Experimental Heat Transfer Analysis of Different Metal and Electroplated Metal Tubes Under Natural Convection

Raman Lal Dewangan[1] , Dilbag Singh Mondloe[2], , Kumar Ram Sahu[3], Umesh Kumar Suryawanshi[4]

[1] M. Tech. Student Dept. of Mechanical Engineering, Government Engineering college Jagdalpur, Chhattisgarh., India

[2] Assistant Professor Dept. of Mechanical Engineering, Government Engineering College , Jagdalpur Chhattisgarh, India,

ABSTRACT

Heat transfer by natural convection occurs due to the movement of fluid induced by the density gradient in a heating or cooling process. Natural convection heat transfer study from heated vertical cylinders is studied experimentally and numerically. Vertical cylinders were performed with four test cylinders made of copper, aluminum, brass and stainless steel metal tubes. The electroplating is done for remaining three metal tubes expect copper cylinder. The electroplating method is required for coating on metals. After coating is completed the experiments were performed for different metal tubes and electroplated metal tubes for various heat inputs. Experiments were performed in experimental setup for different temperature and ambient conditions which were varies from different metals and copper coated metals according to the given heat input by heater from the main supply. Heat loss outside surrounding from the tube is improves by 12.71% for electroplated aluminum tube as compare to copper tube and average surface heat transfer coefficient is improved by 2.21% for electroplated aluminum tube as compare to copper tube.

Keyword: - *Heat transfer Rate, Natural Convection , Vertical Cylinder, Surface Heat Transfer Coefficient, Temperature Distribution.*

1. INTRODUCTION

Heat transfer by natural convection occurs due to the movement of fluid induced by the density gradient in a heating or cooling process. The natural convection of vertical cylinders has many engineering applications, such as heat loss from process pipes, HVAC system, cooling of electronic components, steam or electric heating in process vessels, heat removal of fuel packages nuclear power and cooling of the nuclear reactor core after the loss of accidents with the refrigerant, heat exchangers, drying processes, electrical components of transmission lines, nuclear energy fields, solar energy and thermal storage systems. The natural convection of the vertical cylinder and of a vertical plate differs significantly due to the effects of curvature. "Heat is a form of energy, the molecules of a substance are in parallel motion, the average kinetic energy per mole of substance is proportional to its absolute temperature**.**

1.1 NATURAL OR FREE CONVECTION: Free or natural Convection: Free or natural convection occurs when the fluid circulates due to natural differences in the density of hot and cold fluids; the denser parts of the fluid move downward due to the greater gravity, compared to the force in the less dense. In heat transfer by natural convection, the number of Grashof is significant for the calculation of heat transfer and the number of nusselt is a function of the Grashof number and the number of prandtls.

Mathematically it is represented by Nu = f (Gr and Pr)

1.2 MECHANISM OF NATURAL CONVECTION

Consider a hot object exposed to cold air. The temperature of the external object will decrease (as a result of heat transfer with cold air) and the air temperature adjacent to the object will increase. As a result, the object is surrounded by a thin layer of warmer air and the heat will be transferred from this layer to the outer layers of the air.

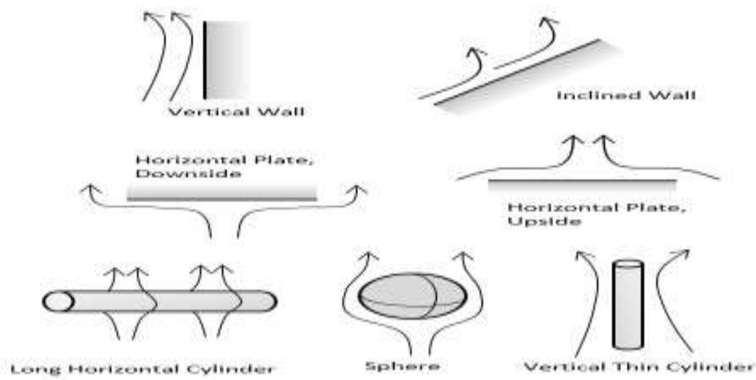


Fig: Natural Convection of Different Heated Bodies

Grashof number: Grashof number is a group without dimensions. It is defined as the relationship between the fluctuating force and the viscous force acting on the fluid. It is represented by the dimensionless group Gr.

Groshof no.= (Bouyancy or fluctuating force)/(viscous force)

It is expressed as

$$Gr\ no. = g\beta\Delta TL^3/\upsilon^2$$

Prandtl number: The Prandtl number is a dimensionless number that approximates the relation of diffusivity of the moment (kinematic viscosity) to the thermal diffusivity and can be expressed as

$$Pr = \upsilon/\alpha$$

The Prandtl number can be expressed alternatively as

$$Pr.no. = (\mu \times cp)/k$$

Nusselt number: the Nusselt number, Nu, is the dimensionless parameter that characterizes the heat transfer by convection. It is defined as the ratio between heat transfer by convection (α) and heat transfer by conduction alone (λ / L).

$$Nu.no. = hL/k$$

2. EELECTROPLATING:

Electroplating is a process that uses an electric current to reduce dissolved metal cations to form a uniform, thin layer of metal on an electrode or cathode. In the process of copper electroplating on the surface of any metal, we have taking concentrated copper sulfate solution and concentrated sulfuric acid solution necessary for our plating object. We must request a glass or a rectangular glass according to the length required for electrode position. A DC or AC power supply with a voltmeter or portable charger to reduce the main current of the source.

Material needed

1M $CuSO_4$, 19.5 V battery/ 5 volts AC mobile charger, copper clips, connecting cables, electrochan objects, cup, 6 M H_2SO_4, nickel strip (optional), silver strip (optional) is required.

Electrochemical reactions

$$\text{At Anode } Cu \rightarrow Cu^{2+} + 2e^- \uparrow$$
$$\text{At Cathode } Cu^{2+} + 2e^- \downarrow \rightarrow Cu$$

2.1 Natural Convection Experimental Setup

The apparatus consist of a brass tube fitted in a rectangular vertical duct. The duct is open at the top end forms an enclosure and serves the purpose of undisturbed surrounding. One side of the duct is made up of Perspex for visualization. An electrical heating element is kept in the vertical tube which in turns heat the tube surface. The heat is lost from the tube to the surrounding air by natural convection. The temperature of vertical tube is measured by an ammeter and a voltmeter and is varied by a dimmerstar. The tube surface is polished to minimize the radiation losses.

2.2 Specification of Experimental Setup:

Outer Diameter of the tube (d) = 38 mm.

Materials: Copper , Brass, Aluminum , Stainless steel, Electroplated Aluminum, Electroplated Brass , Electroplated Stainless Steel metals tubes are used.

Length of the tube (L) = 500 mm

Duct size 200 mm x 200 mm x 800 mm

Multichannel Digital Temperature Indicator 0 – 199 °C .

Digital ammeter 0 – 2 Amp. and Digital Voltmeter 0 – 300 Volts.

Dimmer star 2Amp. 240 Volts quantity 1.

Thermocouple K type 12 nos.

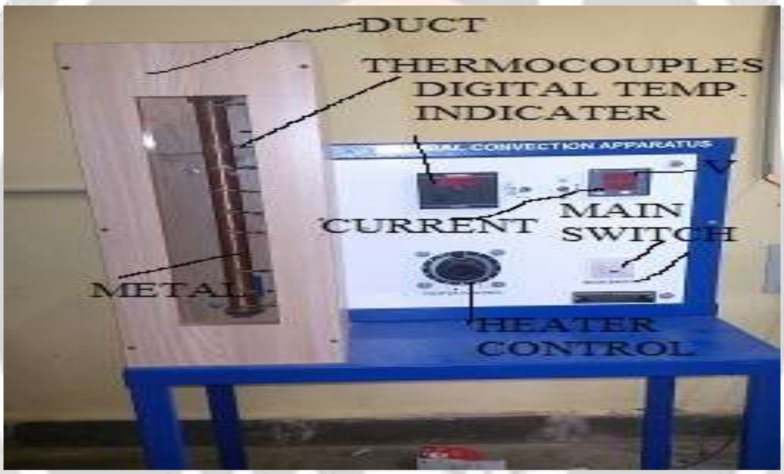


Fig. Experimental Setup Of Natural Convection

Fig. Different metal and electroplated metal tubes

Experimental Reading for different metal and electroplated metal tubes

	Surface Temperature									Ambient Temperature		
Metal Tubes	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
Copper	74.6	75.4	75.3	76.0	76.1	74.9	76.4	75.0	75.3	31.7	31.6	31.5
Al	69.3	70.3	69.2	70.5	69.1	70.2	71.2	70.0	71.2	30.8	30.7	30.8
Brass	67.1	67.3	68.6	69.1	70.0	69.8	70.9	70.1	71.0	31.7	31.8	31.9
SS	60.8	61.1	62.9	61.6	60.0	61.7	60.5	61.0	61.6	31.3	31.5	31.6
Al + Cu	78.5	80.1	79.6	80.3	81.5	79.3	81.5	78.0	80.8	31.7	31.6	31.5
Br + Cu	70.1	70.3	71.2	72.4	73.2	73.5	73.8	74.0	74.3	31.3	31.5	31.6
SS + Cu	62.8	63.2	62.8	62.4	63.5	62.7	63.5	63.7	65.8	30.9	31.2	31.3

2.3 Data Analysis

Heat Transfer coefficient is given by

$$h = \frac{Q}{As \times (Ts - Ta)}$$

Where,

h = Average surface heat transfer coefficient (W/m²°C)
As = Surface Area of heat transfer pipe/tube = π d l (m²)
Ts = Average surface temperature in K/°C
Ta = Ambient temperature in the Duct in (K/°C)
Q = Heat input from the heater inside the tubes (Watts)

$$Ts = \frac{T1 + T2 + T3 + T4 + T5 + T6 + T7 + T8 + T9}{9}$$

$$Ta = \frac{T10 + T11 + T12}{3} \ {}^{\circ}C$$

The surface heat transfer coefficient, of a system transferring heat by natural convection depends on the shape, dimensions and orientations of the fluid and temperature difference between heat transfer surface and the fluid. The dependence of 'h' on all the above mentioned parameters is generally expressed in terms of non dimensional groups as follows :

$$Gr = \frac{g\beta(Ts - Ta)\delta^3}{\upsilon^2}$$

$$Gr = \frac{g\beta\Delta tL^3\rho^2}{\mu^2}$$

$$Gr = \frac{g\beta\Delta tL^3}{\upsilon^2}$$

Where,

g = Gravitational acceleration , m²/s

β = Coefficient of volume expansion , 1/K

δ = Characteristic length of the geometry , m

υ = Kinematics viscosity of the fluid , m²/s

ρ = Density of flowing fluid , Kg/m³

Δt = Average surface and average ambient temperature difference °C

For gases,

$$\beta = \frac{1}{(Tf + 273)}$$

$$Tf = \frac{(Ts + Ta)}{2}$$

$$Pr = \frac{\mu \times Cp}{K\ air}$$

Where,

Pr = Prandtl number

μ = Absolute or dynamic viscosity , kg/m s

Cp = Specific heat capacity , J/kg K

k = Thermal conductivity of the fluid , W/m-k

$$Nu = \frac{h \times L}{K\ air} = \frac{h \times D}{K\ air}$$

Where ,

h = convective heat transfer coefficient (W/m²- k)

L = representative dimension (e.g., diameter for pipes, length of the pipes), (m) and

k = thermal conductivity of the fluid (W/m K).

For a vertical cylinder losing heat by natural convection the following empirical correlation's

For Higher values of Gr.Pr & Constant heat flux/ constant wall temperature.

$$\frac{h \times L}{K\ air} = 0.59(Gr.Pr.)^{0.25} \text{ For } 10^4 < Gr.Pr. < 10^9 \text{ for laminar } Gr.Pr. < 10^9 \quad \_\_\_\_\_\_\_(2)$$

$$\frac{h \times L}{K\ air} = 0.10\ (Gr.Pr.)^{0.333} \text{ For } 10^9 < Gr.Pr. < 10^{12}$$

Turbulent $GrPr > 10^9$ _______(3)

For both constant heat flux and constant wall temperature.

L = length of the cylinder.

All the properties of the fluid are determined at the mean film temperature (Tf).

2.4 Calculation :

(1) Calculate the value of average heat transfer coefficient, neglecting end losses using equation (1) or (2)

(2) Calculate and plot the variation of local heat transfer coefficient along the length of the tube using :

Ts = T1 to T9 and

$$h = \frac{Q}{As \times (Ts - Ta)}$$

and , $q = h\ As\ (Ts - Ta)$

Q = Heat input from the heater inside along the length of the tubes (Watts)
h = Average surface heat transfer coefficient (W/m² °C)
As = Surface Area of heat transfer pipe/tube = π d l (m²)
Ts = Average surface temperature in K/°C
Ta = Ambient temperature in the Duct in (K/°C)
q = Heat loss outside surrounding from the tubes (Watts).

3. Results And Discussions

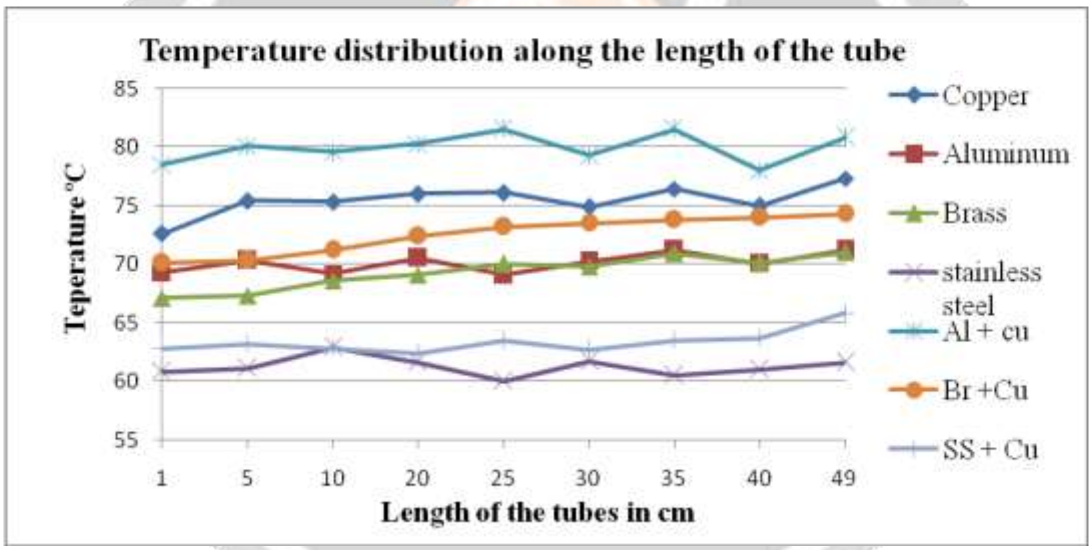
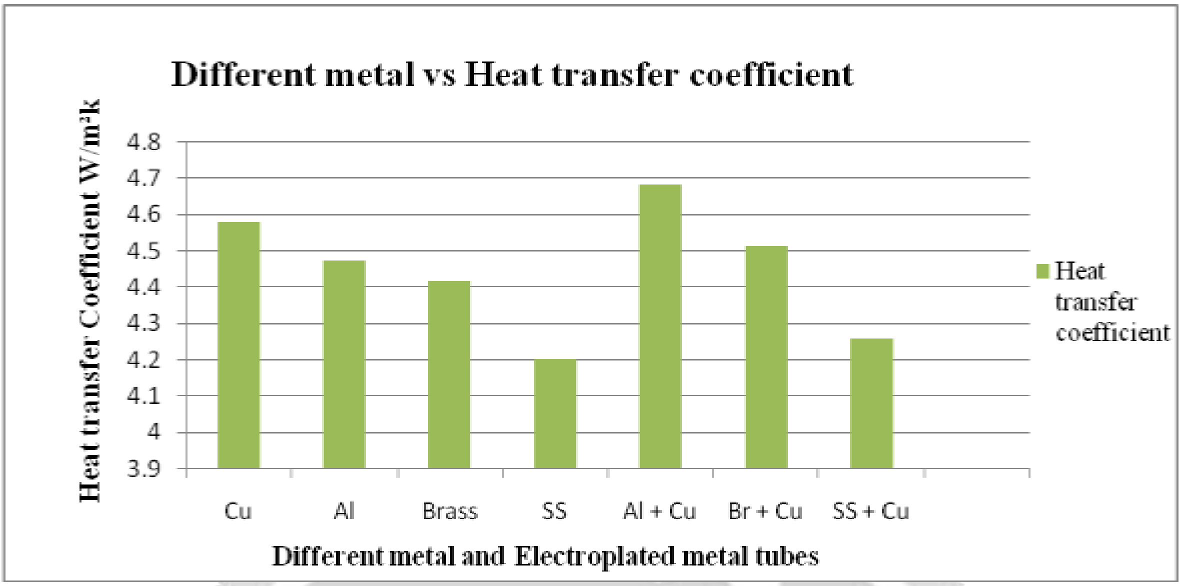
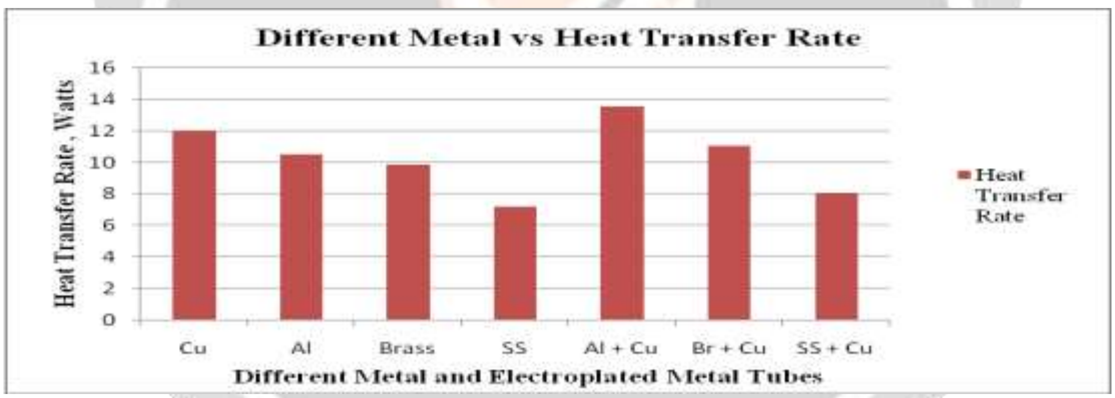


Fig. Temperature distribution along the length of the Different metal tubes

3.1 Temperature distribution along the length of the tube (Experimentally): The above figure shown temperature distribution along the length of the tube. The temperature distribution is highest for the electroplated Al metal tube as compare to copper, brass, aluminum, stainless steel, electroplated brass and electroplated SS metal tubes respectively and lowest for stainless steel metal tube.



3.2 Average surface heat transfer coefficient: The graph shown above Different metal and Electroplated metal tubes verses average surface heat transfer coefficient. The percentage change of average surface heat transfer coefficients (experimentally) are improves range from 2.21% to 9.94% for electroplated aluminum metal tube as compare to different metal and electroplated metal tubes. The calculations are done on mean fluid temperature of air.



3.3 Heat transfer rate: The graph shown above Different metal and electroplated metal tubes verses heat transfer rate. The percentage change of surface heat transfer rates (experimentally) are improves range from 12.71% to 66.95% for electroplated aluminum metal tube as compare to as compare to different metal and electroplated metal tubes. The calculations are done on mean fluid temperature of air.

4. CONCLUSIONS:

The present investigation of natural convection for different metals and electroplated metal tubes has led to following conclusions:

1. The surface heat transfer coefficient is improved by 2.21% of copper electroplated aluminum metal tube as compare to pure copper metal tube.
2. The heat transfer rate is improved by 12.71% of electroplated aluminum metal tube as compare to pure copper metal tube.
3. Identify the temperature distribution along the length of the different metal and electroplated metal tubes.
4. Plotting the graph between different metal and electroplated metal tubes vs heat transfer coefficient and heat transfer rate at mean fluid temperature of air.

5. REFERENCES:

[1]. Eckert ERG, Diaguila AJ. Experimental investigation of free convection heat transfer in vertical tube at large Grashof numbers. NACA 1955:1e14.
[2]. Davis LP, Perona JJ. Development of free convection flow of a gas in a heated vertical open tube.Int J Heat Mass Transf 1971;14(7):889e903.
[3]. Elenbaas W. The dissipation of heat by free convection the inner surface of vertical tubes of different shape of cross-section.Physica 1942;9(8):865e74.
[4]. Ş.Ö. Atayılmaz, İ. Teke, Experimental and numerical study of the natural convection from a heated horizontal cylinder, International Communications in Heat and Mass Transfer 36 (2009) 731–738.
[5]. N.Ahmeda, N. Ali Shaha, D.Vierub ,Natural convection with damped thermal flux in a vertical circular cylinder , Chinese Journal of Physics 56 (2018) 630–644
[6]. M. Arshad, M.H. Inayat, I.R. Chughtai, Heat transfer through vertical cylinder in stationary fluid, The Nucleus 46 (3) (2009) 177e181.

BIOGRAPHIES

M. Tech. Student in Department of Mechanical Engineering, Government Engineering College Jagdalpur ,Chhattisgarh., India