DEPARTMENT OF MECHANICAL ENGINEERING

HEAT TRANSFER-R15

DEPARTMENT OF MECHANICAL ENGINEERING
SVR ENGINEERING COLLEGE
NANDYAL-518501

HEAT TRANSFER LAB MANUAL

LIST OF EXPERIMENTS

1. Thermal Conductivity Of Insulating Powder Apparatus
2. Lagged pipe apparatus
3. Thermal conductivity of metal rod apparatus
4. Heat transfer by natural convection apparatus
5. Heat transfer by forced convection apparatus
6. Critical heat flux apparatus
7. Parallel flow heat exchanger apparatus
8. Counter flow heat exchanger apparatus
9. Stefan Boltzmann apparatus
10. Emissivity measurement of radiating surfaces apparatus

Date:

Exp No:

THERMAL CONDUCTIVITY OF INSULATING POWDER

AIM:

To determine the thermal conductivity of insulating powder at various heat inputs.

THEORY:

FORIER LAW OF HEAT CONDUCTION:

A Materials having lower thermal conductivity are called insulators. Examples for good conductors include all metals. While asbestos, magnesia, glass wool etc., are some the examples for insulators.

The radial heat conduction for single hollow sphere transferring heat from inside to outside is given by

$$Q = \frac{4k\pi . r_i r_o (T_i - T_o)}{r_o - r_i}$$

This law states that rate of heat flow through a surface is directly proportional to the area normal to the surface and the temperature gradient across the surface.

$$Q \ \alpha \frac{dT}{dX}$$

$$Q = -kA\frac{dT}{dX}$$

Negative sign indicates that the heat flows from higher temperature to the lower temperature. K is called the thermal conductivity.

THERMAL CONDUCTIVITY:

This can be defined as the amount of heat that can flow per unit time across a unit cross sectional area when the temperature gradient is unity. The units of thermal conductivity are w/m-K. Materials having higher thermal conductivity are called conductors while those

Where:

Q = rate of heat transfer in watts = V X I

k = Thermal conductivity w/m-k

r_i = radius of inner sphere in meters

r_o = radius of outer sphere in meters

T_i =Temperature of the inner sphere

T_o =Temperature of the outer sphere

DESCRIPTION OF APPARATUS:

The apparatus consists of two concentric copper spheres. Heating coils is provided in the inner sphere. The space between the inner and outer spheres are filled by the insulating powder whose thermal conductivity is to be determined. The power supply to the heating coils is adjusted by using dimmer stat. Chromel - Alumel thermocouples are used to record the temperatures. Thermocouples 1 to 6 are embedded on the surface of inner sphere and 7 to 12 are embedded on the outer shell surface.

SPECIFICATIONS:

1. Radius of inner sphere = 50mm
2. Radius of outer sphere = 100 mm
3. Voltmeter 0-300V & Ammeter 0-5amps.
4. Dimmer stat – 2 amps.
5. Temperature indicator 0-300^{0}c

PROCEDURE:

1. Connect the unit to an AC source 240 V 5amps and switch on the MCB.
2. Operate the dimmer stat slowly to increase the heat input to the heater and adjust the voltage to any desired voltage (do not exceed 150V).
3. Maintain the same heat input throughout the experiment until the temperature reaches a steady state.
4. Note down the following readings provided in the Observation table.
5. Repeat the experiment for other heat inputs.

OBSERVATION TABLE:

Sl. No.	Heat Input		Inner Surface temp C						Outer Surface temp C					
	V	A	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
1.														
2.														

3.														

Average T_i = $\frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6}{6}$ ^oC

Average T_o = $\frac{T_7 + T_8 + T_9 + T_{10} + T_{11} + T_{12}}{6}$ ^oC

$$k = \frac{Q(r_o - r_i)}{4\pi\, r_i r_o (T_i - T_o)} \quad w/mK$$

GRAPH:

Plot the graph K vs Heat Input

PRECAUTIONS:

1. Keep the dimmer stat to zero before starting the experiment.
2. Take readings at study state condition only.
3. Use the selector switch knob and dimmer knob gently.

RESULT:

The thermal conductivity of insulating powder at various heat inputs has been determined.

Date:

Exp No:

LAGGED PIPE

AIM

To determine thermal conductivity of different insulating materials, Overall heat transfer coefficient of lagged pipe and thermal resistance.

APPARATUS

The apparatus consists of three concentric pipes mounted on suitable stand. The hollow space of the innermost pipe consists of the heater. Between first two cylinders the insulating material with which lagging is to be done is filled compactly. Between second and third cylinders, another material used for lagging is filled. The third cylinder is concentric to other outer cylinder. The thermocouples are attached to the surface of cylinders appropriately to measure the temperatures. The input to the heater is varied through a dimmerstat .

SPECIFICATIONS:

Diameter of heater rod d_H= 20 mm

Diameter of heater rod with asbestos lagging d_A= 40mm

Diameter of heater rod with asbestos and saw dust lagging d_S=80mm

Effective length of the cylinder l= 500mm.

PROCEDURE:

1. Switch on the unit and check if channels of temperature indicator showing proper change temperature.
2. Switch on the heater using the regulator and keep the power input at some particular value.
3. Allow the unit to stabilize for about 20 to 30 minutes
4. Now note down the ammeter reading, voltmeter reading, which gives the heat input, temperatures 1,2,3 are the temperature of heater rod, 4,5,6 are the temperatures on the asbestos layer, 7 and 8 are the temperatures on the sawdust lagging.
5. The average temperature of each cylinder is taken for calculation.
6. The temperatures are measured by thermocouple with multipoint digital temperature indicator.
7. The experiment may repeat for different heat inputs.

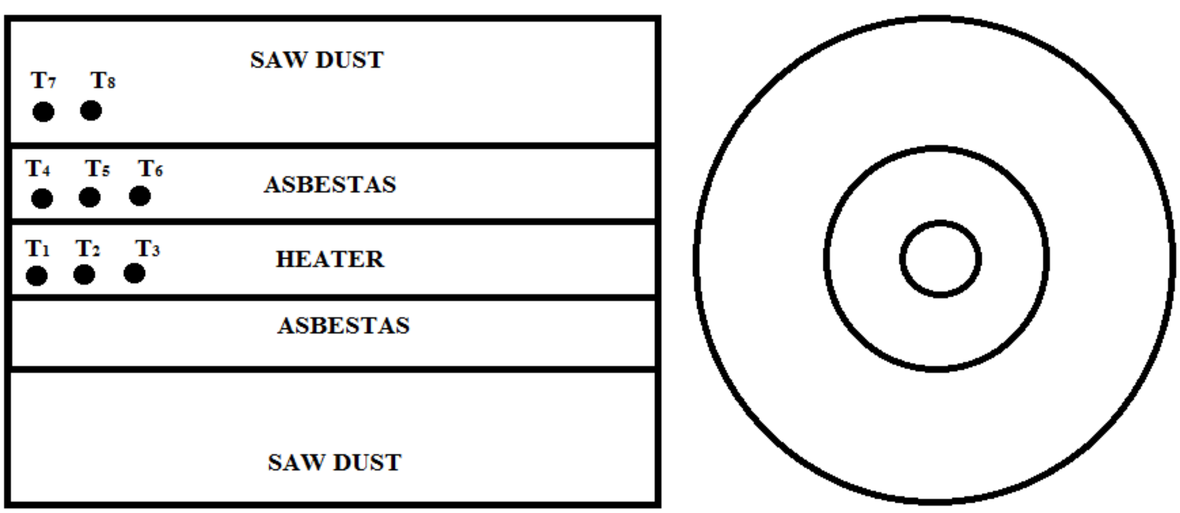

Fig: Lagged pipe Apparatus

OBSERVATIONS:

Sl. No.	V Volt	I amps	Heater Temp(T_H)				Asbestos Temp(T_A)				Sawdust Temp(T_S)		
			T_1	T_2	T_3	$(T_H)_{Avg}$	T_4	T_5	T_6	$(T_A)_{Avg}$	T_7	T_8	$(T_S)_{Avg}$
1													
2													
3													

CALCULATIONS:

1. Mean readings

$$(T_H)_{Aveg} = \frac{T_1 + T_2 + T_3}{3} \ {}^oC$$

$$(T_A)_{Aveg} = \frac{T_4 + T_5 + T_6}{3} \ {}^oC$$

$$(T_S)_{Aveg} = \frac{T_7 + T_8}{2} \ {}^oC$$

2. Temperature difference

$$\nabla T_1 = (T_H)_{Aveg} - (T_A)_{Aveg}$$

$$\nabla T_2 = (T_H)_{Aveg} - (T_S)_{Aveg}$$

3. Heat flow Q=VI

4. Thermal conductivity of Asbestos lagging

$$k_{Asbestos} = \frac{Q \ln (r_2 / r_1)}{2\pi L \Delta T_1} W / mK$$

5. Thermal conductivity of Asbestos lagging

$$k_{Sawdust} = \frac{Q \ln (r_3 / r_2)}{2\pi L \Delta T_2} W / mK$$

6. Overall heat transfer coefficient $U = \frac{1}{r_1}\left(\frac{1}{\left[\frac{1}{k_1}\ln\frac{r_2}{r_1} + \frac{1}{k_2}\ln\frac{r_3}{r_2}\right]}\right)\frac{W}{m^2 k}$

7. Thermal resistance of Asbestos $R_{\text{Asbestos}} = \frac{\Delta T_1}{Q} k / W$

8. Thermal resistance of Sawdust $R_{\text{Sawdust}} = \frac{\Delta T_2}{Q} k / W$

PRECAUTIONS:

1) Keep dimmer stat to ZERO position before start.
2) Increase voltage gradually.
3) Keep the assembly undisturbed while testing.
4) While removing or changing the lagging materials do not disturb the thermocouples.
5) Do not increase voltage above 150V
6) Operate selector switch of temperate indicator gently.

<u>RESULTS</u>: Thermal conductivity of different insulating materials, Overall heat transfer coefficient of lagged pipe and thermal resistance has been determined.

1. Thermal conductivity of asbestos powder lagging $k_{Asbestos}$ =…………………
2. Thermal conductivity of sawdust lagging $k_{Sawdust}$ =……………………….
3. Overall heat transfer coefficient U=…………………………
4. Thermal resistance of Asbestos R_{Asbestos} =……………………………
5. Thermal resistance of Sawdust R_{Sawdust} =………………………………..

Date:
Exp No:

THERMAL CONDUCTIVITY OF METAL ROD

AIM:

To determine the thermal conductivity of given metal rod.

THEORY:

From Fourier's law of heat conduction

$$Q = -kA \frac{dT}{dx}$$

where

Q = Rate of heat conducted, W

A = Area of heat transfer, m^2

k = Thermal conductivity of the material, W/m-K

$\frac{dT}{dx}$ = Temperature gradient

Thermal conductivity is a property of the material and may be defined as the amount of heat conducted per unit time through unit area, when a temperature difference of unit degree is maintained across unit thickness.

DESCRIPTION OF THE APPARATUS:

The apparatus consists of a brass rod, one end of which is heated by an electric heating coil while the other end projects into the cooling water jacket. The rod is insulated with glass wool to minimize the radiation and convection loss from the surface of the rod and thus ensure nearly constant temperature gradient throughout the length of the rod. The temperature of the rod is measured at five different locations. The heater is provided with a dimmerstat for controlling the heat input. Water is circulated through the jacket and its flow rate and temperature rise can be measured.

SPECIFICATIONS :

Specimen material	:	Brass rod
Size of the Specimen	:	ϕ20 mm, 450mm long
Cylindrical shell	:	300mm long
Voltmeter	*:*	*Digital type, 0-300volt, AC*
Ammeter	:	Digital type, 0-20amp, AC
Dimmer for heating Coil	:	0-230v, 12amps
Heater	:	Band type Nichrome heater, 250 W
Thermocouple used	:	11 nos.
Temperature indicator	:	Digital type, 0-200^{0}c, Cr-Al

PRODEDURE:

1. Power supply is given to the apparatus.
2. Give heat input to the heater by slowly rotating the dimmer and adjust the voltage to say 60 V, 80 V, etc
3. Start the cooling water supply through the jacket and adjust its flow rate so that the heat is taken away from the specimen constantly.
4. Allow sufficient time for the apparatus to reach steady state.
5. Take readings of voltmeter and ammeter.
6. Note the temperatures along the length of the specimen rod at 5 different locations.
7. Note down the inlet & outlet temperatures of cooling water and measure the flow rate of water.

8. Repeat the experiment for different heat inputs.

OBSERVATION TABLE:

CALCULATION:

Plot the variation of temperature along the length of the rod. From the graph, obtain dT/dx, which is the slope of the straight line passing through/near to the points in the graph. Assuming no heat loss, heat conducted through the rod = heat carried away by the cooling water

$$kA\frac{\mathrm{dT}}{\mathrm{dx}} = m_f C_p \left(T_{11} - T_{10}\right)$$

Where, 'k' = thermal conductivity of metal rod, (W/m-K)

'A' = Cross sectional area of metal rod = $\pi d^2/4$ (m^2)

'V' Volt	*'I' Amp*	*Metal rod thermocouple reading (0C)*									*Water temp (0C)*		*Volume flow rate of water, V cc/min*
											In let	*Outlet*	
		T_1	*T_2*	*T_3*	*T_4*	*T_5*	*T_6*	*T_7*	*T_8*	*T_9*	*T_{10}*	*T_{11}*	
1.													
2.													
3.													

‘d’ = diameter of the specimen = 20 mm

‘C_p’ = Specific heat of water = 4.187 kJ/kg-K

Thus, the thermal conductivity ‘k’ of metal rod can be evaluated.

$$k = \frac{m_f C_p \left(T_{11} - T_{10}\right)}{A \frac{dT}{dx}}$$

GRAPH:

Plot the graph Distance vs Temperature.

PRECAUTIONS:

4. Keep the dimmer stat to zero before starting the experiment.
5. Take readings at study state condition only.
6. Use the selector switch knob and dimmer knob gently.

RESULT:

The thermal conductivity of given metal rod has been determined.

Date:
Exp No:

HEAT TRANSFER BY NATURAL CONVECTION

AIM:

To find out heat transfer coefficient and heat transfer rate from vertical cylinder in natural convection.

THEORY:

Natural convection heat transfer takes place by movement of fluid particles on solid surface caused by density difference between the fluid particles on account of difference in temperature. Hence there is no external agency facing fluid over the surface. It has been observed that the fluid adjacent to the surface gets heated, resulting in thermal expansion of the fluid and reduction in its density. Subsequently a buoyancy force acts on the fluid causing it to flow up the surface. Here the flow velocity is developed due to difference in temperature between fluid particles.

The following empirical correlations may be used to find out the heat transfer coefficient for vertical cylinder in natural convection.

$$Nu = 0.53(Gr.\Pr)^{\frac{1}{4}} \quad \textbf{for } Gr.Pr<10^5$$

$$Nu = 0.56(Gr.\Pr)^{\frac{1}{4}} \quad \textbf{for } 10^5<Gr.Pr<10^8$$

$$Nu = 0.13(Gr.\Pr)^{\frac{1}{3}} \quad \textbf{for } 10^8<Gr.Pr<10^{12}$$

Where,

Nu = Nusselt number = $\frac{hL}{k}$

Gr = Grashof number = $\frac{L^3 \beta g (T_S - T_a)}{\nu^2}$

Pr = Prandtl number = $\frac{\mu C_p}{k}$

β = Coefficient of Volumetric expansion (or) temperature co-efficient of thermal conductivity in $\frac{1}{K}$

For ideal gases β = $\frac{1}{T_f}$

Where 'T_f' is the absolute film temperature at which the properties are taken.

SPECIFICATIONS:

Specimen	: Stainless Steel tube,
Size of the Specimen	: Outer diameter 45mm, 500mm length
Heater	: Nichrome wire type heater along its length
Thermocouples used	: 6nos.
Ammeter	: Digital type, 0-2amps, AC
Voltmeter	: Digital type, 0-300volts, AC
Dimmer stat for heating coil	: 0-230 V, 2 amps, AC power
Enclosure with acrylic door	: For visual display of test section (fixed)

APPARATUS:

The apparatus consists of a stainless steel tube fitted in a rectangular duct in a vertical position. The duct is open at the top and bottom and forms an enclosure and serves the purpose of undisturbed surroundings. One side of the duct is made of acrylic sheet for visualization. A heating element is kept in the vertical tube, which heats the tube surface. The heat is lost from the tube to the surrounding air by natural convection. Digital temperature indicator measures the temperature at different points with the help of seven temperature sensors, including one for measuring surrounding temperature. The heat input to the heater is measured by Digital Ammeter and Digital Voltmeter and can be varied by a dimmer stat.

PROCEDURE:

1. Ensure that all ON/OFF switches given on the panel are at OFF position.
2. Ensure that variac knob is at zero position, provided on the panel.
3. Now switch on the main power supply (220 V AC, 50 Hz).
4. Switch on the panel with the help of mains ON/OFF switch given on the panel.
5. Fix the power input to the heater with the help of variac, voltmeter and ammeter provided.
6. Take thermocouple, voltmeter & ammeter readings when steady state is reached.
7. When experiment is over, switch off heater first.
8. Adjust variac to zero position.
9. Switch off the panel with the help of Mains On/Off switch given on the panel.
10. Switch off power supply to panel.

TABULAR COLUMN:

Sl. No.	V Volts	I Amps	Thermocouple readings °C					
			T_2	T_3	T_4	T_5	Chamber	
							Lower T_1	Upper T_6
1.								
2.								
3.								

CALCULATIONS:

1. Temperature of vertical cylinder wall $T_w = \frac{T_2 + T_3 + T_4 + T_5}{4} + 273.15$ º K =...........
2. Surrounding ambient temperature $T_\infty = \frac{T_1 + T_6}{2}$ =_______+ 273.15 º K
3. Obtain the properties of air at a mean temperature of $T_f = \frac{T_w + T_\infty}{2}$ ºK
4. Volumetric coefficient of thermal expansion $\beta = \frac{1}{T_f}$
5. Rayleigh Number Ra = Gr.Pr
6. Grashof Number, $Gr = \frac{L^3 \beta g (T_w - T_\infty)}{\nu^2}$

   Where,

   Pr= Prandtl number (from Data book at T_f)………………

   ν =kinematic viscosity……….. m^2/sec (from Data book at T_f)
7. Nusselt Number $Nu = \frac{hL}{k}$

   The following correlations are used to find Nusselt Number

$$Nu = 0.53(Gr.\mathrm{Pr})^{\frac{1}{4}}$$ **for Gr.Pr<10⁴**

$$Nu = 0.59(Gr.\mathrm{Pr})^{\frac{1}{4}}$$ **for 10^4<Gr.Pr<10^9**

$$Nu = 0.10(Gr.\mathrm{Pr})^{\frac{1}{3}}$$ **for 10^9<Gr.Pr**

8. Free convective heat transfer coefficient

$$h = \frac{Nu.k}{L}$$ W/m²–K

9. Heat transfer rate by convection

$Q_c = h A (T_w - T_\infty)$

$Q_c = h \pi d L (T_w - T_\infty)$ watt

10. Heat Input to the coil

$Q_i = V \times I$ watts

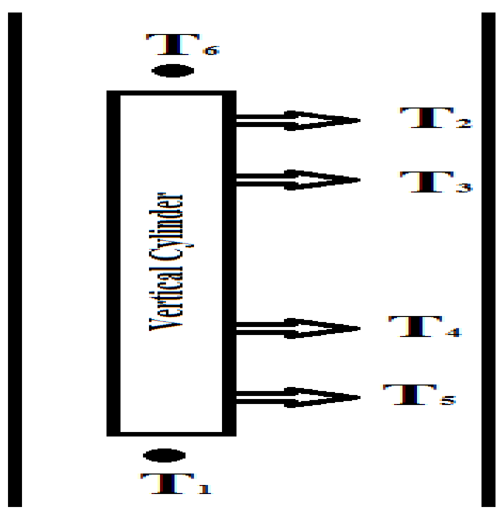

Fig: Natural Convection Apparatus

PRECAUTIONS:

1. Never switch on the main power supply before ensuring that all on / off switches give on the panel are at off position.

2. Never run the apparatus if power supply is less than 180 or above 200 Volts.
3. Make sure that convection should conduct in closed container.
4. Before switch on the main supply observer that the dimmer is in zero position.

RESULT:

The convective heat transfer coefficient and heat transfer rate from vertical cylinder in natural convection has been determined.

1. Convective heat transfer coefficient=…………………………..
2. Heat transfer rate=………………………………….

Date:

Exp No:

HEAT TRANSFER BY FORCED CONVECTION

AIM:

To determine the convective heat transfer coefficient and the rate of heat transfer by forced convection for flow of air inside a horizontal pipe.

THEORY:

Convective heat transfer between a fluid and a solid surface takes place by the movement of fluid particles relative to the surface. If the movement of fluid particles is caused by means of external agency such as pump or blower that forces fluid over the surface, then the process of heat transfer is called forced convection.

In convectional heat transfer, there are two flow regions namely laminar & turbulent. The non-dimensional number called Reynolds number is used as the criterion to determine change from laminar to turbulent flow. For smaller value of Reynolds number viscous forces are dominant and the flow is laminar and for larger value of Reynolds numbers the inertia forces become dominant and the flow is turbulent. Dittus –Boelter correlation for fully developed turbulent flow in circular pipes is,

$$N_u = 0.023 \,(Re)^{0.8}\,(Pr)^{n} \qquad \text{(from data book)}$$

Where

n = 0.4 for heating of fluid

n = 0.3 for cooling of fluid

Nusselt number= $N_u = \dfrac{hd}{k}$

R_e = Reynolds Number = $\dfrac{Vd}{\vartheta}$

P_r = Prandtl Number = $\dfrac{\mu C_P}{k}$

DESCRIPTION OF THE APPARATUS:

The apparatus consists of a blower to supply air. The air from the blower passes through a flow passage, heater and then to the test section. Air flow is measured by an orifice meter placed near the test section. A heater placed around the tube heats the air, heat input is controlled by a dimmer stat. Temperature of the air at inlet and at outlet are measured using thermocouples. The surface temperature of the tube wall is measured at different sections using thermocouples embedded in the walls. Test section is enclosed in a asbestos rope where the circulation of rope is avoid the heat loss to outside.

PROCEDURE:

1. Start the blower after keeping the valve open, at desired rate.
2. Put on the heater and adjust the voltage to a desired value and maintain it as constant
3. Allow the system to stabilize and reach a steady state.
4. Note down all the temperatures T_1 to T_7, voltmeter and ammeter readings, and manometer readings.
5. Repeat the experiment for different heat input and flow rates.

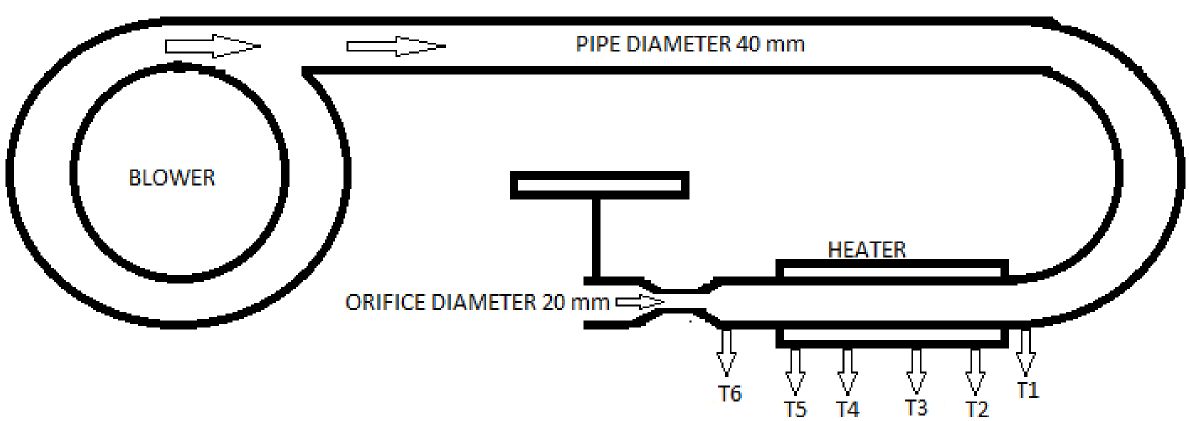

Fig:- FORCED CONVECTION APPARATUS

SPECIFICATIONS:

Specimen : Copper Tube

Size of the Specimen	: I.D. 25mm x 300mm long
Heater	: Externally heated, Nichrome wire Band Heater
Ammeter	: Digital type, 0-20amps, AC
Voltmeter	: Digital type, 0-300volts, AC
Dimmer stat for heating Coil	: 0-230v, 2amps
Thermocouple Used	: 7 nos.
Centrifugal Blower	: Single Phase 230v, 50 hz, 3000rpm
Manometer	: U-tube with water as working fluid
Orifice diameter, ‘d_2’	: 20 mm
G. I pipe diameter, ‘d_1’	: 40 mm
Coefficient of discharge	: 0.62
Length of the tube	: 500 mm

OBSERVATION TABLE:

Sl. No	**Heater input Q (Watts)**	Diff. in Mano	Air temp. °C	Tube surface Temperature °C

	V volt	I amp	V X I	meter reading h_m mm	Inlet T_1	Outlet T_7	T_2	T_3	T_4	T_5	T_6
1.											
2.											
3.											

MODEL CALCULATIONS:

Method -I:

1. Velocity of the air in the tube $V_a = \frac{Q}{a_1}$

   Discharge of the air in the tube $Q = \frac{C_d a_1 a_2 \sqrt{2gh_m}}{\sqrt{a_1^2 - a_2^2}}$

   Where

   Coefficient of discharge C_d= 0.62

   Area of GI pipe $a_1 = \frac{\Pi}{4} d_1^2$ →d_1 is diameter of the GI pipe = 40mm.

   Area of Orifice $a_2 = \frac{\Pi}{4} d_2^2$ →d_2 is diameter of the Orifice = 20mm.

   h_m Differential manometer reading .

2. Properties of air are taken at temperature $T_f = \frac{T_h + T_s}{2}$

   Average surface temperature of the tube $T_h = \frac{T_2 + T_3 + T_4 + T_5}{4}$

Mean temperature of air $T_s = \frac{T_1 + T_6}{2}$

3. Reynolds Number $R_e = \frac{V_a d_1}{\nu}$

   ($\nu = Kinematic Viscosity$ From data book at T_f)

4. Nusselt number Nu = 0.023 $R_e^{0.8}$ $P_r^{0.3}$

   (Pr= Prandtl number from data book at T_f)

5. Nusselt number N_u = $\frac{hd_1}{k}$

6. Forced convective heat transfer co-efficient $h = \frac{N_u k}{d_1}$ W/m² - K

   (k= thermal conductivity from data book at T_f)

Method -II:

From Newton's Law of Cooling:

1. Rate of heat transfer $Q = hA(T_h - T_s)$

   Where

   Amount of heat supplied Q = V X I Watts

   Surface area of the pipe $A = \prod d_1 L$

Forced convective heat transfer co-efficient $h = \frac{Q}{\prod d_1 L (T_h - T_s)}$ W/m² - K

PRECAUTIONS:

1. Never switch on main power supply before ensuring that all on/off switches given on the panel are at off position
2. Never run the apparatus if power supply is less than 180 or above 200 volts.

<u>RESULT</u>:

The convective heat transfer coefficient and the rate of heat transfer by forced convection for flow of air inside a horizontal pipe has been determined.

1. The convective heat transfer coefficient by forced convection h=………………
2. The rate of heat transfer by forced convection Q=………………………………..

Date:

Exp No:

CRITICAL HEAT FLUX APPARATUS

AIM:

To study the phenomenon of the boiling heat transfer and to plot the graph of heat flux versus temperature difference.

APPARATUS:

It consists of a cylindrical glass container, the test heater and a heater coil for initial heating of water in the container. This heater coil is directly connected to the mains and the test heater is also connected to the mains via a Dimmer stat and an ammeter is connected in series to the current while a voltmeter across it to read the voltage.

The glass container is kept on the table. The test heater wire can be viewed through a magnifying lens. Figure enclosed shows the set up.

SPECIFICATIONS:

1. Length of Nichrome wire L = 52 mm
2. Diameter of Nichrome wire D = 0.25 mm (33 gauge)
3. Distilled water quantity = 4 liters
4. Thermometer range : 0 – 100 ^{0}C
5. Heating coil capacity (bulk water heater) : 2 kW
6. Dimmer stat
7. Ammeter
8. Voltmeter

THEORY:

When heat is added to a liquid surface from a submerged solid surface which is at a temperature higher than the saturation temperature of the liquid, it is usual that a part of the liquid to change phase. This change of phase is called ‘boiling’. If the liquid is not flowing and present in container, the type of boiling is called as ‘pool boiling’. Pool boiling is also being of various types depending upon the temperature difference between the surfaces of liquid. The different types of zones are as shown in the figure A. The heat flux supplied to the surface is plotted against (T_w - T_s) where Ts is the temperature of the submerged solid and ‘T_w’ is the saturation temperature of the liquid at exposed pressure. The boiling curve can be divided into three regions:

I. Natural convection region
II. Nucleate boiling region
III. Film boiling region

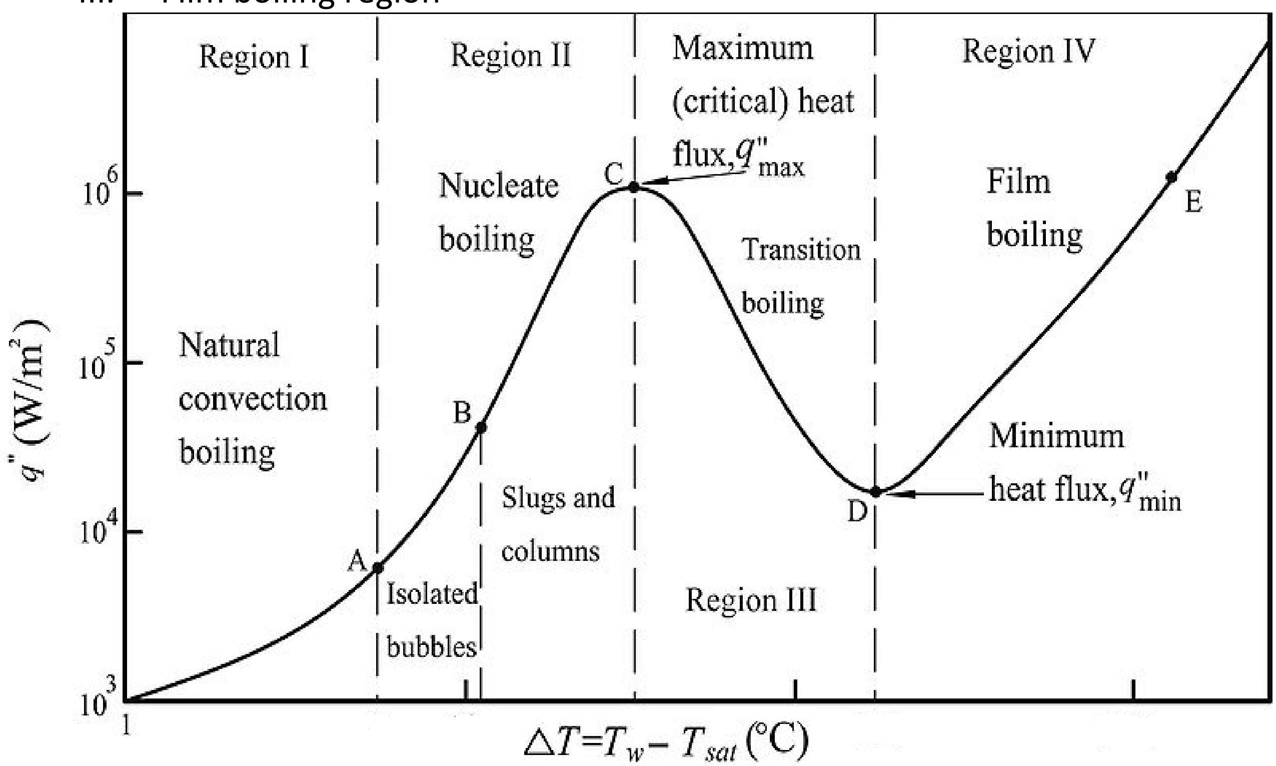

Figure A TYPICAL POOL BOILING CURVE

As temperature difference (T_w - T_s) is very small (1^0C or so), the liquid near to the surface gets slightly superheated and rises up to the surface. The heat transfer from the heating surface to the liquid is similar to that by natural convection and hence this region is called 'natural convection region'.

When (T_w - T_s) becomes a few degrees, vapor bubble start forming at some discrete locations of the heating surface and we enter into 'Nucleate boiling region'. Region II consists of two parts. In the first part, the bubbles formed are very few in number and before reaching the top liquid surface, they get condensed. In second part, the rate of bubble formation as well as the locations where they are formed increases with increase in temperature difference. A stage is finally reached when the rate of formation of bubbles is so high that they start coalesce and blanket the surface with a vapor film. This is the beginning of region III since the vapor has got very low thermal conductivity, the formation of vapor film on the heating surface suddenly increases the temperature beyond the melting point of the submerged surface and as such the end of ‘Nucleate boiling’ is important and its limiting condition is known as critical heat flux point or burn out point.

The pool boiling phenomenon up to critical heat flux point can be visualized and studied with the help of apparatus described above.

PROCEDURE:

1. Distilled water of about 5 liters is taken into the glass container.
2. The test heater (Nichrome wire) is connected across the studs and electrical connections are made.
3. The heaters are kept in submerged position.
4. The bulk water is switched on and kept on, until the required bulk temperature of water is obtained. (Say 40^0 C)
5. The bulk water heater coil is switched off and test heater coil is switched on.
6. The boiling phenomenon on wire is observed as power input to the test heater coil is varied gradually.
7. The voltage is increased further and a point is reached when wire breaks (melts) and at this point voltage and current are noted.
8. The experiment is repeated for different values of bulk temperature of water. (Say 60^0 C, and 80^0 C).

OBSERVATION TABLE:

Sl. No	Bulk water Temperature in ^{0}C ‘T_w’	Specimen temperature in ^{0}C ‘T_s’	Voltage ‘V’ in Volt	Current ‘I’ in Amps	Heat Input ‘Q’ in watt	Critical heat Flux q = Q/A In W/m^2
1						

2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
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MODEL CALCUALATIONS:

a. Area of Nichrome wire $A = \pi \times D \times L$ = __________
b. Heater input $Q = V \times I$ = __________
c. Critical heat flux $q = Q/A$ = __________

PRECAUTIONS:

1. All the switches and Dimmer stat knob should be operated gently.
2. When the experiment is over, bring the Dimmer stat to zero position.
3. Run the equipment once in a week for better performance.
4. Do not switch on heaters unless distilled water is present in the container.

RESULT:

The phenomenon of the boiling heat transfer is studied and plotted the graph of the heat flux versus temperature difference and critical heat flux is calculated.

Critical heat flux q=-------------

Date:

Exp No:

PARALLEL FLOW AND COUNTER FLOW HEAT EXCHANGER

AIM:

To determine LMTD, effectiveness and overall heat transfer coefficient for parallel and counter flow heat exchanger

SPECIFICATIONS:

Length of heat exchanger	L	=2440 mm
Inner copper tube	ID	=12 mm
	OD	=15 mm
Outer GI tube	ID	=40 mm
Geyser capacity		=1 Lt, 3 kW

THEORY:

Heat exchanger is a device in which heat is transferred from one fluid to another. Common examples of heat exchangers are:

i. Condensers and boilers in steam plant
ii. Inter coolers and pre-heaters
iii. Automobile radiators
iv. Regenerators

CLASSIFICATION OF HEAT EXCHANGERS:

1. **Based on the nature of heat exchange process:**
   i. Direct contact type – Here the heat transfer takes place by direct mixing of hot and cold fluids
   ii. Indirect contact heat exchangers – Here the two fluids are separated through a metallic wall. ex. Regenerators, Recuperators etc

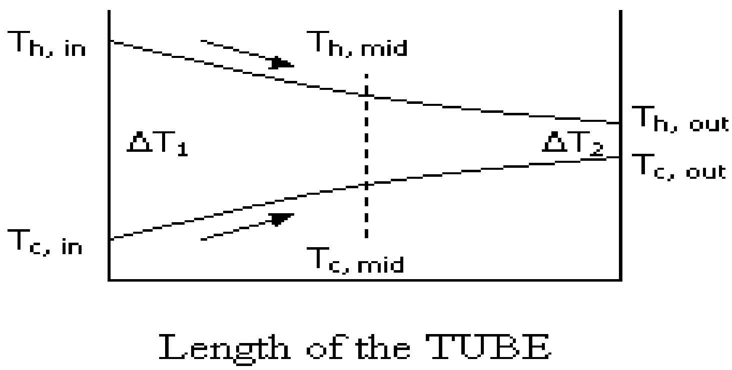
2. **Based on the relative direction of fluid flow:**
   i. Parallel flow heat exchanger – Here both hot and cold fluids flow in the same direction.
   ii. Counter flow heat exchanger – Here hot and cold fluids flow in opposite direction.
   iii. Cross-flow heat exchangers – Here the two fluids cross one another.

LOGARITHMIC MEAN TEMPERATURE DIFFERENCE (LMTD):

This is defined as that temperature difference which, if constant, would give the same rate of heat transfer as usually occurs under variable conditions of temperature difference.

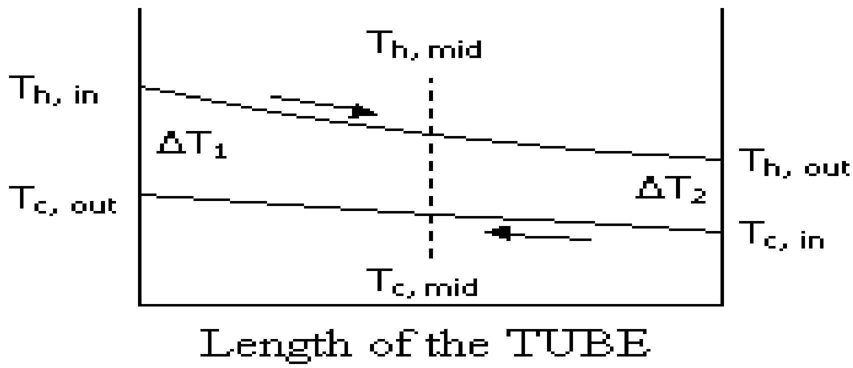
FOR PARALLEL FLOW:

Where



LMTD = $\dfrac{(T_{ho} - T_{co}) - (T_{hi} - T_{ci})}{\ln\left(\dfrac{T_{ho} - T_{co}}{T_{hi} - T_{ci}}\right)} = \dfrac{\theta_2 - \theta_1}{\ln\left(\dfrac{\theta_2}{\theta_1}\right)}$

For Counter flow:



$$\text{LMTD} = \frac{(T_{hi} - T_{ci}) - (T_{ho} - T_{ci})}{\ln\left(\frac{T_{hi} - T_{co}}{T_{ho} - T_{ci}}\right)} = \frac{\theta_2 - \theta_1}{\ln\left(\frac{\theta_2}{\theta_1}\right)}$$

T_{ho} = Outlet temperature of hot fluid

T_{co} = Outlet temperature of cold fluid

T_{hi} = Inlet temperature of hot fluid

T_{ci} = Inlet temperature of cold fluid

OVERALL HEAT TRANSFER COEFFICINET:

The rate of heat transfer between hot and cold fluid is given by

$$Q = U_o A_o / \text{LMTD}$$

Where,

U_o is overall heat transfer coefficient based on outer surface area of tubes, W/m²-K

A_o is the total outer surface area of tubes, m²

EFFECTIVENESS:

Effectiveness of a heat exchanger is defined as the ratio of actual heat transfer rate to the theoretical maximum possible heat transfer rate.

Effectiveness: $\varepsilon = \dfrac{Q}{Q_{\max}}$

It can be shown that

$$\varepsilon = \frac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}} \quad \text{if } m_h c_h < m_c c_c$$

And

$$\varepsilon = \frac{T_{co} - T_{ci}}{T_{hi} - T_{ci}} \quad \text{if } m_c c_c < m_h c_h$$

Where,

m_h and m_c are the mass flow rate of hot and cold fluids respectively in kg/s;

c_h and c_c are the specific heat of hot and cold fluids respectively in J/kg–K.

DESCRIPTION OF THE APPRATUS:

The apparatus consists of a concentric tube heat exchanger. The hot fluid namely hot water is obtained from the Geyser (heater capacity 3 kW) & it flows through the inner tube. The cold fluid i.e. cold water can be admitted at any one of the ends enabling the heat exchanger to run as a parallel flow or as a counter flow exchanger. Measuring jar used for measure flow rate of cold and hot water. This can be adjusted by operating the different valves provided. Temperature of the fluid can be measured using thermocouples with digital display indicator. The outer tube is provided with insulation to minimize the heat loss to the surroundings.

PROCEDURE:

1. First switch ON the unit panel
2. Start the flow of cold water through the annulus and run the exchanger as counter flow or parallel flow.
3. Switch ON the geyser provided on the panel & allow to flow through the inner tube by regulating the valve.
4. Adjust the flow rate of hot water and cold water by using rotameters & valves.
5. Keep the flow rate same till steady state conditions are reached.
6. Note down the temperatures on hot and cold water sides. Also note the flow rate.
7. Repeat the experiment for different flow rates and for different temperatures. The same method is followed for parallel flow also.

OBSERVATION TABLE:

PARALLEL FLOW

Sl. No.	Hot water flow rate m_h, kg/s	Cold water flow rate m_c, kg/s	Temperature of cold water in °C		Temp. of hot water in °C	
			Inlet T_{ci}	Outlet T_{co}	Inlet T_{hi}	Outlet T_{ho}
1.						
2.						
3.						

COUNTER FLOW

Sl. No.	Hot water flow rate	Cold water flow rate	Temperature of cold water in °C	Temp. of hot water in °C

	m_h, kg/s	m_c, kg/s	Inlet T_{ci}	Outlet T_{co}	Inlet T_{hi}	Outlet T_{ho}
1.						
2.						
3.						

EQUATIONS USED:

1. Heat transfer from hot water

$Q_h = m_h C_{ph} (T_{hi} - T_{ho})$ watts

m_h = mass flow rate of hot water kg/sec
C_{ph} = Specific heat of hot water = 4186.8 J kg-K

2. Heat gain by the cold fluid

$Q_c = m_c C_{pc} (T_{co} - T_{ci})$ watts

m_c = Mass flow of cold fluid, kg/s

C_{pc} = Specific heat of cold fluid = 4186.8 J/kg -K

3. $Q = \dfrac{Q_h + Q_c}{2}$ watts

$$LMTD = \frac{\theta_2 - \theta_1}{\ln\left(\frac{\theta_2}{\theta_1}\right)}$$

$\theta_1 = T_{hi} - T_{ci}$ and $\theta_2 = T_{ho} - T_{co}$ for parallel flow heat exchanger

$\theta_1 = T_{ho} - T_{ci}$ and $\theta_2 = T_{hi} - T_{co}$ for counter flow heat exchanger

5. Overall heat transfer coefficient based on outside surface area of inner tube

$U_o = \dfrac{Q}{A_o.LMTD}$ W/m² °K

Where,

A_o =π d_o l m²

d_o = Outer diameter of the tube = 0.0125 m

L = length of the tube = 1.5 m

6. Effectiveness:

Find $C_h = m_h\, c_{ph}$ and $C_c = m_c c_{pc}$

Effectiveness = $\dfrac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}}$ if $C_h < C_c$

And Effectiveness = $\dfrac{T_{co} - T_{ci}}{T_{hi} - T_{ci}}$ if $C_c < C_h$

This is applicable both for Parallel and counter flow heat exchanger

7. Effectiveness using NUMBER OF TRANSFER UNIT (NTU) method

i) NTU = $\dfrac{U_o A_o}{C_{min}}$

Note: if $C_h<C_c$ then $C_h = C_{min}$, $C_c = C_{max}$

And if $C_c<C_h$ then $C_c = C_{min}$, $C_h = C_{max}$

ii) Effectiveness of parallel flow heat exchanger

$$\varepsilon = \frac{1 - e^{-NTU\left[1+\frac{C_{min}}{C_{max}}\right]}}{1+\dfrac{C_{min}}{C_{max}}}$$

iii) Effectiveness of counter flow heat exchanger

$$\varepsilon = \frac{1 - e^{-NTU\left[1 - \frac{C_{\min}}{C_{\max}}\right]}}{1 - \frac{C_{\min}}{C_{\max}} e^{-NTU\left[1 - \frac{C_{\min}}{C_{\max}}\right]}}$$

RESULT:

The overall heat transfer coefficient of parallel flow and counter flow heat exchangers has been determined.

STEFAN BOLTZMANN APPARATUS

AIM:

To determine the value of Stefan Boltzmann constant for radiation heat transfer.

APPARATUS:

Hemisphere, Heater, Temperature indicator, Stopwatch.

THEORY:

Stefan Boltzmann law states that the total emissive power of a perfect black body is proportional to fourth power of the absolute temperature of black body surface.

$$E_b = \sigma T^4$$

Where

σ = Stefan Boltzmann constant = 5.6697×10^{-8} W/(m² K^4)

DESCRIPTION:

The apparatus consists of a flanged copper hemisphere fixed on a flat non-conducting plate. A test disc made of copper is fixed to the plate. Thus the test disc is completely enclosed by the hemisphere. The outer surface of the hemisphere is enclosed in a vertical water jacket used to heat the hemisphere to a suitable constant temperature. Three Cr-Al thermocouples are attached at three strategic places on the surface of the hemisphere to obtain the temperatures. The disc is mounted on an ebonite rod which is fitted in a hole drilled at the center of the base plate. Another Cr-Al thermocouple is fixed to the disc to record its temperature. Fill the water in the SS water container with immersion heater kept on top of the panel.

SPECIFICATIONS:

Specimen material	:	Copper
Size of the disc	:	ϕ 20mm x 0.5mm thickness
Base Plate	:	ϕ 250mm x 12mm thickness (hylam)
Heater	:	1.5 kW capacity, immersion type
Copper Bowl	***:***	***ϕ 200mm***
Digital temperature indicator	:	0 -199.9° C
Thermocouples used	:	3 nos. on hemisphere
Stop Watch	:	Digital type
Overhead Tank	:	SS, approx. 12 liter capacity
Water Jacket	:	ϕ 230 mm, SS
Mass of specimen, 'm'	:	5 gm
Specific heat of the disc C_p	:	0.38 kJ/kg K

PROCEDURE:

1. Remove the test disc before starting the experiment.
2. Allow water to flow through the hemisphere, Switch on the heater and allow the hemisphere to reach a steady state temperature.
3. Note down the temperatures T_1,T_2 & T_3. The average of these temperatures is the hemisphere temperature T_h .
4. Insert the test disc at the bottom of the hemisphere and lock it. Start the stop clock simultaneously.
5. Note down the temperature of the test disc at an interval of about 15 sec for about 15 to 20 minutes.

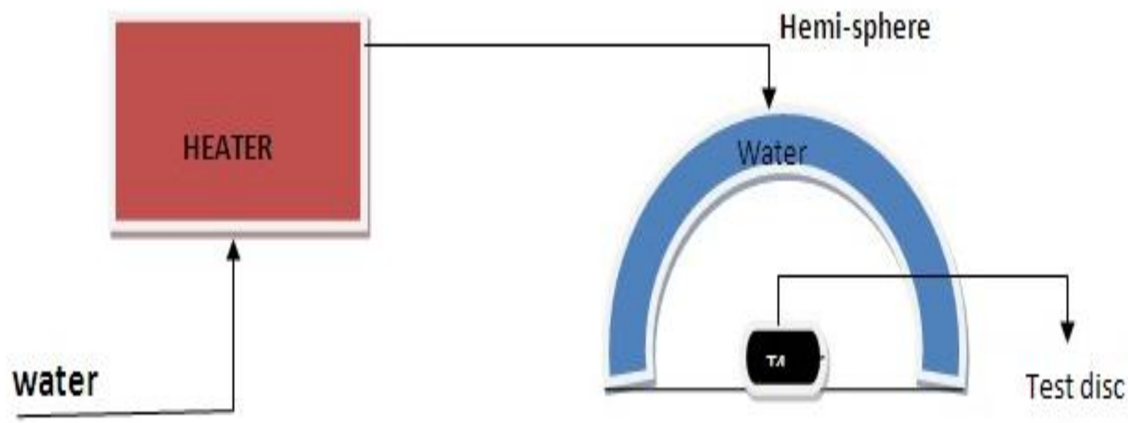


FIG: STEFAN BOLTZMANN APPARATUS

OBSERVATION TABLE:

Let T_d = Temperature of the disc before inserting into the plate in K

Thermocouple	***Temperature of the copper hemisphere ° C***
T_1	
T_2	
T_3	
T_h Average of T_1 , T_2 and T_3 =	

Temperature – time response of test disc:

Time 't'	Temperature T_d	Time 't'	Temperature T_d

sec	° C	sec	° C

CALCULATIONS:

1. Plot the graph of temperature of the disc v/s time to obtain the slope (dT/dt) of the line, which passes through/nearer to all points.
2. Average temperature of the hemisphere

$$T_h = \frac{T_1 + T_2 + T_3}{3} + 273.15$$

3. T_d = Temperature of the disc before inserting to Test chamber º K (ambient)

4. Rate of change of heat capacity of the disc = $mC_p \frac{dT}{dt}$

Net energy radiated on the disc = $\sigma A_d (T^4_h - T^4_d)$

Where

A_d = area of the disc = $\frac{\pi}{4} d^2$ in m^2

d = 20 mm

C_p = specific heat of copper = 0.38 kJ/kg–K

Rate of change of heat capacity of the disc = Net energy radiated on the disc

$$mC_p \frac{dT}{dt} = \sigma A_d (T^4_{avg} - T^4_d)$$

Thus 'σ' can be evaluated as shown

$$\sigma = \frac{mC_p \frac{dT}{dt}}{A_d (T^4_{avg} - T_d^4)}$$

Result: The experiment on Stefan Boltzmann apparatus has been conducted and the value of Stefan Boltzmann constant is determined.

Date:
Exp No:

EMISSIVITY MEASUREMENT OF RADIATING SURFACES

AIM:

To determine the emissivity of given test plate surface.

THEORY:

Any hot body maintained by a constant heat source, loses heat to surroundings by conduction, convection and radiation. If two bodies made of same geometry are heated under identical conditions, the heat loss by conduction and convection can be assumed same for both the bodies, when the difference in temperatures between these two bodies is not high. In such a case, when one body is black & the other body is gray from the values of different surface temperatures of the two bodies maintained by a constant power source emissivity can be calculated. The heat loss by radiation depends on

a) Characteristic of the material
b) Geometry of the surface and
c) Temperature of the surface

The heat loss by radiation when one body is completely enclosed by the other body is given by

$$Q = \frac{\sigma A_1 (T_1^{\,4} - T_2^{\,4})}{\frac{1}{\varepsilon} + \frac{A_1}{A_2}\left[\frac{1}{\varepsilon_2} - 1\right]}$$

If a body is losing heat to the surrounding atmosphere, then the area of atmosphere A_2 >> area of body A_1. Thus if anybody is losing heat by radiation to the surrounding atmosphere equation (1) takes the form.

$$Q = \sigma A_1 (T_1^4 - T_2^4)$$

Where

σ = Stefan Boltzmannn constant = 5.6697×10^{-8} $W/m^2 K^4$

A_1 = Surface area in m²

ε = Emissivity

T_1 = surface temperature of the body in K and

T_2 = surrounding atmospheric temperature in K

Let us consider a black body & a gray body with identical geometry being heated under identical conditions, assuming conduction & convection heat loss to remain the same.

Let Q_b and Q_g be the heat supplied to black & gray bodies respectively. If heat input to both the bodies are same,

$$Q_b = Q_g$$

Assuming, heat loss by conduction and convection from both bodies to remain same.

Heat loss by radiation by the black body = Heat loss by radiation by the gray body

$$\sigma A_b \varepsilon_b (T_b^4 - T_a^4) = \sigma A_g \varepsilon_g (T_g^4 - T_a^4)$$

As geometry of two bodies are identical $A = A_g = A_b$ and $\varepsilon_b = 1$ for black body.

Therefore, $\varepsilon_g = \dfrac{(T_b^4 - T_a^4)}{(T_g^4 - T_a^4)}$

Where

Suffix 'b' stands for black body,

Suffix ‘g’ stands for gray body,

Suffix ‘c’ stands for chamber.

DESCRIPTION:

The experimental set up consists of two circular aluminium plates of identical dimensions. One of the plates is made black by applying a thick layer of lamp black while the other plate whose emissivity is to be measured is a gray body. Heating coils are provided at the bottom of the plates. The plates are mounted on asbestos cement sheet and kept in an enclosure to provide undisturbed natural convection condition. Three thermocouples are mounted on each plate to measure the average temperature. One thermocouple is in the chamber to measure the ambient temperature or chamber air temperature. The heat input can be varied with the help of variac for both the plates , that can be measured using digital volt and ammeter.

SPECIFICATIONS:

Specimen material	: Aluminum
Specimen Size	: ϕ 150 mm, 10 mm thickness (gray & black body)
Voltmeter	: Digital type, 0-300v
Ammeter	: Digital type, 0-3 amps
Dimmer stat	: 0-240 V, 2 amps
Temperature Indicator	: Digital type, 0-300°C, K type
Thermocouple Used	: 7 nos.
Heater	: Sand witched type Nichrome heater, 400 W

PROCEDURE:

1. Switch on the electric mains.
2. Operate the dimmer stat very slowly and give same power input to both the heater Say 60 V by using (or) operating cam switches provided panel.
3. When steady state is reached note down the temperatures T_1 to T_7 by rotating the temperature selection switch gently.
4. Also note down the volt & ammeter reading
5. Repeat the experiment for different heat inputs.

OBSERVATION TABLE:

Sl. No.	***Heater input***		Temperature of black surface °C			Temperature of gray surface °C			Chamber Temp °C
	V	I	T_1	T_2	T_3	T_5	T_6	T_7	T_4
1.									
2.									
3.									

SPECIMEN CALCULATIONS:

1. Temperature of the black body $T_b = \dfrac{(T_1 + T_2 + T_3)}{3} + 273.15$ K
2. Temperature of the gray body $T_g = \dfrac{(T_5 + T_6 + T_7)}{3} + 273.15$ K
3. Temperature of the Chamber $T_c = (T_7 + 273.15)$ K

4. Heat input to the coils Q = V x I watt

5. Emissivity of gray body $\varepsilon_g = \varepsilon_b \left[\frac{(T_b^4 - T_C^4)}{(T_g^4 - T_C^4)} \right]$

Result:

Emissivity of the black body is greater than gray body.

The emissivity of the test plate (gray body) surface is determined =………………..