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Research Article

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Free Convection Heat Transfer: An Experimental Study

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Abstract The following paper reports the results of an experimental study to determine the heat transfer coefficient through natural convection from a vertical cylinder. The vertical cylinder is heated through a heating tube which is placed inside the cylinder and the heat is lost to the surrounding ambience through natural convection. Local values of heat transfer coefficient are plotted along the length of the cylinder. Results show that the heat transfer coefficient decreases as a power function with increasing length.

Keywords Nusselt number, natural convection, heat transfer coefficient

Introduction

Natural convection phenomenon is due to the temperature difference between the hot surface and the atmosphere and it is not created by any external agency. If the solid surface is hotter than its surrounding, its immediate surrounding is heated up, its density decreases and it moves in an upward direction under the action of buoyancy forces. When a hot body is kept in a still atmosphere heat is transferred to the surrounding fluid by natural convection. The fluid layer in contact with the hot body gets heated; rise up due to the decrease in its density and the cold fluid rushes in to take place. The process is continuous and the heat transfer takes place due to the relative motion of hot and cold fluid particles.

Experimental Setup

The present experimental set up is designed and fabricated to study the natural convection phenomenon from a vertical cylinder in terms of the variation of local heat transfer co – efficient along the length and also the average heat transfer co – efficient and its comparison with the value obtained by using an appropriate correction. The apparatus consists of a copper tube fitted in a rectangular duct in a vertical fashion. The duct is open at the top and bottom and forms an enclosure and serves the purpose of undisturbed surrounding. One side of the duct is made up of for visualization. An electric heating element is kept in the vertical tube which in turn heats the tube surface. The heat is lost from the tube to the surrounding air by natural convection. The temperature of the vertical tube is measured by seven thermocouples. The heat input to the heater is measured by volt and ammeters and is varied by dimmer stat. The vertical cylinder with the thermocouple positions are shown in fig. while the possible flow pattern and also the expected variation of local heat transfer co – efficient is shown in the figure below. The tube surface is polished to minimize the radiation losses.

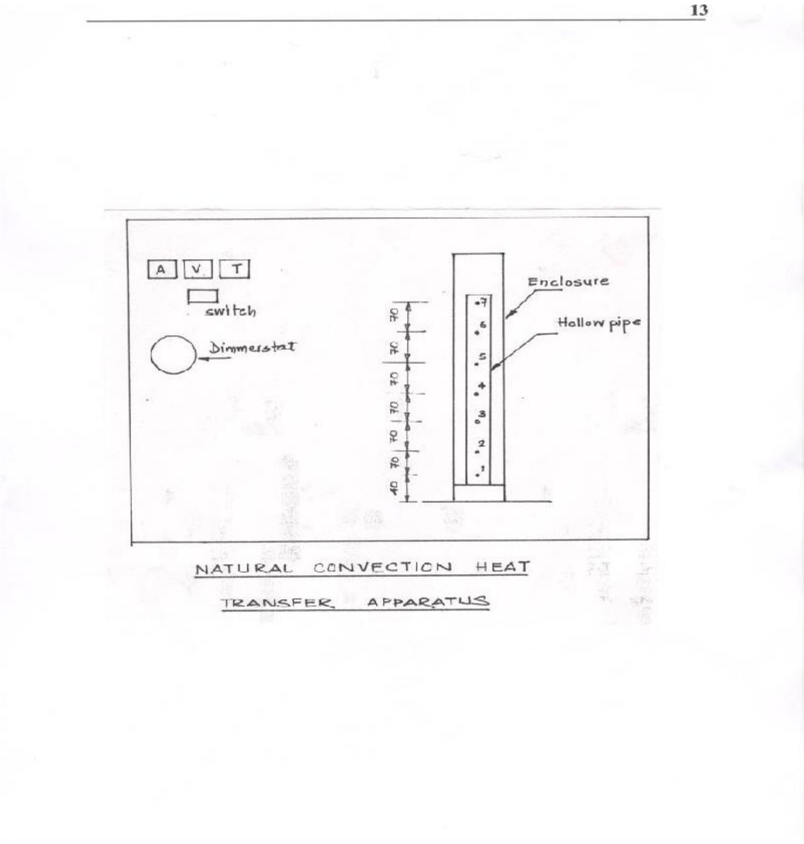


Figure 1: Schematic of the experimental set up

Specifications

- Diameter of the tube : 42 mm.
- Length of tube (*L*): 50 cm.
- Duct size : 20 cm × 175 cm. × 55cm.
- No. of thermocouples = 7 and are shown as (1) to (8) and marked on temperature indicator. Thermocouple No. 8 reads the ambient temperature & is kept in the duct.
- Voltmeter and ammeter – 1 each
- Dimerstat 0 – 2A
- Heater: 400 W

Procedure

- Put on the supply and adjust the variac to obtain the required heat input (say 100 W., 150 W, 200 W.)
- Wait till the steady state is reached which is confirmed from temperature readings (T_1 to T_7).
- Measure surface temperature at the various points T_1 to T.
- Note the ambient temperature, T_a.
- Repeat the experiment for different heat input but do not exceed 200 W.

Observation Table

Setup No.	Time	V (Volts)	I (Amp)	$Q = V \times I$	$T1$	$T2$	$T3$	$T4$	$T5$	$T6$	$T7$	$T8$
I	15:47	90	0.85	76.5	82	80	84	85	86	82	82	32
	16:02				85	84	88	89	89	84	84	33
	16:17				89	88	92	93	93	88	88	34
	16:32				91	89	94	94	94	89	89	34
	16:47				92	90	95	96	96	91	91	34
	17:02				92	91	96	96	96	91	91	34

Theoretical Calculations:

- Heat transfer coefficient is given by, $h = \frac{Q}{A_s(T_s - T_a)}$

Where, h is the average heat transfer coefficient, Q is the heat transfer rate, A_s is the area of the heat transferring surface, T_s is the average surface temperature, T_a is the average ambient temperature. The surface heat transfer coefficient of a system transferring heat by natural convection depends on the shape, dimension, and the orientation of the fluid and the temperature difference between the heat transferring surface and the fluid. The dependence on the heat transfer coefficient is usually represented non-dimensionally as

$$\frac{hL}{k} = C\left[\frac{gL^3\beta\Delta T}{\vartheta^2}.\frac{\mu C_p}{k}\right]^n$$

Where, $\frac{hL}{k}$ is the Nusselt number, $\frac{gL^3\beta\Delta T}{\vartheta^2}$ is the Grashof's number, and $\frac{\mu C_p}{k}$ is the Prandtl number.

L is the characteristic dimension of the surface, k is the thermal conductivity of the fluid, μ is the dynamic viscosity of the fluid, ϑ is the kinematic viscosity of the fluid, C_p is the specific heat of the fluid, β is the coefficient of the volumetric expansion for the fluid, g is the acceleration due to gravity, and C is a constant.

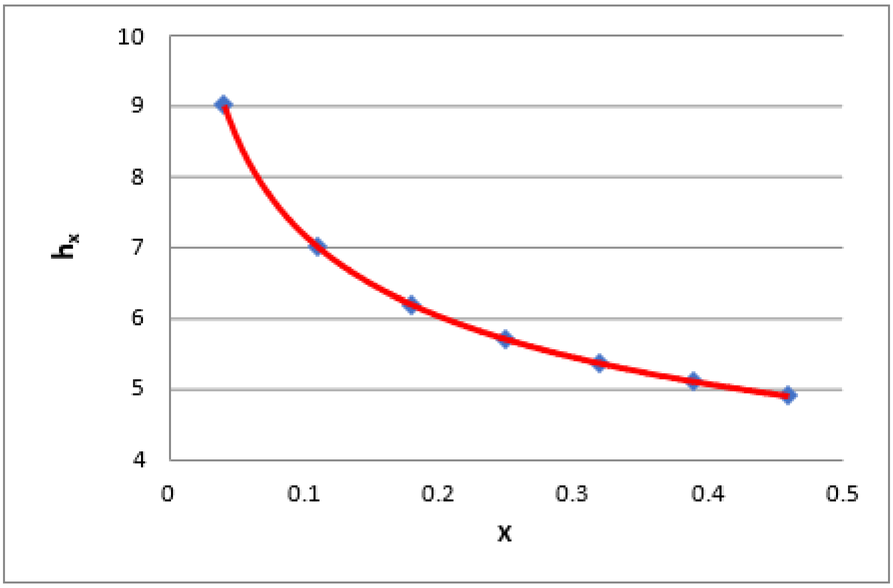
For a vertical cylinder losing heat by natural convection, the constant C and n present in the Nusselt number correlation have been determined by the following empirical correlation obtained.

$$\frac{hL}{k} = 0.59\ (Gr.Pr)^{0.25}\ for\ 10^4 < Gr.\mathrm{Pr} < 10^9$$

$$\frac{hL}{k} = 0.13\ (Gr.Pr)^{0.33}\ for\ 10^9 < Gr.\mathrm{Pr} < 10^{12}$$

All properties of the fluid are determined at film temperature. Using the above correlation we get the following results.

X (m)	$(Gr)_x$	$(Nu)_x=0.59*(Gr.Pr)^{0.25}$	$(h)_x$
0.04	$4.036*10^5$	13.740	9.019
0.11	$8.395*10^6$	29.324	6.997
0.18	$3.678*10^7$	42.427	6.187
0.25	$9.855*10^7$	54.280	5.699
0.32	$2.066*10^8$	65.321	5.358
0.39	$3.741*10^8$	75.768	5.099
0.46	$6.139*10^8$	85.784	4.893



Results

The heat transfer co – efficient is having a maximum value at the beginning as expected because of the just starting of the building of the boundary layer and it decreases as expected in the upward direction due to thickening of layer and which is laminar one, this trend is maintained up to half of the length (approximately) and beyond that there is little variation in the valve of local heat transfer co – efficient because of the transition and turbulent boundary layers. The last point showed somewhat increase in the value of *h* which is attributed to and loss causing a temperature drop. The comparison of average heat transfer coefficient is also made with predicated values by using (3) and (4). It is found that the predicted values are somewhat less than experimental value due to the heat loss by radiation.

Conclusion

Thus, through this experiment we have successfully determined the value of the surface heat transfer co – efficient for a vertical tube losing heat by natural convection through the vertical tube. The local heat transfer coefficient decreases as the height increases with the effective range being from 2 to 25. Our result is successfully verified as the value worked out from the experiment lies within the range.

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