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Natural Convection Characteristicsin Vertical Cylinder

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ABSTRACT: *The present experimental study deals with natural convection through vertical cylinder .The experimental set up is designed and used to study the natural convection phenomenon from vertical cylinder in terms of average heat transfer coefficient. Also practical local heat transfer coefficient along the length of cylinder is determined experimentally and is compared with theoretical value obtained by using appropriate governing equations .The set up consist of brass cylinder of length 450mm and outside diameter 32mm with air as a working fluid. The results indicate the temperature variation along the length of cylinder and the comparative study of theoretically and practically obtain local heat transfer coefficient.*

KEYWORDS: *Natural convection, Vertical cylinder, Boundary layer, local heat transfer coefficient*

I. NOMENCLATURE

Q_{in}: Heat input to heater coil,(W)
V: Applied Voltage,(V)
I: Applied Current,(A)
h_{savg}: Average surface heat transfer coefficient,(W/m^2K)
T_{savg}: Average surface temperature,(^0K)
T_∞: Ambient temperature,(^0K)
D: Diameter of the cylinder,(m)
L_c: Characteristics length of cylinder,(m)
g: Acceleration due to gravity = 9.81 m/sec^2
ν: Kinematic viscosity(m^2/s)
Ra: Rayleigh number
Gr: Grashoff number
Pr: Prandtl number
Nu: Nusselt number
β:coefficient of volumetric expansion,(K^{-1})
T_{mf}: Mean film temperature,(^0K)
$h_{1:}$ local heat transfer coefficient,(W/m^2K)
K: Thermal conductivity of air,(W/mK)

II. INTRODUCTION

Natural convection heat transfer has always been of particular interestamong heat transfer problems. In natural convection, fluid motion iscaused by natural means such as buoyancy due to density variations resulting from temperature distribution.Natural convection plays vital role in heat transfer in case of many applications such as electrical componentstransmission lines, heat exchangers and many other places Many experimental studies have been performed during the last threedecades and interesting results have been presented.Y.A.Cengel[1] discussed the natural convection phenomenon in case of vertical cylinder and governing equations to determine heat transfer coefficient. L. Davidson et.al[2] studied the natural convection phenomenon in vertical shell and tube also the effect of different inlet conditions and geometrical dimensions on the developed thermal and velocityboundary layers. Also it was shown that the larger the inlet velocity , the larger the Nusseltnumber. Especially near thetransition region this difference is large and gradually vanishes in thefully turbulent region.L. J. Crane[3] studied the natural convection over the vertical cylinder at very large Prandtl number and discussed how, high Prandtl number affect free convection through vertical cylinder. C.O.Popiel[4]Studied the effect of curvature of the cylinder where the thickness of boundary layer is considerable i,e. thicker.

Also some result of calculations of boundary layer using modified integral method isobtained. HariP.Rani et.al[5] studied numerically unsteady natural convection of air and the effect of variable viscosity over an isothermal vertical cylinder and concluded that as the viscosity increases the temperature and skin friction coefficient increases, while velocity near the wall and Nusselt number decrease.P. Ganesanet.al[6] presented numerical solution for transient natural convection over the vertical cylinder under the combine buoyancy effect, also it is observed that time taken to reach steady state increases with Schmidt number and decreases as combined buoyancy ratio parameter increases. A. Shiriet.al[7] studied experimental analysis of natural convection in near wall region of vertical cylinder and measured the mean and turbulence quantities in the near wall region, where the varying thermal properties also affect the flow due to the strong temperature gradient there. A new set of boundary layer equations are established to represent the variable properties of the flow in this region. This experimental investigation also reveals that the strong temperature gradients adversely affect both the steady and unsteady temperature results because of the conduction. H. A. Mohammed et.al[8] studiedmixed convection heat transfer inside a vertical circular cylinder for upward and downward flows, for hydrodynamically fully developed and thermally developing laminar air flow under constant wall heat flux boundary conditions. The results show that the surface temperature values for downward flow were higher than that for upward flow but it was lower than that for horizontal cylinder.J. Wojthowak et.al[9] studiedexperimentally the laminar free convective average heat transfer in air from isothermal vertical slender cylinder having circular cross-section using a transient technique. The present experiment of natural convection through the vertical cylinder of brass having specific dimensions gives the analysis of temperature distribution along the length of cylinder. To measure temperature, at different level the thermocouples are fitted. The average heat transfer coefficient and local heat transfer coefficient are estimated using energy balance in the system and the same are found out by using appropriategoverning equations. The result indicate the variation of heat transfer coefficient with the length of cylinder and this results are compared for both practically determined and theoretically evaluated heat transfer coefficient.

III. EXPERIMENTATION AND METHODOLOGY

The apparatus consist of a brass tube fitted in rectangular duct in vertical fashion. The duct is open 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 visualisation. 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 dimmerstat. The vertical cylinder with thermocouple position is shown in Fig.1. The tube surface is polished to minimise the radiation loss.

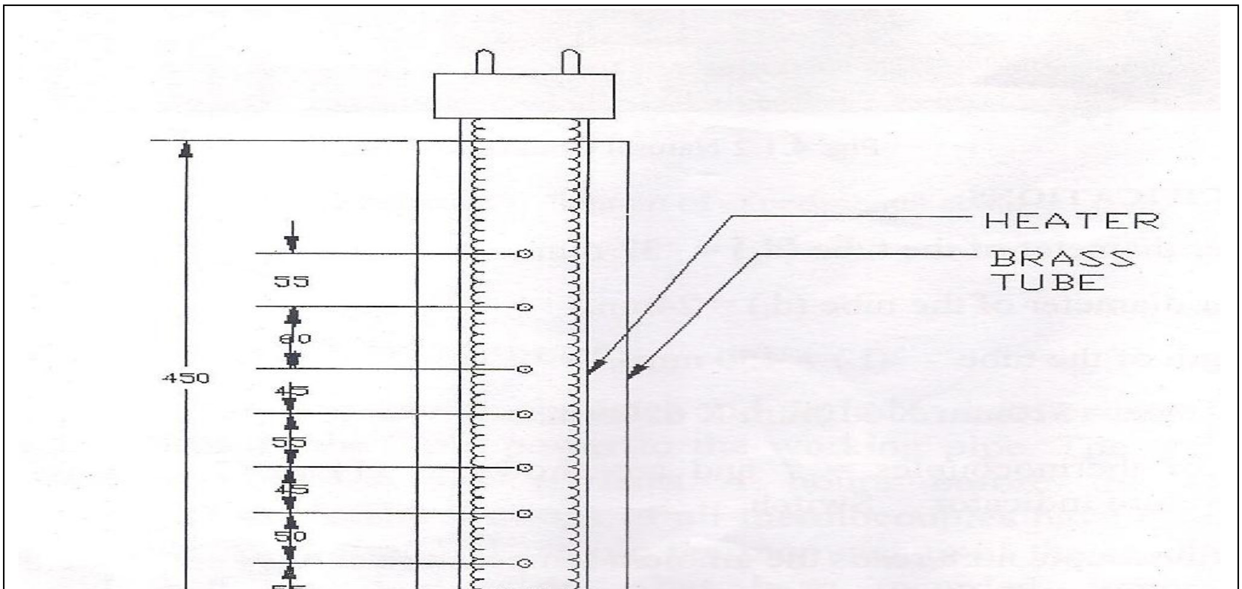

Fig.1 Heater assembly for vertical cylinder(Dimensions are in mm)

The voltage regulator, ammeter and digital voltmeter have been used to control and measure the input power to the working pipe as shown in Fig.2. The apparatus has been allowed to turn on for at least 4 hours before the steady-state condition was achieved. The readings of all thermocouples have been recorded every half an hour by a digital electronics thermometer until the reading became constant, and then the final reading has been recorded. Record the ambient temperature. The input power to the heater could be changed to cover another run in shorter period of time and to obtained steady-state

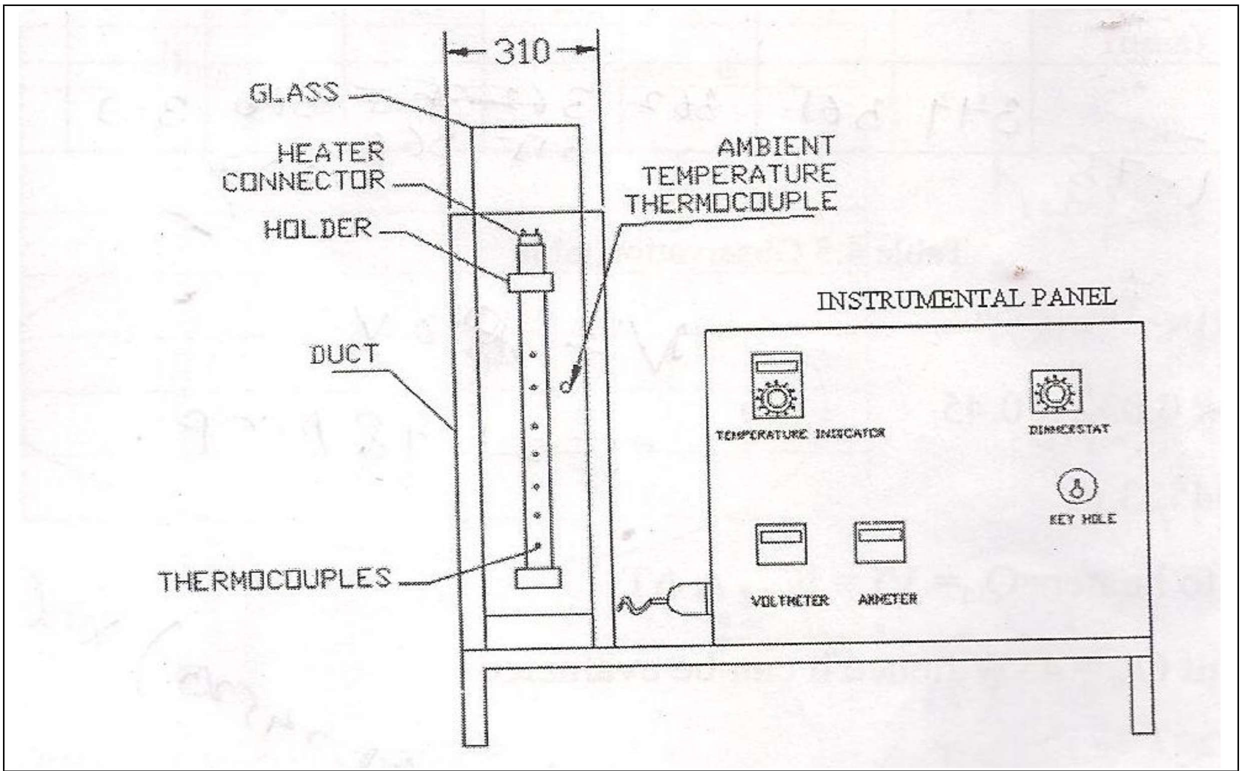

Fig.2.Schematic diagram of experimental setup

The net power input to heater is given as;

Q_{in}=V*I=h_{savg}A ΔT (1)

Where;
A=πDL

$\Delta T = T_{savg} - T_{\infty}$

The equation (1) gives practical value of heat transfer coefficient.

Now,
To make comparison of this practical value with the theoretical value, we have to use following governing equations for natural convection through vertical cylinder.

$Gr = \beta g L_c^3 \Delta T / \nu^2$(2)

Ra =Gr * Pr (3)

Where;
β = Thermal expansion coefficient
=$(1 / T_{mf})$ K^{-1}

$T_{mf} = (T_{savg} + T_{\infty}) / 2$

All the other properties of air are determined at T_{mf} (K)

Hence using free convection correlations
We have, For $10^4 < Ra < 10^9$
$Nu = 0.59*(Ra)^{0.25} = hL_c/ K$ (4)

Where, K is thermal conductivity of air at T_{mf}(K).
From equation (4) value of theoretical heat transfer coefficient is determined.
Thus using this procedure it is possible to find average practical and theoretical heat transfer coefficient.

Procedure to find local practical heat transfer coefficient and local theoretical heat transfer coefficient.

For h_1(Practical):

$Q_{in} = (VI*L_{c1})/L = h_1A_1\Delta T$ (5)

$A_1 = \pi DL_{c1}$
$T_{save} = T_1$
$T_{mf} = (T_{save}+T_\infty)/2$
Where,
T_1 = Temperature at 1st thermocouple
L_{c1} = Length of cylinder upto 1st thermocouple from base
L = Total length of cylinder

For h_1(Theoretical)
All the properties are determined at T_{mf} (K)
$Gr=\beta gL_{c1}^3\Delta T/v^2$(6)
$Ra = Gr*Pr$(7)
$Nu = h_1L_{c1}/K = 0.59(Ra)^{0.25}$ (8)

From equation (5) local practical heat transfer coefficient and equation (8) local theoretical heat transfer coefficient is determined.
By following same procedure local heat transfer coefficients at various positions are determined.

IV. RESULTS AND DISCUSSION

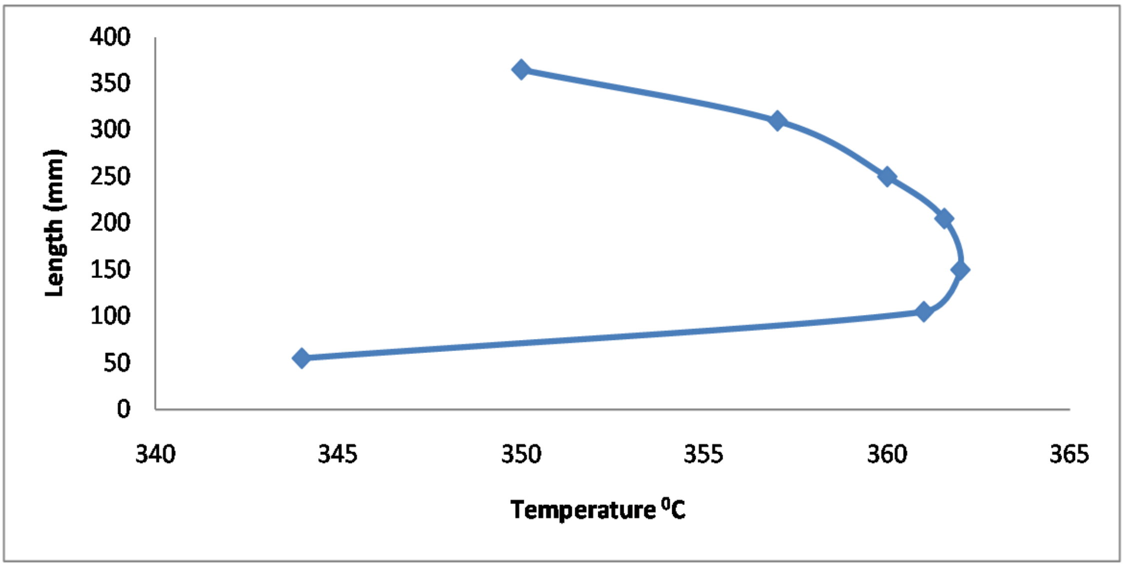

Fig.3.Temperature Variation along the Length Of Cylinder

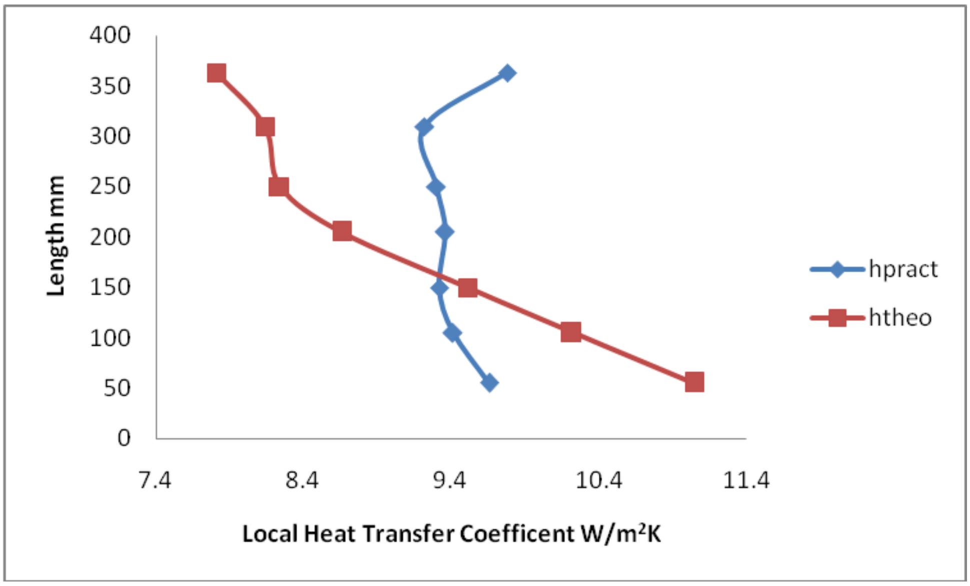

Fig.4. Variation of local heat transfer coefficient along the length of cylinder.

The first graph (Fig.3) shows variation of temperature along the length of cylinder. It is observed that as the length of cylinder increases from bottom to top, temperature also goes on increasing up to length nearly about half the length of cylinder, and then decreases continuously after the maximum temperature point is achieved.The second graph (Fig.4) shows comparison between practical and theoretical heat transfer coefficient along the length of cylinder, it is observed that value of practical heat transfer coefficient is less than theoretical heat transfer coefficient up to length nearly half of cylinder where both the lines are intersecting, due to existence of transition region of thermal boundary layer. After this, the value of practical heat transfer coefficient increases which is more than theoretical heat transfer coefficient due to turbulence flow of air.

V. CONCLUSION

5.1 The heat transfer coefficient is having maximum value at the beginning because starting of development of boundary layer i.e. thin layer and decrease in upward direction due to thickening of boundary layer. This trend is maintained nearly uptohalf length and beyond this there is little variation in the value of localheat transfer coefficient because of the presence of transition and turbulent boundary layers. The last point shows somewhat increase in the value which is attributed to end loss causing a temperature drop.

5.2. From Fig.4.

5.2.1. The practical heat transfer coefficient is less than theoretical heat transfer coefficient due to thin starting of boundary layer formation approximately upto half thelength of vertical length of cylinder.

5.2.2 Then these both the curves intersect each other, at this point, temperature decreases due to transition region.

5.2.3 After this, trend of the curve is such that value of practical heat transfer coefficient is more as compare to the theoretically calculated this is due to turbulence effect of boundary layer.

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