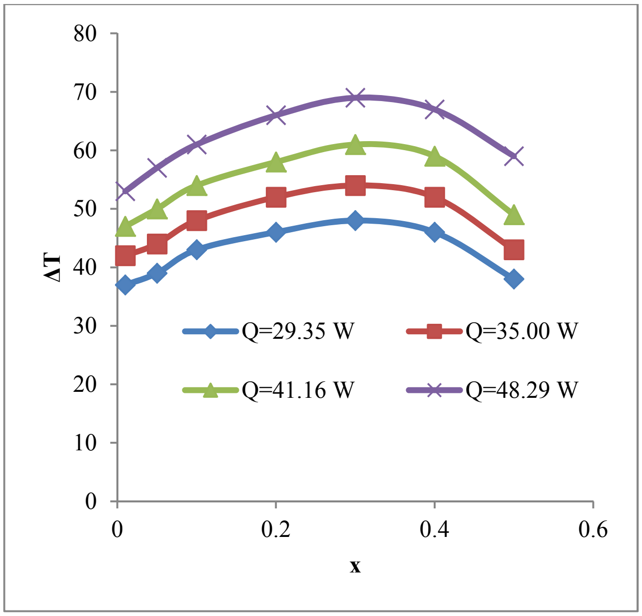


Fig. 4: ΔT *Vs* x for θ=60°

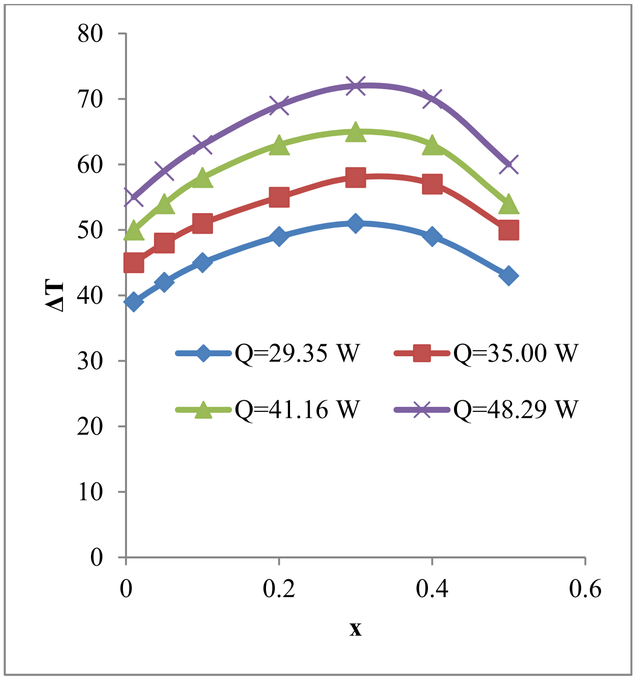


Fig. 5: ΔT *Vs* x for θ=45°

Variation of ΔT with x (Fig. 2-5) is increases up to the certain length and reached maximum value, after that gradually decreases at the upper end[3]. This can be justify by that, the thermal boundary layer's thickness is increasing gradually from the lower end of the tube causes decrease in the $h_x$implies increase in the ΔT along the x. Now at the upper end of the tube due to the formation of the transition state the local mixing of the air increases so $h_x$increases causes decrease in the ΔT. As the cavity position changes from vertical to inclined position, its ΔT along the x is increases Fig. (6-9). This can be describe by that as air is heated near the tube and became lighter, so due to density difference and gravity effect it moves in upward direction and to cover this place, upper part of air moves in downward causes the circulation of the air inside the cavity. So when cavity is in vertical position the air flow parallel to the gravity vector and when the cavity made in inclined position moves in upwards as well as radial direction with the help of inclined surface of the cavity causes decrease in the $h_x$that raises the ΔTalong the x.

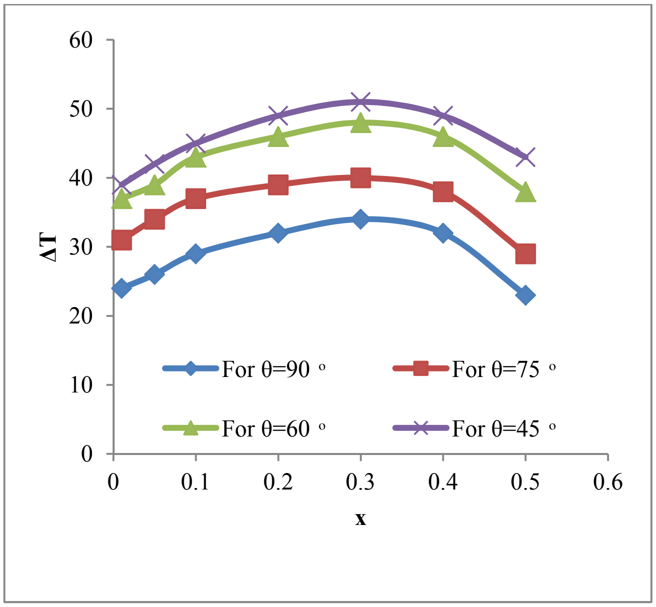


Fig. 6:ΔT Vs x **for Q=29.35 W**

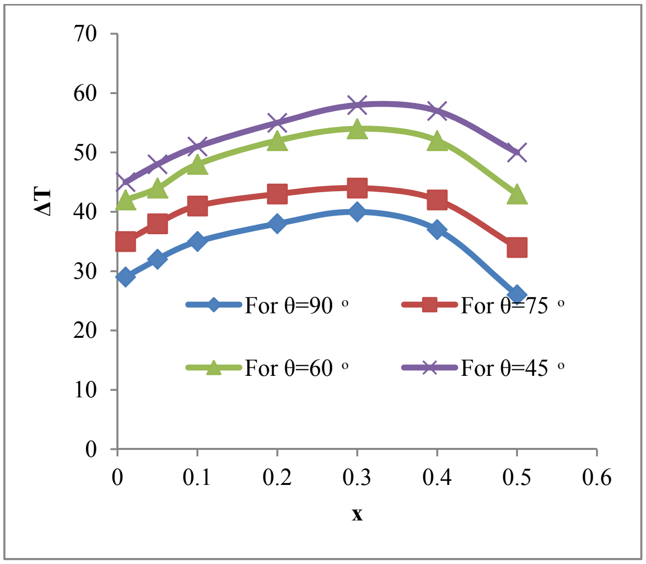


Fig. 7:ΔT Vs x **for Q=35.00 W**

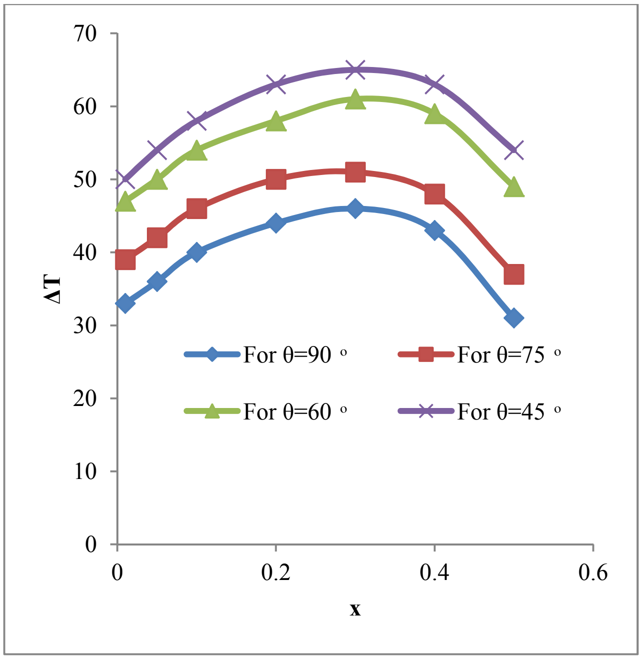


Fig. 8:ΔT Vs x **for Q=41.16 W**

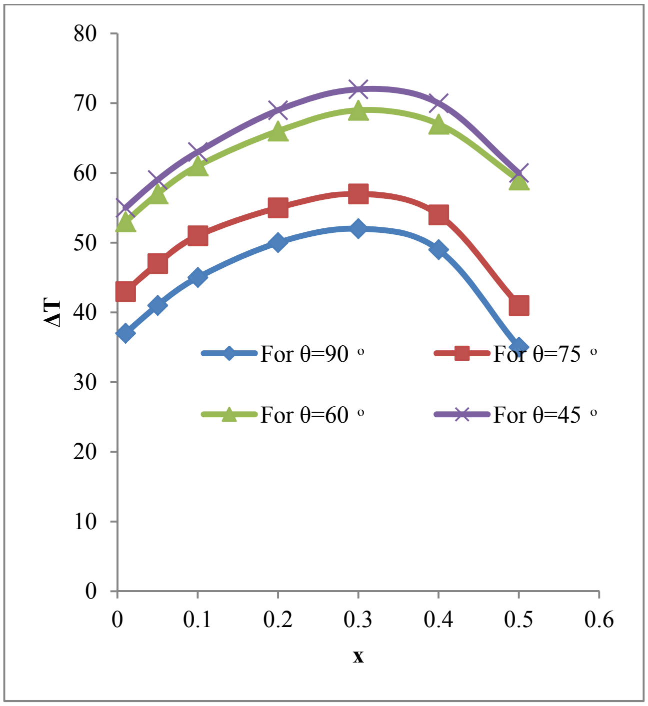


Fig. 9:ΔT Vs x **for Q=48.29 W**

5.2 Variation of the local Nusselt number with axial tube length:

$\boldsymbol{Nu_x}$at different Q (29.35 W, 35.00 W, 41.16 W and 48.29 W) at different θ ($90^0, 75^0, 60^0$ and 45^0)along the x is shown in the Fig. below respectively.

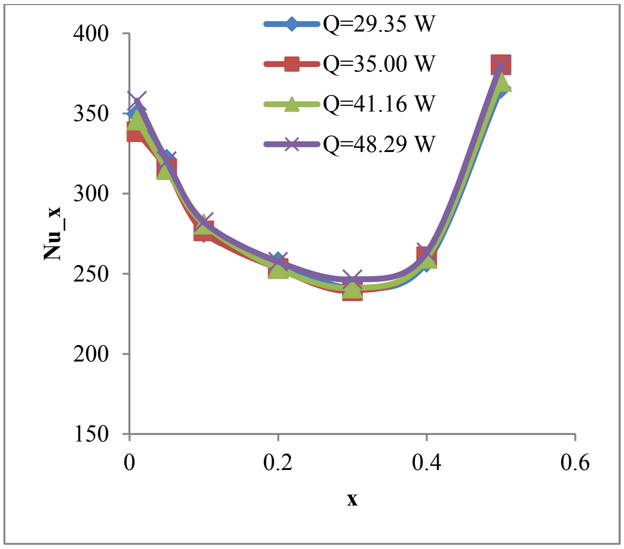


Fig. 10: For θ=90°

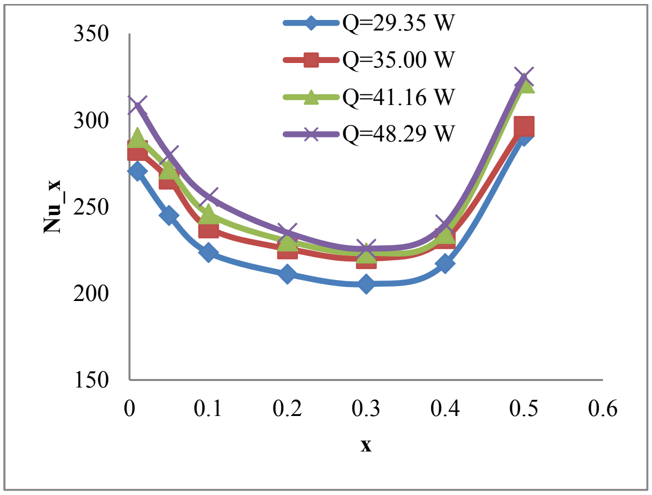


Fig. 11: For θ=75°

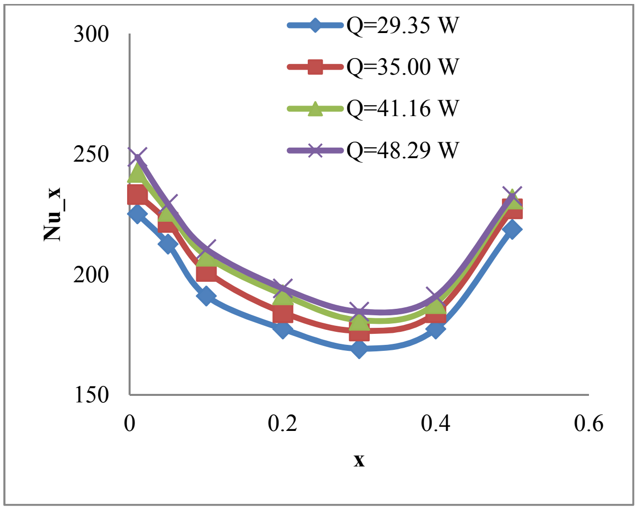


Fig. 12: For θ=60°

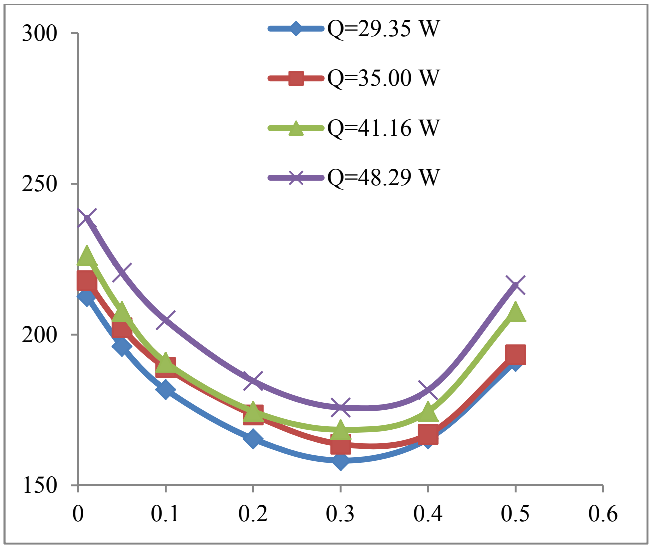


Fig. 13: For θ=45°

Fig. from 10-13 shows that the variation of the Nu_x along x inside the rectangular cavity at different Q for θ from 90^0 to 45^0. The Fig. illustrated that as Nu_x decreases with the increase of the x for all Q at all θ. Nu_x decreases up to certain length of the tube and then gradually start increasing at the upper end of the tube. This can be justify that at the start of the x, thickness of the boundary layer is less due to which h_x is high but as we move in axially upward direction of the tube, boundary layer's thickness is gradually increasing due to which $h_x$decreases, but at the upper end of the tube, a transition state of the boundary layer is formed due to this loss of heat occurs causes increases the h_x.

The effect of the θ on the Nu_x at different Q is shown in the Fig. 14-17. The variation of Nu_x in inclined case is similar to the vertical case, but as we moved towards inclined position the Nu_x is lessening, because when the cavity was at the vertical case (90°) the movement of the air in vertical direction by the virtue of density difference and gravity effect but when the cavity was made in inclined position the movement of the air in vertical direction as well as in radial direction due to which thickness of the boundary layer is increases causes decrease in the h_x.

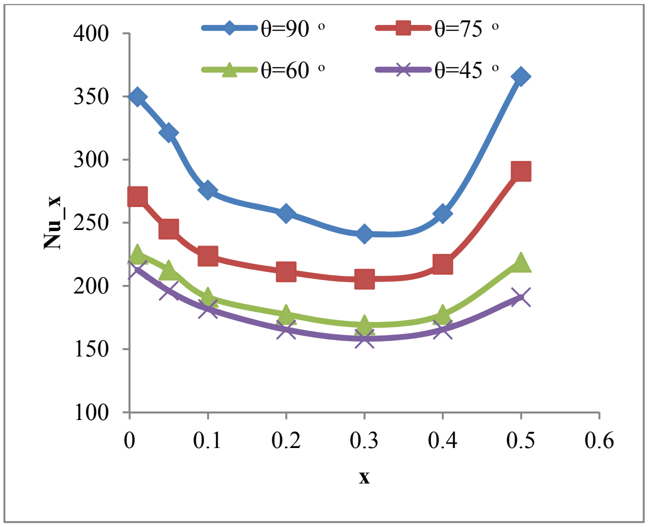


Fig. 14: For Q=29.35 W

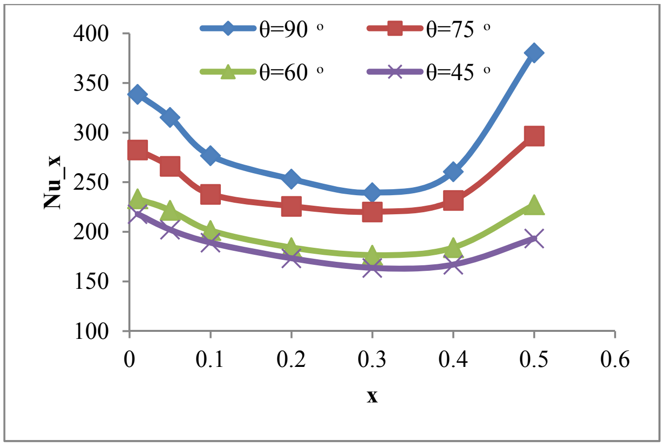


Fig. 15: For Q=35.00 W

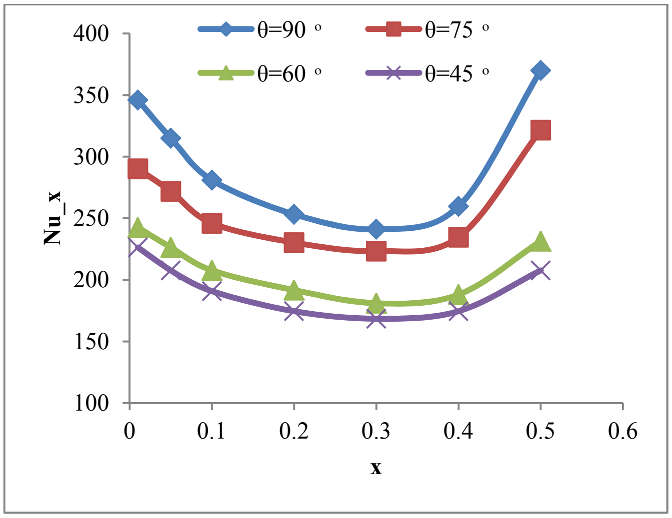


Fig. 16: For Q=41.16 W

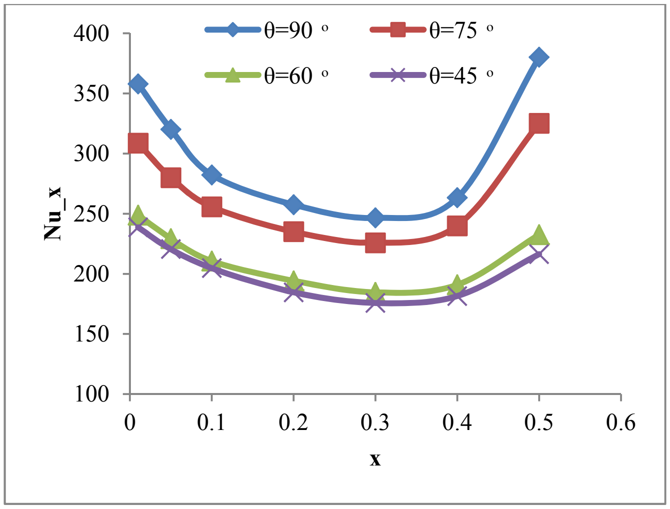


Fig. 17 : For Q=48.29 W

6.3 Variation of Average Nusselt Number With Rayleigh Number :

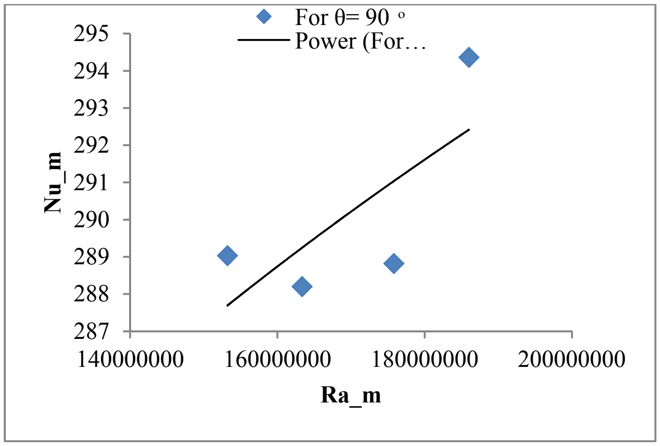


Fig. 18: Nu_m Vs Ra_m

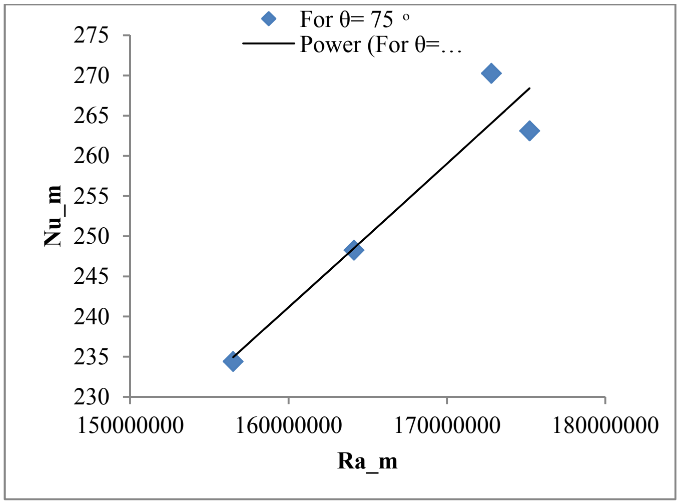


Fig. 19: Nu_m Vs Ra_m

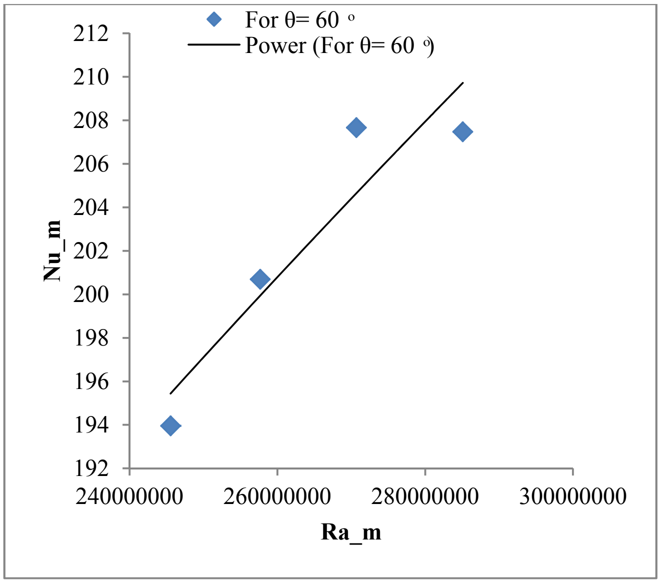


Fig. 20: Nu_m Vs Ra_m

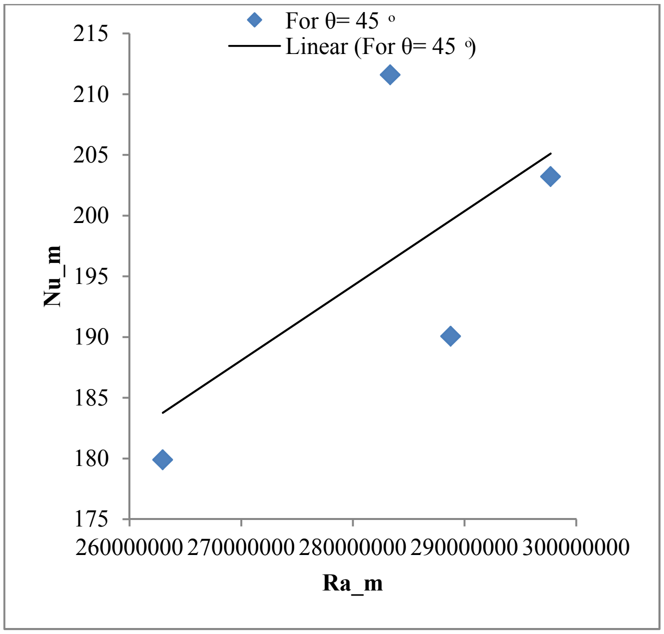


Fig. 21: Nu_m Vs Ra_m

The variation between the Nu_m with the Ra is shown in the Fig. 18 to 21. Nu_m increases with increase in the Ra at all θ. At higher value of Q Nu_m increases more rapidly with the Ra due to higher heat transfer rate at higher Rayleigh number. The following correlations are developed on the basis of the $Nu_m = cRa_m^n$.

For 90^0

$$Nu_m = 59.066Ra_m^{0.084}$$

For 75^0

$$Nu_m = 5.16E(-08)Ra_m^{1.1786}$$

For 60^0

$$Nu_m = 0.0214Ra_m^{0.4722}$$

For 45^0

$$Nu_m = 4.1058E(-06)Ra_m^{0.908516}$$

6. CONCLUSION

Natural convection heat transfer from the vertical tube in a closed cavity was investigated experimentally. Experiment was conducted at various Q (29.35 W, 35.00W, 41.16 W and 48.29 W) for a different $\theta(90^0, 75^0, 60^0 \& 45^0)$ in a closed square cavity. The following main point can be concluded from the experiment-

- ΔT along the x increases up to certain height and then decreases due to the loss of heat at the end of the tube in each inclination at every Q.

-Nu_x decrease with x of the tube up-to certain height and then gradually increases at the top end.

-Nu_x increases with the increase of the Q as well increase of θ from 45^0 to 90^0.

-Nu_m of the tube increases with increase in the Ra at each and every cases.

7. NOMENCLATURE

g Gravity acceleration, m/sec^2

β Volumetric coefficient of thermal expansion K^{-1}

h_x Local convective heat transfer coefficient $W/(m^2 K)$

k Thermal conductivity, W/mK

Gr Grashof number, $(g\beta\Delta Tx^3)/\vartheta^2$

Nu_x Local Nusselt number, $(h_x L)/K$

Nu_m Average Nusselt number

Pr Prandtle number, $(\mu c_p)/K$

Ra Rayleigh number, $Gr.Pr$

Ra_m Average Rayleigh number

Q Electric Power of main heater, W

q Heat Flux, $\frac{Q}{A_s}$ W/m^2

A_s Surface area m^2

μ Dynamic viscosity of air, Kg/ms

ρ Density of air, Kg/m^3

ϑ Kinematic viscosity of air, μ/ρ

L Length of the tube *(m)*

T_∞ Ambient air temperature inside the cabinet

T_x Inside Surface temperature along the tube.

x Local vertical length of the heated tube

from lower end, m

ΔT_x Temperature Difference, $(T_x - T_\infty)$, C

α Thermal Diffusivity, m^2/sec

σ Steffen Boltzmann constant

ε Emissivity

T_f Bulk mean temperature

W Watt

V Applied voltage

I Applied current

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