Experiment No. 1

Unsteady state heat conduction

Objective

To determine the thermal conductivity of a solid body using analytical transient-temperature/heat flow charts from the measurements taken on a similar body but having a different thermal conductivity.

Theory

Analytical solutions are available for temperature distribution and heat flow as a function of time and position for simple solid shapes which are suddenly subjected to convection with a fluid at a constant temperature. These solutions were presented in graphical form by M.P. Heisler and are called Heisler Charts. Typical chartsfor a large plate, long cylinder and sphere are shown in Figures 1, 2 and 3.

To use these charts, it is necessary to evaluate appropriate dimensionless parameters as follows:

$\theta = \dfrac{T(r,t) - T_\infty}{T_i - T_\infty}$ = Dimensionless temperature

$Bi = \dfrac{hb}{k}$ =Biot number

$\tau = \dfrac{\alpha t}{b^2}$ =Dimensionless time or Fourier number

where

α = Thermal diffusivity of the cylinder ($m^2 s^{-1}$)

h = Heat transfer coefficient ($Wm^{-2}\,°C^{-1}$)

k = Thermal conductivity of the cylinder ($Wm^{-1}\,°C^{-1}$)

t = Time since step change (s)

$T(r,t)$ = Temperature at centre of cylinder (T_3 at time t) (°C)

T_i = Initial temperature of cylinder (T_3 at $t=0$)(°C)

T_∞ = Temperature of water bath (T_1) (°C)

b = Radius of cylinder (m)

r = Radial position within the cylinder (at axis $r=0$) (m)

Since the flow of water vertically upwards through the duct is constant for all of the measurements, the heat transfer coefficient h will remain constant for each shape.

Apparatus

HT17 Unsteady State Heat Transfer Accessory

PC running Windows™ 98 or later with available USB socket

HT10XC Computer Compatible Heat Transfer Service Unit

Equipment Set-up

Before proceeding with the exercise, ensure that the equipment has been prepared as follows:

Locate the hot water bath of the HT 17 Unsteady State Heat Transfer Accessory alongside the HT10XC Heat Transfer Service Unit on a suitable bench.

Ensure that the lid of the hot water bath is fitted and the inlet at the base of the flow duct is connected to the outlet of the circulating pump using flexible tubing.

Ensure that the drain valve on the water bath is closed. Then, fill the bath with clean water until the level is coincident with the centre of the holes in the vertical flow duct as shown in the diagram in Figure 4.

Connect thermocouple T_1 from the flow duct inside the water bath (lead exits via a grommet inthe lid of the water bath) to socket T_1 on the front of the HT10XC service unit.

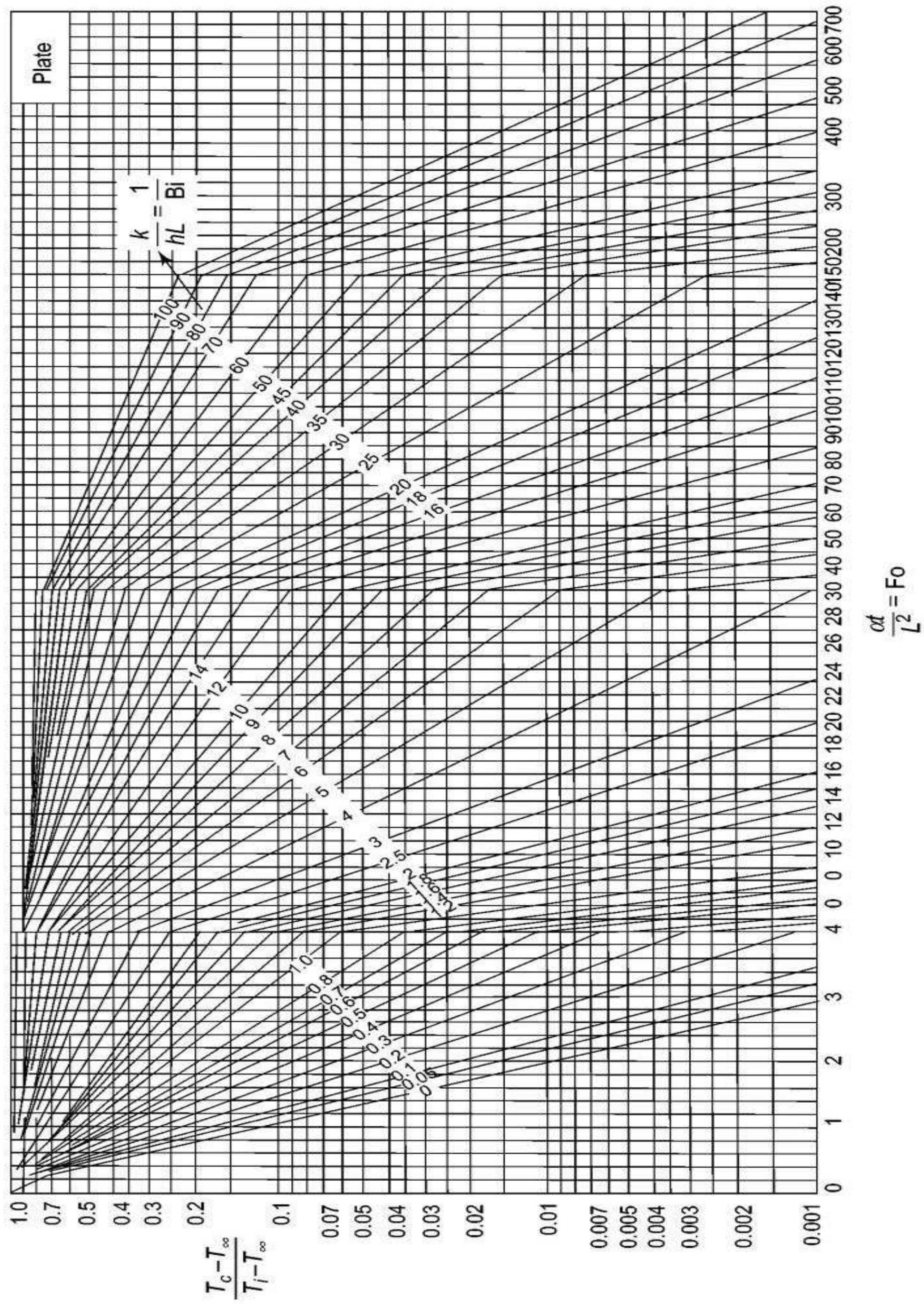


Figure 1 : Temperature-time history at mid-plane of an infinite plate of thickness *2L*

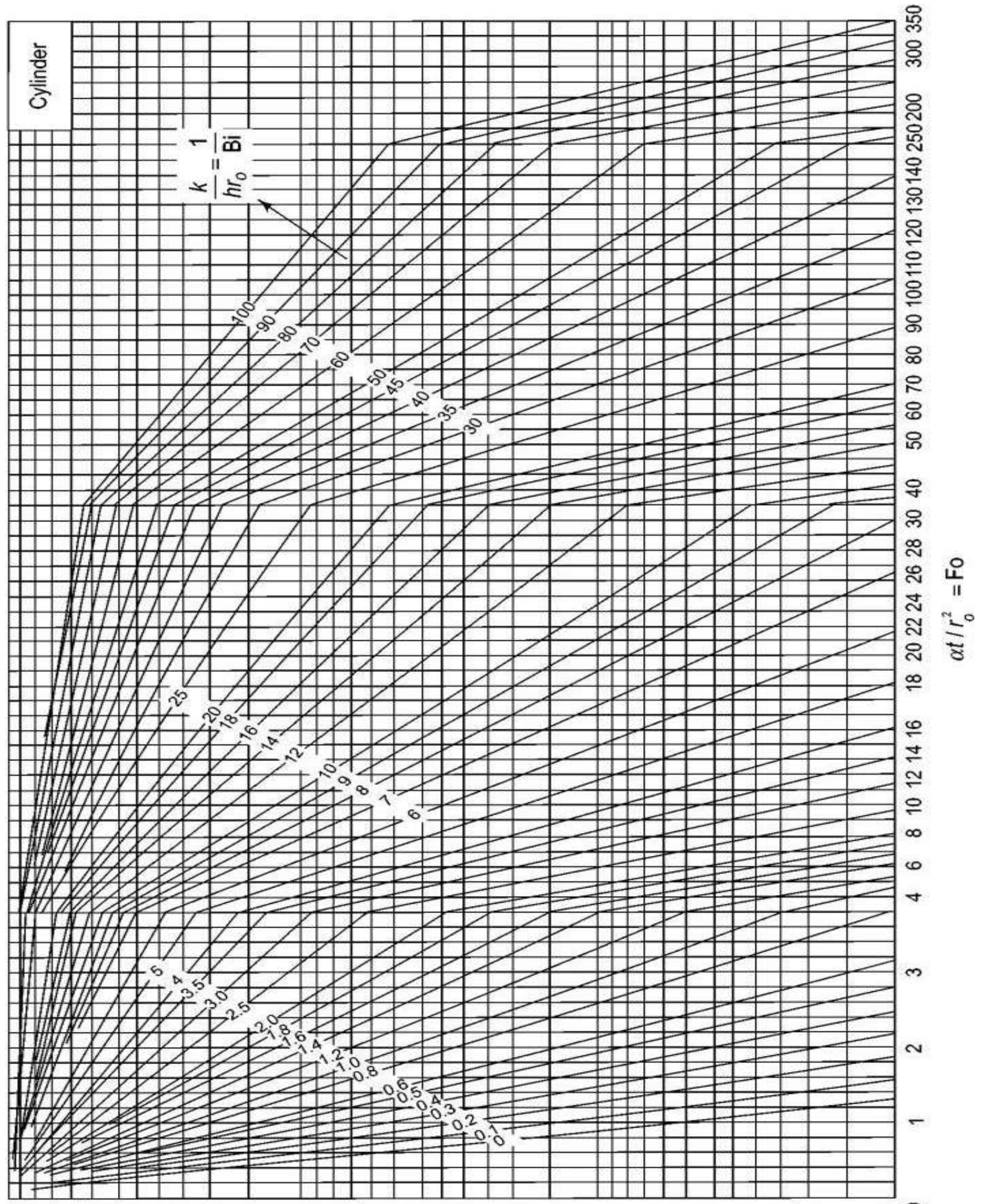


Figure 2 : Temperature-time history at the centre line of an infinitely long cylinder of radius r_o

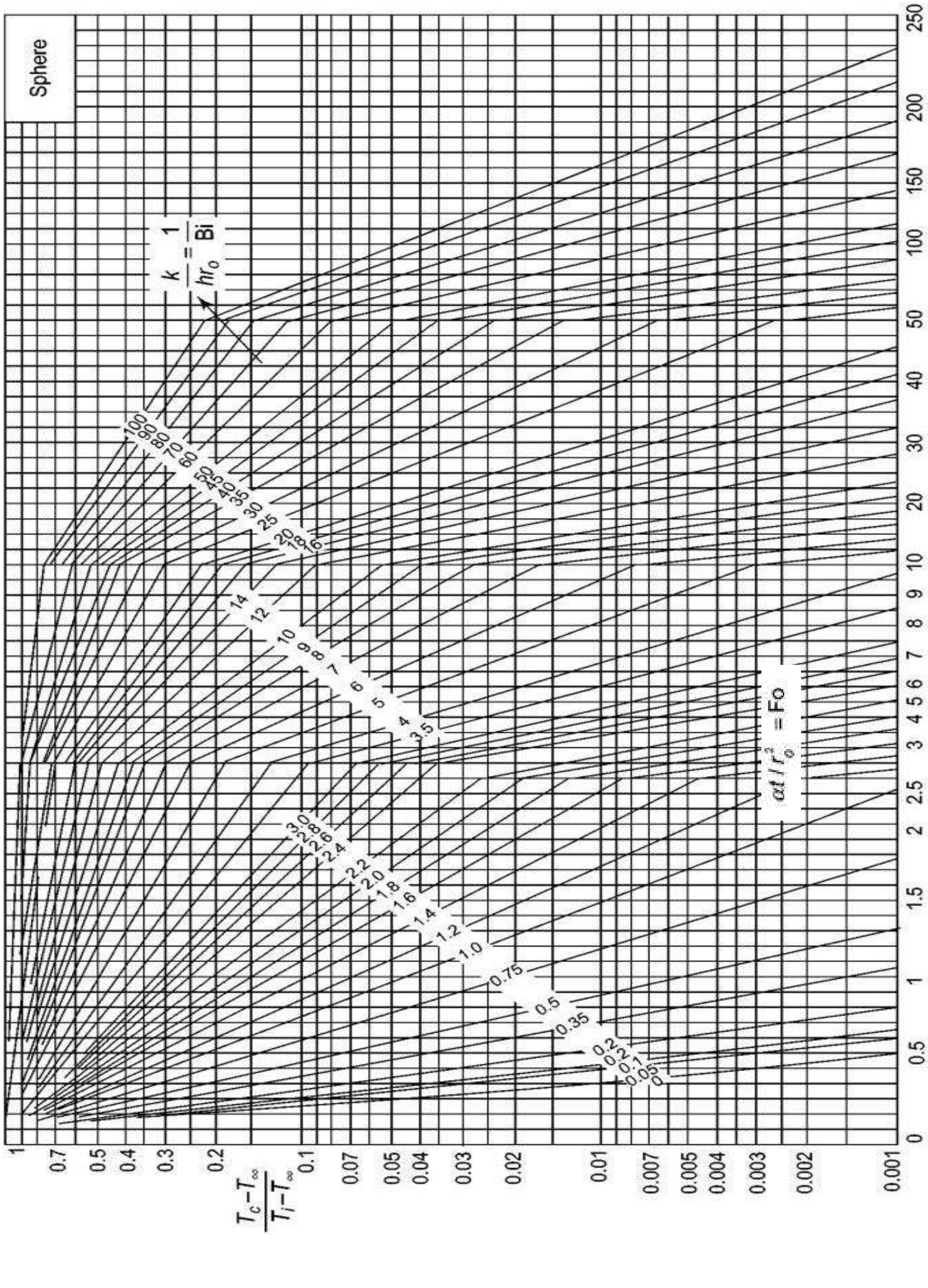


Figure 3 : Temperature-time history at centre of a solid sphere of radius r_o

Connect thermocouple T_2 on the shape holder to socket T_2 on the front of the HT10XC service unit.

Connect thermocouple T_3 inside the large brass shape to socket T_3 on the front of the HT10XC service unit.

Set the VOLTAGE CONTROL potentiometer to minimum (anticlockwise) and the selector switch to MANUAL.Then, connect the power lead from the circulating pump alongside the water heating tank to the socket marked Output 2 at the rear of the service unit.

Note: The voltage control potentiometer is used to set the speed of the circulating pump on this equipment NOT the power to the heating element.

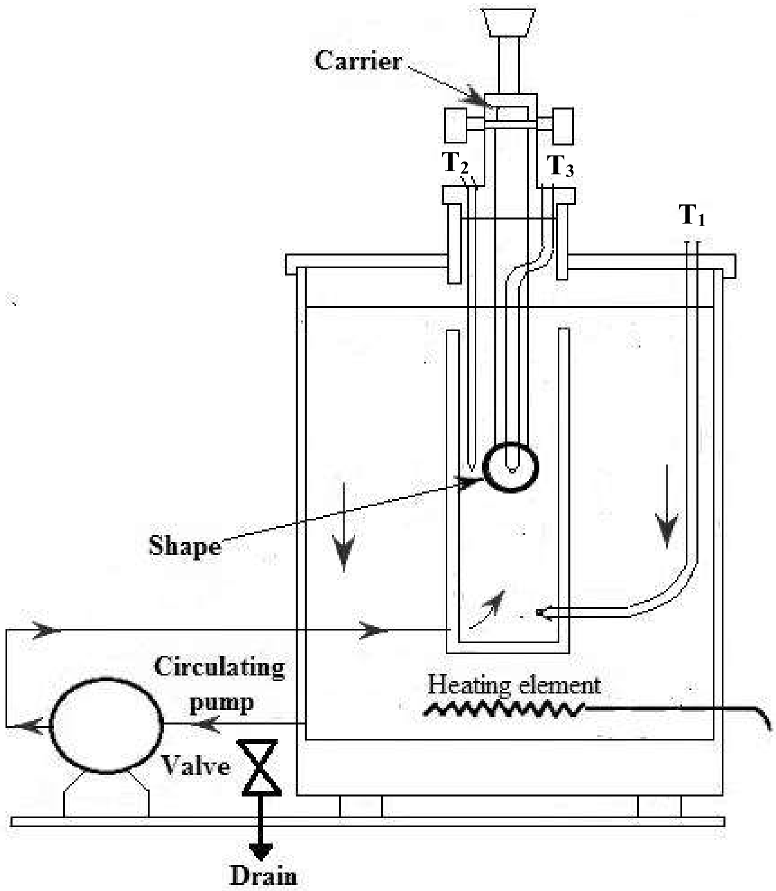


Figure 4: Schematic diagram of unsteady state heat conduction setup with thermocouples T_1, T_2 and T_3

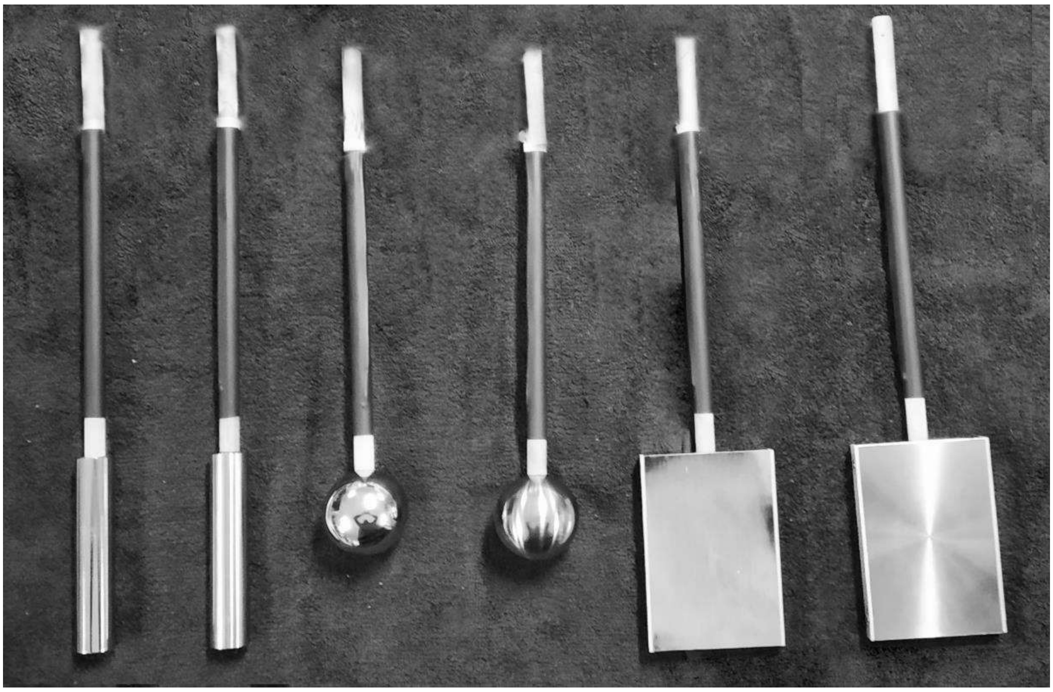


Figure 5: Solid shapes used in the experiment. From left to right: Brass cylinder, Steel cylinder, Brass sphere, Steel sphere, Brass plate and Steel plate.

Connect the power lead from the water bath (terminated at the connection box alongside the heating tank) to an electrical supply.

Ensure that the service unit is connected to an electrical supply.

Connect the HT10XC service unit to the PC using the USB cable provided, and run the HT17 software. Select Exercise A.

Click on the 'Sample' menu from the top toolbar, and select 'Configure…'

In the Sample Configuration menu that appears, check that Sampling Operation is set to Automatic with a sample interval of 1 second and continuous duration. Change the setting if required. Close the sample configuration window by selecting 'OK'.

Place the various shapes in a suitable location where they can stabilize at room temperature. If laboratory stands/clamps are available then the shapes can be suspended from the stands via the insulated rod attached to each shape.

Note: Always pick up the metal shapes via the insulated rod. Heat transferred to the shape by holding in the hand will delay the stabilization of the shape at a uniform temperature.

Also, since the water bath will take approximately 40 minutes to heat to the required temperature,it should be switched on immediately as described in the Procedure section.

Figure 6: Experimental setup

Experimental Procedure

Switch on the front Mains switch (If the panel meters do not illuminate, check the RCD (Residual-current device) and any other circuit breakers at the rear of the service unit.All the switches at the rear should be up).

Check that the water bath is filled with water.Then, switch on the electrical supply to the water heater (switch on the RCD which is located on the connection box adjacent to the water heater).

Ensure that the green light is illuminated on the water heater, indicating that electrical power is being supplied to the unit.

Adjust the thermostat on the water heater to setting ‘4’ and check that the red light is illuminated indicating that power is being supplied to the heating element.

Set the voltage to the circulating pump to 12 volts using the voltage control box on the mimic diagram software display.

Allow the temperature of the water to stabilise (monitor the changing temperature T_1).

The water must be in the range 60 – 70 °C for satisfactory operation.If outside this range, adjust the thermostat and monitor T_1 until the temperature is satisfactory.

Attach the brass cylinder to the shape holder (insert the insulated rod into the holder and secure using the transverse pin) but do not hold the metal shape or subject it to a change in temperature.Check that the thermocouple attached to the shape is connected to T_3 on the HT10XC. Check that the thermocouple wire is located in the slot at the top of the shape holder.

Check that the temperature of the shape has stabilised (same as air temperature T_2).

Switch off the electrical supply to the water bath (switch off the RCD on the connection box) to minimise fluctuations in temperature if the thermostat switches on/off.

Start continuous data logging by selecting the 

icon on the software toolbar.

Allow the temperature of the shape to stabilise at hot water temperature (monitor the changing temperature T_3 on the mimic diagram software screen).

When temperature T_3 has stabilised , select the 

icon to end data logging.

Select the  icon to create a new results sheet.

Switch on the electrical supply to the water bath to allow the thermostat to maintain the water temperature.

Remove the brass cylinder from the shape holder.Then, fit the stainless steel cylinder.

Repeat the above procedure to obtain the transient response for the stainless-steel cylinder.Remember to create a new sheet results sheet afterwards ready for the next set of results.

Remove the stainless steel cylinder from the shape holder.

The response of the other shapes can be determined using the same procedure as above.

Observation Table

S. No.	Shape	$T_i\,(^\circ\text{C})$	$T_\infty\,(^\circ\text{C})$	$T_3\,(^\circ\text{C})$	Time $t\,(\text{s})$
1	Brass small dia. cylinder				
2	Steel small dia. cylinder				
3	Brass large dia. cylinder				
4	Steel large dia. cylinder				
5	Brass plate				
6	Steel plate				

Results and Calculations

Determine the value of h using the results obtained for the brass cylinder as follows:

Plot the first graph using the Graph screen of the software. Select the graph screen using the icon, then select the icon to open the graph configuration screen. The available results are listed on the left. Highlight the first required series (the temperatures T_2 and T_3 for the brass cylinder) and use the red arrow button to transfer them to 'Series on Primary Axis', then select 'OK'. The graph may be printed to a printer (if available) by selecting the icon.

Establish where $t = 0$ (i.e. T_2 step changes from room temperature to T_∞).

Choose a point on the temperature/time plot for the brass cylinder and measure the corresponding values of temperature T_3 and time t. (the point should be close to the finaltemperature e.g. 2 or 3 degrees away from the final temperature).

Calculate θ using T_i (T_3 at $t = 0$), T_∞, and T_3 i.e. $T(r = 0, t)$

Calculate τ using α, t, b (assume $\alpha = 3.7 * 10^{-5}\,\text{m}^2\text{s}^{-1}$ for brass)

Read value of $\dfrac{1}{Bi}$ on chart using the calculated values for θ and τ.

Calculate h using Bi, b, and k (assume $k = 121\,\text{Wm}^{-1}{}^\circ\text{C}^{-1}$ for brass)

This value of h will be the same for the stainless steel cylinder since the size, shape, surface finish and water velocity are constant.

Plot the graph for the stainless steel cylinder. First highlight the results for the brass cylinder and use the red arrow button to transfer them back to 'Available Series'. Then select the results for the stainless steel cylinder from the available series, and transfer them to the primary Y-axis. Select 'OK', then print the graph (if a printer is available).

Choose a point on the temperature/time plot for the stainless steel cylinder and measure the corresponding values of temperature T at time t. (the point should be close to the final temperature e.g. 2 or 3 degrees away from the final temperature).

Calculate θ using T_i (T_3 at $t = 0$), T_∞, and T_3 i.e. $T(r = 0, t)$

Calculate τ using α, t and b (assume $\alpha = 0.6 * 10^{-5}$ m^{2}s^{-1} for stainless steel)

Read value of $\frac{1}{Bi}$ on chart using the calculated values for θ and τ.

Calculate k using Bi, b and h (use the calculated value of h obtained using results from the brass cylinder. The typical value of k for stainless steel is 25 Wm^{-1}°C^{-1})

Conclusion

You have observed the use of analytical transient-temperature/heat flow charts to analysehow the temperature changes between the surface and the centre of a solid shape when exposed to a step change in temperature on the boundary.

Relevant dimensionless parameters have been used for the analysis.

Note: The use of Heisler charts, as demonstrated in this exercise, is restricted to simple regular shapes with constant thermal properties. When the bodies have an irregular shape or the surface is not maintained at a uniform temperature, the problems must be solved using a numerical approach, such as finite-difference or finite element method.

Experiment No. 2

Forced convection heat transfer through pin fin

Objective

I. To obtain the variation of temperature along the length of a pin fin under forced convection from the experiment.

II. To determine the value of heat transfer coefficient under forced convection from the experiment.

III. To evaluate :

a. Theoretical values of temperature along the length of the fin.

b. Effectiveness and efficiency of the fin.

Theory

The heat transfer in convection is given by Newton's law of cooling $q = hA\Delta T$ where q is the heat transfer rate, h is the heat transfer coefficient and ΔT is the temperature difference, A is the surface area through which heat transfer occurs. To increase the heat transfer rate q, whether increase the surface A or increase the heat transfer coefficient h. But in some case it is not possible to increase h, in that case the only way is increase the surface area, the surface area is increased by attaching some extra material in the form of rod (circular or rectangular) on the surface where higher heat transfer rate is required. That extra material attached to the surface is called extended surface or fins.

Fins are called plane surface fins if they are attached to plane surface, circumferential fins if attached to cylindrical surface. The cross-section of fin may be circular, rectangular, triangular or parabolic.

- *Temperature distribution and heat transfer from a fin of finite length with insulated tip:*

Temperature distribution along the length of the fin is:

$$\frac{\theta}{\theta_0} = \frac{T - T_\infty}{T_1 - T_\infty} = \frac{\cosh m(L - x)}{\cosh mL}$$

$m = \sqrt{\frac{hP}{kA}}$

$T =$ temperature at any distance x from the base

$T_\infty =$ ambient temperature

$T_1 =$ base Temperature

$L =$ length of the fin (150 mm)

$h =$ heat transfer coefficient

$P =$ perimeter of the fin

$A =$ cross-section area of the fin

$k =$ thermal conductivity of the fin

Heat transfer rate $q = \theta_0 \sqrt{hPkA}$

- *Fin effectiveness*

  Effectiveness of a fin is defined as the ratio of the heat transfer with fin to heat transfer from the surface without fin. For insulted tip effectiveness of the fin:

$$\varepsilon = \sqrt{\frac{Pk}{hA}} \tanh mL$$

- *Fin efficiency*

  The efficiency of a fin is defined as the ratio of the actual heat transferred by the fin to the maximum heat transferred to the fin if the entire fin area is at the same temperature. Efficiency of the fin:

$$\eta = \frac{\tanh mL}{mL}$$

Procedure

- Connect the equipment to electric power supply.
- Keep the thermocouple selector switch (thermotech) to one position.
- Switch on the blower and take initial readings (at zero Watt) T_1, T_2, T_3, T_4, T_5 *and* T_6.
- Turn the dimmer stat knob clockwise and adjust the power input to the heater to the desired value.

- Allow the unit to stabilize. Approximate time to stabilize the temperature is 40-50 minutes. Meanwhile reading should be taken at 10 minutes interval to observe the steady state.
- Press the thermotech selector and note down the temperature T_1 to T_6.
- Note down the difference in the level of the manometer.
- Repeat the experiment for different power input to the heater.

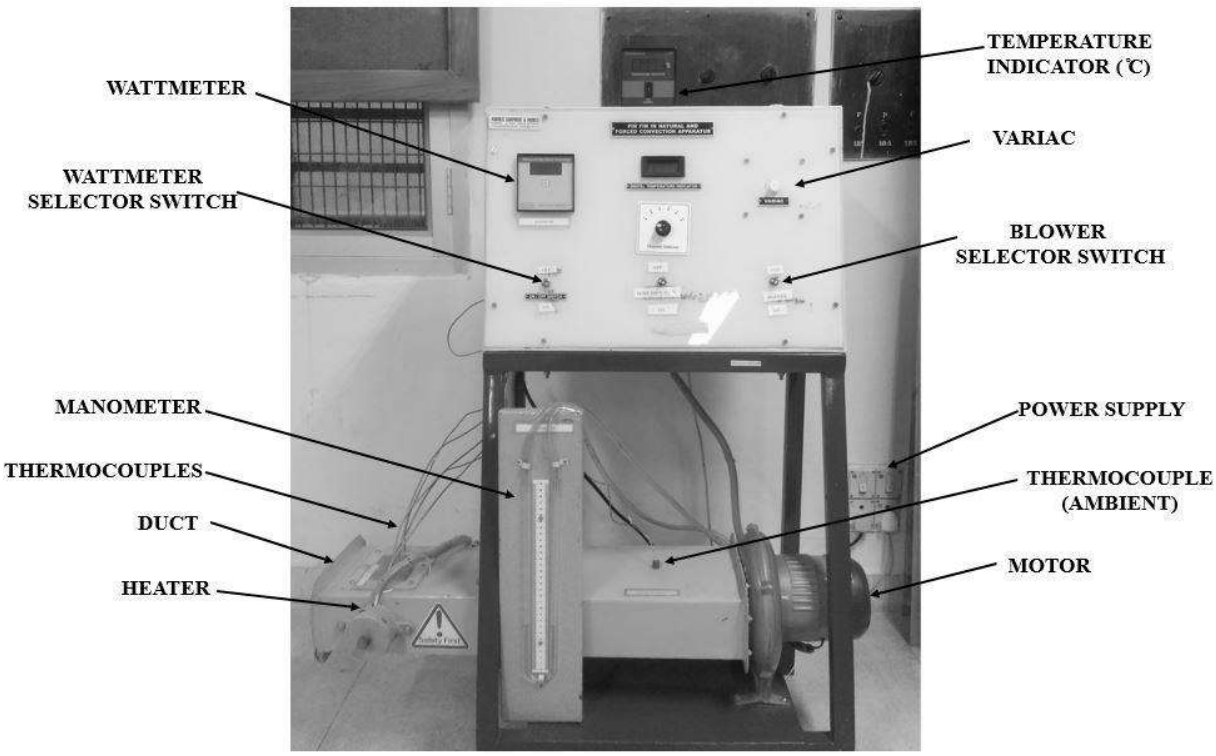


Figure 1: Experimental Facility of Pin Fin in Forced Convection

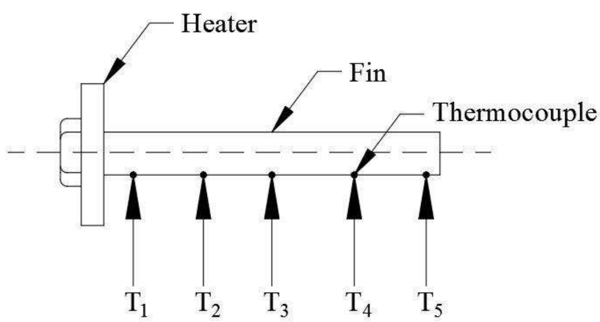


Figure 2: Location of thermocouple on Fin

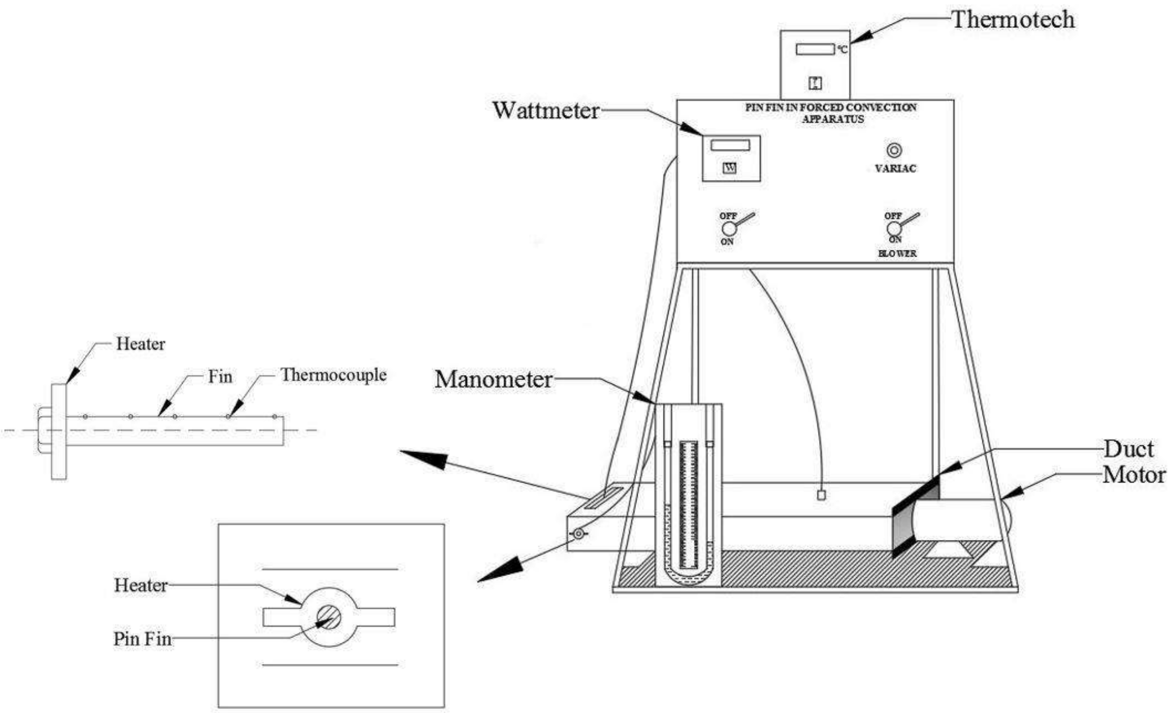


Figure 3: Schematic of Pin Fin Apparatus in Forced Convection

Precautions

- Switch on the blower before turning on the heater.
- When the experiment is complete, first turn off the heater then after some time turn off the blower.
- Do not stop the blower in between the testing period.

Table 1: Location of Thermocouple on fin

Sr. No.	1	2	3	4	5
***x* (mm)**	30	60	90	120	150

Observation Table

Sr. No.	Time (min)	Heat Input (W)	Pressure drop h (cm)	Temperatures (°C)					
				T_1	T_2	T_3	T_4	T_5	T_6
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

Results and calculations

i. Average surface temperature of fin is given by

$$T_s = \frac{(T_1 + T_2 + T_3 + T_4 + T_5)}{5}$$

$$T_m = \frac{(T_s + T_6)}{2}$$

$T_6 =$ ambient temperature

$T_m =$ mean temperature

ii. Properties of air are evaluated at T_m

a) Kinematic viscosity (v) = ……….. m^2/s

b) Prandtl number (Pr) = …………..

c) Thermal conductivity of air (K_a) = ………….W/m-K

iii. Velocity at orifice:

$$V_0 = c_d\left(\sqrt{2gh\frac{\rho_w-\rho_a}{\rho_a}}\right).(1-\beta^4)^{-0.5}$$

$\beta = 0.52$

Coefficient of discharge (c_d) = 0.85

Density of manometric fluid (ρ_w) = 1000 kg/m^3

iv. Velocity of air in the duct:

$$V_a = \frac{\text{(velocity at orifice)}\times\text{(cross-sectional area of orifice)}}{\text{(cross-sectional area of duct)}}$$

$$V_a = V_0\left(\frac{\frac{\pi}{4}d_0^2}{W\times B}\right)$$

d_o = diameter of orifice (0.02 m)

W = width of the duct (0.15 m)

B = breadth of the duct (0.1 m)

v. Nusselt number (Nu) = $C\,R_e^n\,\text{Pr}^{1/3}$

$$Nu = \frac{hD}{k_a}$$

$$\text{Reynolds Number}\,(R_e) = \frac{DV_a}{\nu}$$

$$\text{Prandtl Number}\,(Pr) = \frac{\mu c_p}{k_a}$$

C is a constant and n is index values, which are given in table below for different ranges of Reynolds number.

Reynolds Number	*C*	*n*
0.4-4	0.989	0.33
4-40	0.911	0.385
40-4000	0.683	0.466
4000-40000	0.293	0.618
40000-400000	0.27	0.805

Specifications

- Length of the fin (L)= 150 mm
- Diameter of the fin (D) = 16 mm
- Thermal conductivity of the fin material (brass) = 110 W/m-K

Properties of air at mean temperature

Temperature (K)	ρ (kg/m^3)	C_p (kJ/kg-K)	$\mu(\times 10^{-7})$ (N-s/m^2)	$v(\times 10^{-6})$ (m^2/s)	$K_a(\times 10^{-3})$ (W/m-K)	α (m^2/s)	*Pr*
250	1.3947	1.006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1.007	184.6	15.89	26.3	22.5	0.707
350	0.9950	1.009	209.2	20.92	30.0	29.0	0.700
400	0.8711	1.014	230.1	26.41	33.8	38.3	0.690

Discussion

Discuss about your findings in the results and explain reasons for deviations of the experimental results with the theoretical solution.

Conclusions

Conclude the experimental results obtained in the experiments.

Experiment No.3

Study of critical heat flux (Boiling heat transfer)

Objectives

(a) To calculate the critical heat flux at various bulk temperatures of water.

(b) To compare the experimentally obtained critical heat flux at the saturation temperature with that obtained by Zuber's correlation.

Theory

When heat is added to a liquid from a submerged solid surface which is at a temperature higher than the saturation temperature of the liquid, it is usual for a part of the liquid to change phase. This change of phase is called boiling. Boiling is of various types, the type depending upon the temperature difference between the surface and the liquid. The different types are indicated in Figure 1, in which a typical experimental boiling curve obtained in a saturated pool of liquid is drawn.

This heat flux supplied to the surface is plotted against (T_w - T_s), the difference between the temperature of the surface and the saturation temperature of the liquid. It is seen that the boiling curve can be divided into three regions:

1. Natural Convection Region
2. Nucleate Boiling Region
3. Film Boiling Region

The region of natural convection occurs at low temperature differences (of the order of 10^o C or less). Heat transfer from the heated surface to the liquid in its vicinity causes the liquid to be superheated. This superheated liquid rises to the free liquid surface by natural convection, where vapour is produced by evaporation. As the temperature difference (T_w- T_s) is increased, nucleate boiling starts. In this region, it is observed that bubbles start to form at certain locations on the heated surface. Region *II* consists of two parts. In the first part, *II-a*, the bubbles formed are very few in number. They condense in the liquid and do not reach the free surface.

In the second part, *II-b*, the rate of bubble formation as well as the number of locations where they are formed, increases. Some of the bubbles now rise all the way to the free surface Withthe increasing temperature difference, a stage is finally reached when the rate of formation of bubbles is so high, that they start to coalesce and blanket the surface with a vapour film. This is the beginning of region *III* viz. film boiling. In the first part of this region *III-a*, the vapour film is unstable, so that film boiling may be occurring on a portion of the heated surface area, while nucleate boiling may be occurring on the remaining area. In the second part, *III-b*, a stable film covers the entire surface. The temperature difference in this region is of the order of 1000°C and consequently radiative heat transfer across the vapour film is also significant.

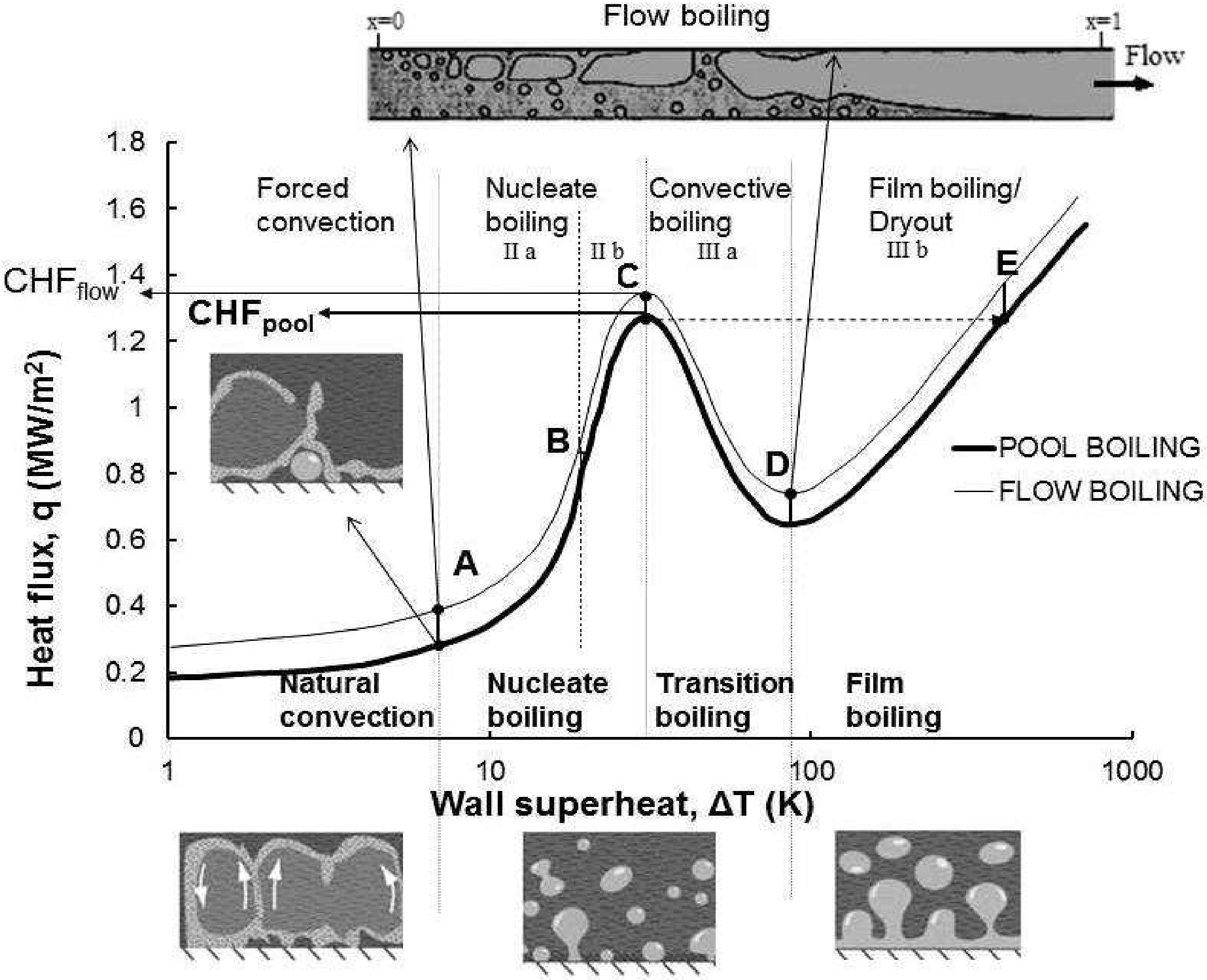


Figure 1: Pool boiling curve

It will be observed from Figure 1, that the heat flux does not increase in a regular manner with the temperature difference. In region *I*, the heat flux is proportional to $(T_w - T_s)^n$where n is slightly greater than unity (about 1.3). When the transition from natural convection to nucleate boiling occurs the heat flux starts to increase more rapidly with temperature difference, the value of *n* increasing to about 3. At the end of region *II*, the boiling curve reaches a peak (Point A). Beyond this, in region *III-a*, inspite of increasing temperature difference, the heat flux decreases because the thermal resistance to the heat flow increases with the formation of a vapour film. The heat flux passed through a minimum (Point B) at the end of region *III-a*. It starts to increase again with $(T_W - T_S)$ only when stable film boiling begins and radiation becomes increasingly important.

It is of interest to note how the temperature of the heating surface changes as the heat flux is steadily increased from zero. Up to the point A, natural convection boiling and then nucleate boiling occur and the temperature of the heating surface is obtained by reading off the value $(T_W - T_S)$ from the boiling curve and adding to it the value T_S. If the heat flux is increased even a little beyond the value at A, the temperature of the surface will shoot up to the value corresponding to the point C. It is apparent from Figure 1, that the surface temperature corresponding to point C is high. For most surfaces, it is high enough to cause the material to melt. Thus in most practical situations, it is undesirable to exceed the value of heat flux corresponding to point A. This value is therefore of considerable engineering significance and is called the critical or peak heat flux. The pool boiling curve as described above is known as Nukiyama Pool Boiling Curve. The discussion so far has been concerned with various types of boiling which occur in saturated pool boiling. If the liquid is below the saturation temperature we say that sub-cooled pool boiling is taking place. Also in many practical situations, e.g. steam generators, one is interested in boiling the liquid flowing through tubes. This is called forced convection boiling and may also be saturated or sub-cooled or nucleate or film type.

Thus in order to completely specify boiling occurring in any process, one must state. (i) Whether it is forced convection boiling or pool boiling, (ii) whether the liquid is saturated or sub-cooled, and (iii) whether it is in the natural convection, nucleate or film boiling region.

Apparatus

The apparatus consists of a cylindrical glass container housing the test heater and a heater coil for the initial heating of the water. This heater coil is directly connected to the mains (Heater R1) and the test heater (Nichrome wire) is connected also to mains via a dimmerstat. An ammeter is connected in series while a voltmeter across it to read the current and voltage, respectively. The glass container is kept on an iron stand which could be fixed on a platform.

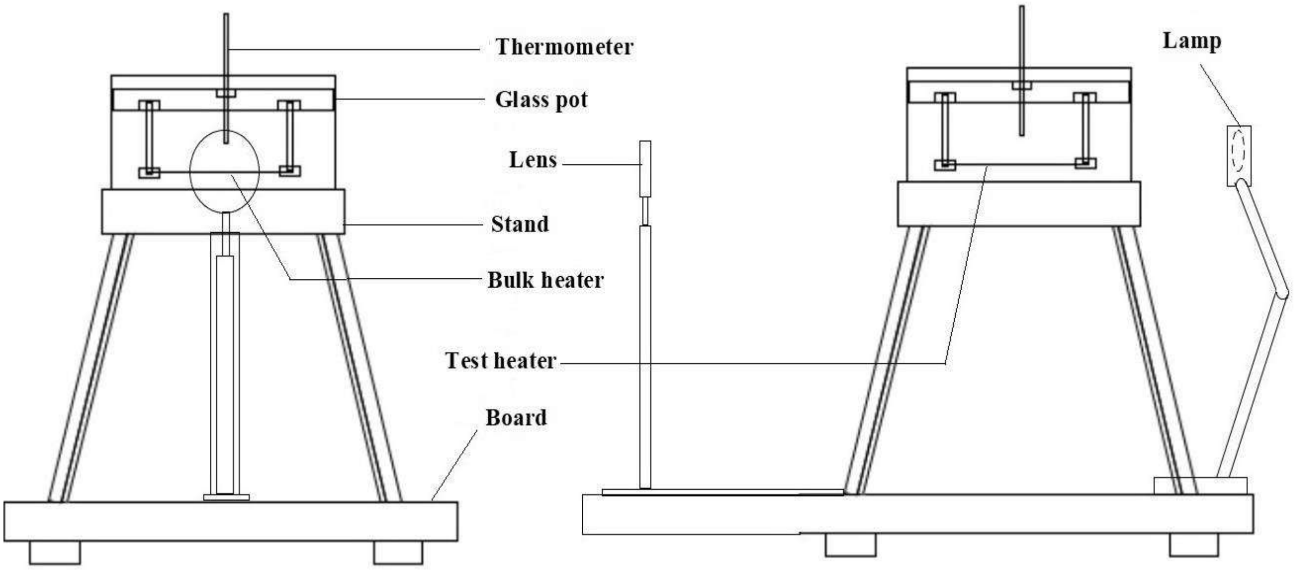


Figure 2: Schematic diagram of critical heat flux apparatus

There is provision of illuminating the test heater wire with the help of a lamp projecting light from behind the container and the heater wire can be viewed through lens. Theschematic arrangement of the apparatus is shown in Figure 2

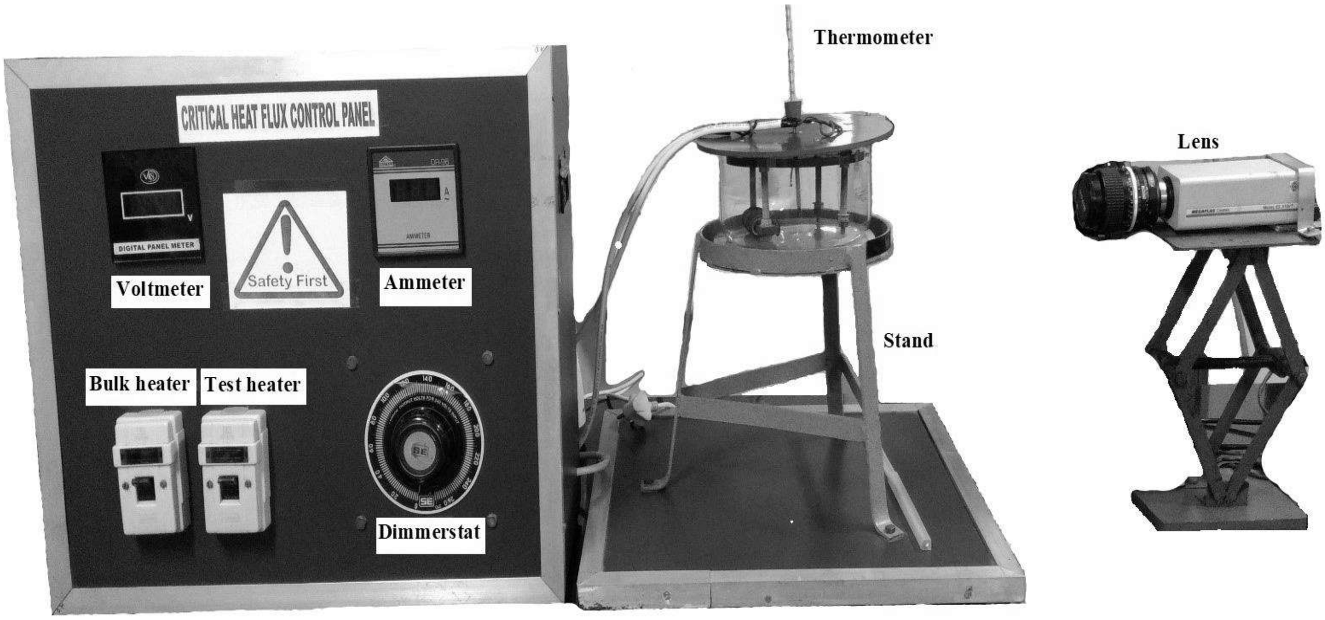


Figure 3: Schematic diagram of critical heat flux apparatus

Technical Specifications

1. Glass Container — Diameter - 200 mm

   Height - 100 mm

2. Heater for initial Heating

Nichrome Heater (R1) 1 kW

3. Test Heater (R2)

Nichrome wire size mm (phi) (to be calculated according to wire used say 36 SWG to 40 SWG)

4. Test heater length (R2) 100 mm
5. Dimmerstat for (3) --- Test heater
6. Voltmeter for (3)
7. Ammeter for (3)
8. Thermometer (3)

Experimental Procedure

This experimental set up is designed to study the pool boiling phenomenon up to critical heat flux point. The pool boiling over heater wire can be visualised in the different regions up to critical heat flux point at which the wire melts. The heat from the wire is slowly increased by gradually increasing applied voltage across the test wire and the change over from natural convection to nucleate boiling can be seen.

The formation of bubbles and their growth in size and number can be visualised, followed by the vigorous bubble formation and their immediate carrying over to surface and ending thus in the breaking of the wire indicating the occurrence of critical heat flux point. This is repeated for various temperatures of the water inthe container up to the saturation temperature.

1. Take 3 to 4 litres of distilled water in the container.
2. See that both the heaters are completely submerged.
3. Connect the heater coil R1 (1 kW Nichrome coil) and test heater wire across the studs and make the necessary electrical connections.
4. Switch on the heater R1.
5. Keep it on till you get the required bulk temperature of water in the container say 50°C, 60°C, 70°C
up to the saturation temperature.
6. Switch off the heater R1.
7. Switch off the heater R2.
8. Very gradually increase the voltage across it by slowly changing the variac from one position to the other and stop a while at each position to observe the boiling phenomenon on wire.

9. Go on increasing the voltage till wire breaks and carefully note the voltage and current at this point.

10. Repeat this experiment by altering the bulk temperature of water.

Observations(For Finding Critical Heat Flux Values)

1. Diameter of test heater wire, $d = 0.2$ mm
2. Length of the test heater, $L = 10$ cm
3. Surface area, $A = \pi d L$ m^2

Observation Table

Bulk Temperature ofwater (˚C)	Ammeter Reading (A)	Voltmeter Reading (V)
40		
50		
60		
70		
80		
90		
95		
Saturation Temperature		

Note

The Ammeter and the Voltmeter readings are to be noted down when the wire melts.

Precautions

1. Keep the variac at zero voltage position before starting the experiments.
2. Take sufficient amount of distilled water in the container so that both the heaters are completely immersed.
3. Connect the test heater wire across the studs tightly.
4. Do not touch the water or terminal points after putting the switch in the on – position.
5. Very gently operate the variac in steps and allow sufficient time in between.
6. After the attainment of critical heat flux condition decrease slowly the voltage and bring it to zero.

Results and Calculations(Experiment Based)

The critical heat flux at various bulk temperatures of water can be calculated by the following procedure.

Heat input = $V \cdot I$ Watt

Critical $q = 0.86 V \cdot I$ MW

$$(q/A)_{critical} = \frac{0.86 V \cdot I}{A} \text{ MW/m}^2$$

Note

Here 0.86 is overall efficiency of heater specified by the manufacturer.

Peak heat flux in saturated pool boiling =

Zuber has the following equation for calculating the peak heat flux in saturated pool boiling

$$\frac{q}{A} = \frac{\pi}{24} \cdot \lambda \cdot \rho_v \left(\frac{\sigma g (\rho_L - \rho_v)}{\rho_v^2} \right)^{1/4} \left(\frac{\rho_L - \rho_v}{\rho_L} \right)^{1/2}$$

Where λ , σ, ρ_L and ρ_v are evaluated at the liquid saturation temperature.

λ = Latent heat = 2257000 J/kg

σ = Surface tension = 0.0589 N/m

ρ_v = Vapour density = 0.6 kg/m^3

ρ_L = liquid density = 957.9 kg/m^3

It can be observed that the critical heat flux value goes on decreasing as the bulk temperature approaches the saturation temperature as expected (Figure 3)

The experimental value of critical heat flux at the saturation temperature is comparable to that obtained byZuber's correlation.

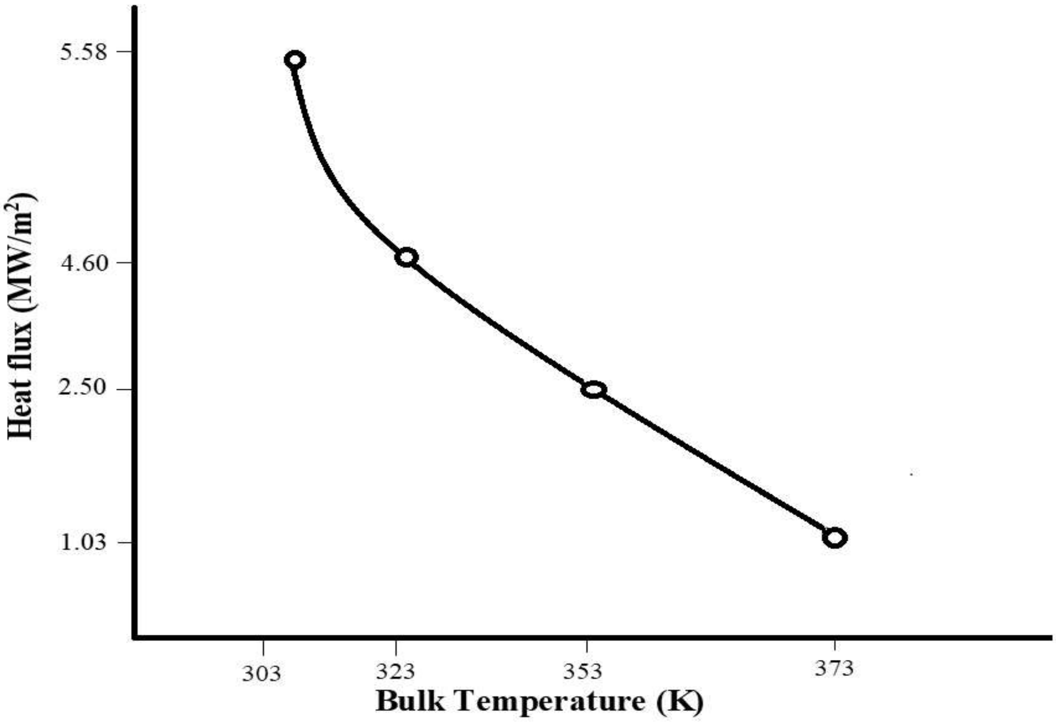


Figure 4: Critical heat variation with bulk temperature

Reference

Yunus A. Cengel ,*Heat And Mass Transfer*, 4th edition , McGraw-Hill, (2011).

Experiment No. 4
Measurement of emissivity

Objectives

1. To measure the emissivity of the test plate at various surface temperatures by using the experimental setup.
2. To plot variation of emissivity with a surface temperature of the test plate.

Theory

All substances at all temperature emit thermal radiation. Thermal radiation is an electromagnetic wave and does not require any material medium for propagation. All bodies can emit radiation and have also the capacity to absorb all or part of the radiation coming from the surroundings towards it.

An idealized black surface is one which absorbs all the incident radiation with reflectivity and transmissivity equal to zero. The radiant energy emitted per unit time per unit area from the surface of the body is called the emissive power and is usually denoted by e. The emissivity of a surface is defined as the ratio of the emissive power of the surface to the emissive power of the hypothetical black surface at the same temperature. It is denoted by ε.

Thus

$$\varepsilon = \frac{e}{e_b} \tag{1}$$

For a black body absorptivity = 1, and by the knowledge of Kirchhoff's Law emissivity of the blackbody also becomes unity.

Emissivity being a property of the surface depends on the nature of the surface and temperature.

It is obvious from the Stefan-Boltzmann Law that the prediction of the emissive power of a surface requires knowledge about the value of its emissivity and therefore much experimental research in radiation has been concentrated on measuring the value of emissivity as a function of surface temperature.

The present experimental set up is designed and fabricated to measure the property of emissivity of a test plate surface at various temperatures.

Under steady state conditions.

Let

W_1 = Heater input to black plate, watts = $V_1 I_1$

W_2 = Heater input to black plate, watts = $V_2 I_2$

A =Area of the plates= $\frac{\pi}{4} D^2$

T_S = Temperature of the black plate in Kelvin

T_D = Ambient temperature in Kelvin

D = Diameter of Aluminium Discs

ε_b = Emissivity of the black plate (To be assumed unity)

ε = Emissivity of the non-black test plate

σ = Stefan-Boltzmann constant

By using Stefan-Boltzmann law:

$$W_1 - W_2 = (\varepsilon - \varepsilon_b) A \sigma (T^4{}_s - T_D{}^4) / 0.86$$

Note

Here 0.86 is overall efficiency of plate heaters specified by the manufacturer.

Apparatus

The experimental set up consists of two circular Aluminium plates identical in size and provided with heating coils at the bottom. The plates are mounted on an asbestos cement sheet and are kept in an enclosure so as to provide undistributed natural convection surrounding.

The heat input to the heater is varied by separated dimmerstats and is measured by using an ammeter and a voltmeter/wattmeter with the help of double pole double-throw switches. The temperature of the plates is measured by thermocouples. Separated wires are connected to diametrically opposite points to get the average surface temperatures of the plates. Another thermocouple is kept in the enclosure to read the ambient temperature of the enclosure.

Plate-1 is blackened by a thick layer of lamp black to form the idealized black surface whereas the plate2 is the test plate whose emissivity to be determined.

The heater inputs to the two plates are dissipated from the plates by conduction, convection, and radiation. The experimental set up is designed in such a way that under steady state condition the heat dissipation by conduction and convection is same for both the plates.

When their surface temperatures are the same and the difference in the heater input readings is because of the difference in radiation characteristics due to their different surface emissivity.

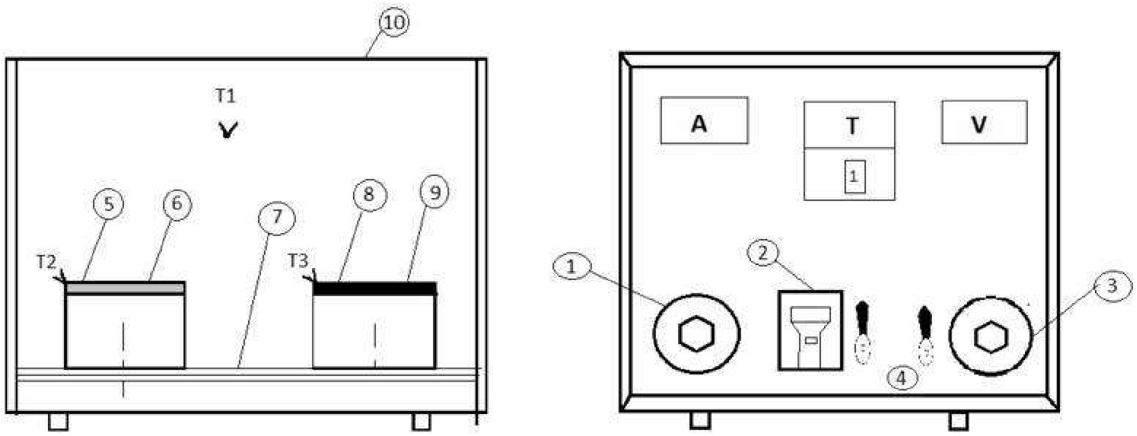


Figure 1: Schematic diagram for emissivity measurement apparatus

1-Dimmer state (Black plate), 2-Main switch, 3-Dimmer state (Test plate), 4-D.P.D.T switch,

5-Test plate heater, 6-Test plate, 7-Asbestos sheet, 8-Black plate heater, 9-Black plate,

10-Enclosure, T1 to T3-Thermocouple, A-Ammeter, V- Voltmeter, T- Temperature indicator

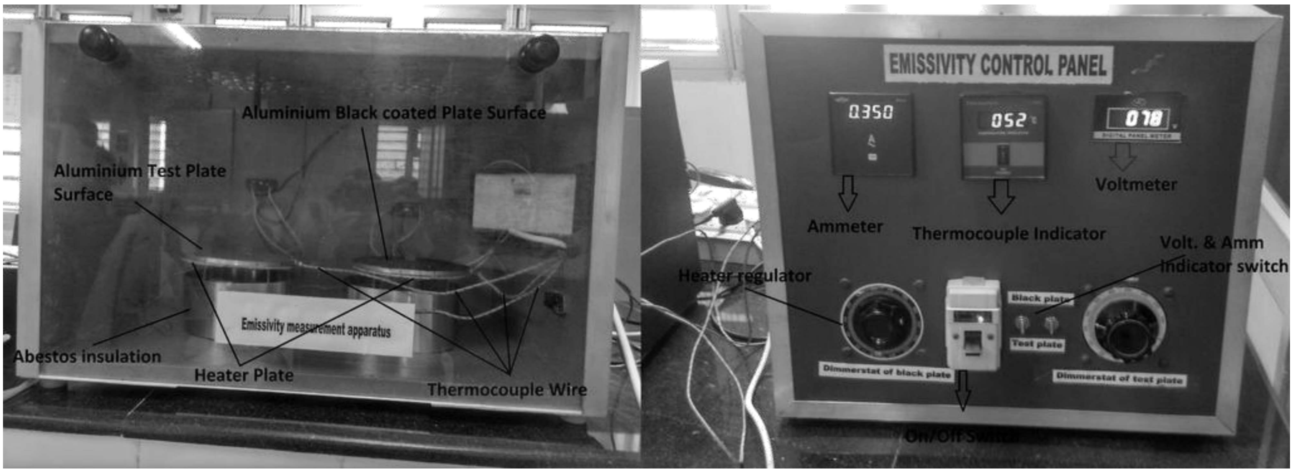


Figure 2: Apparatus in The Heat Transfer Laboratory

Procedure

1. Give power supply to temperature indicator (230 v single phase) and adjust the reading in it equal to room temperature by rotating the compensation knob (Normally this is pre-adjusted)
2. Select the proper range of voltage on wattmeter/ voltmeter and Ammeter.
3. Gradually increase the power input to the heater of the black plate and adjust it to some value 30,50,75 watts and adjust the power input to the test plate to slightly less value than the black plate 27,35,55 watts etc.
4. Check the temperatures of the two plates at small time intervals and adjust the power input of the test plate only by means of the dimmerstat such that the two plates are maintained at the same temperature.
5. This will require some trial and error and one has to wait sufficiently long (more than one hour or so) to obtain the steady state condition.
6. After attaining the steady state record the reading of W_1, W_2 , T_s, and T_D .
7. The same procedure is repeated for various plate surface temperatures in increasing order.

Precaution

1. Use stabilized A.C. single phase supply (preferably).
2. Always keep the dimmerstats at zero position before the start.

3. Use the proper voltage range on voltmeters.
4. Gradually increase the heater inputs.
5. See that the black plate is having a layer of lamp black uniformly.

Note

There is the possibility of getting absurd results if the supply voltage is fluctuating or if the input is not adjusted till the satisfactory steady-state condition is reached.

Specifications

1. Test plate Diameter = 160 mm.
2. Black plate Diameter = 160 mm.
3. Heater for the black plate, Nichrome strip wound on mica sheet and sandwich between two mica sheets.
4. Heater for test plate, same as above.
5. Enclosure size 58 cm $\times$ 30 cm $\times$ 30 cm approx. With one side of Perspex.
6. Thermocouples [Iron constantan]
7. Temperature Indicator 0- 300C with compensation for room temperature which is to be adjusted initially.
8. D.P.D.T. Switch.

Results and Discussions

By using the expression

$$W_1 - W_2 = (\varepsilon - \varepsilon_b) \cdot A \cdot \sigma \cdot (T_s^4 - T_D^4) / 0.86$$

and assuming that ε_b = 1(for the black plate)

The emissivity of the test plate can be calculated at a various surface temperature of the plate.

With the increase in temperature, the test surface becomes somewhat dull and therefore its emissivity increases with an increase in surface temperature

This fact could be verified by performing the experiments at various values of T_S and can be plotted in a graph as shown in Figure 3.

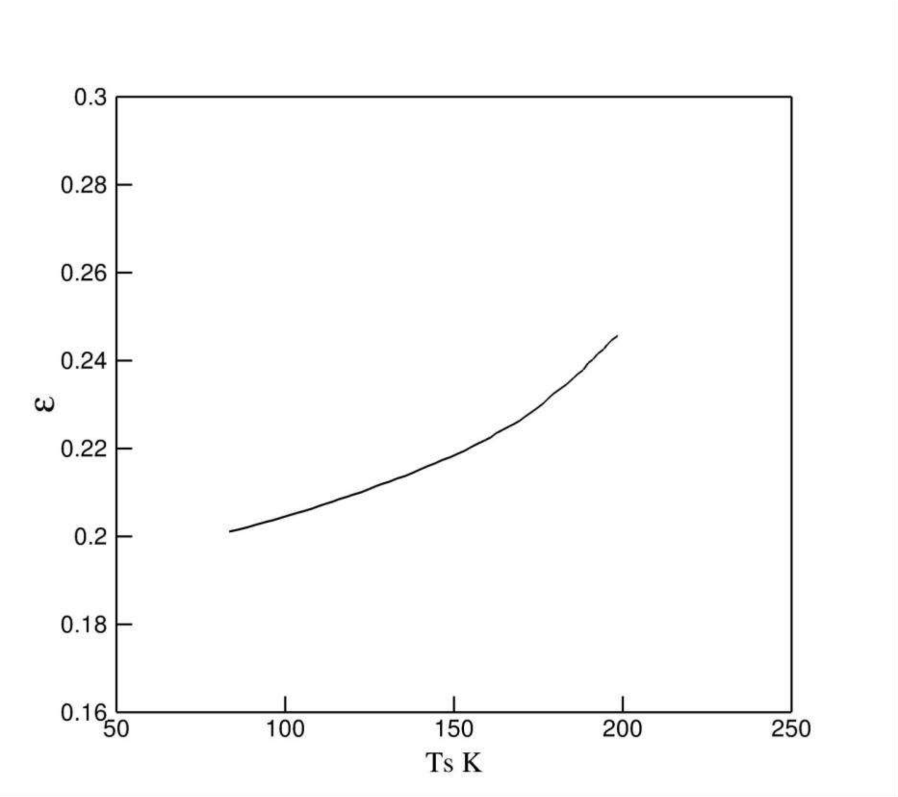


Figure 3: Variation of ε against T_s

Experiment No 6

Heat transfer through extended surface

Objectives

I. Measuring the temperature distribution along an extended surface and comparing the result with a theoretical analysis

II. Calculating the heat transfer from an extended surface resulting from combined modes of free convection and radiation heat transfer and comparing the result with the theoretical analysis

III. Determining the thermal conductivity of the rod material

Theory

Part 1:

The term extended surface is commonly used to depict an important special case involving heat transfer by conduction within a solid and heat transfer by convection (and/or radiation) from the boundaries of the solid. The direction of heat transfer in extended surfaces from the boundaries is perpendicular to the principal direction of heat transfer in the solid. A temperature gradient exists along each fin or pin due to the combination of the conductivity of the material and heat loss to the surroundings (greater at the root and less at the tip).

The temperature distribution along the fin or pin must be known to determine the heat transfer from the surface to its surroundings. Since radiation and natural convection from the surface occur simultaneously, both of these effects must also be included in the analysis.

By considering the steady-state energy balance for an extended surface of uniform material and cross-sectional area, the following equation can be derived

$$\frac{d^2\theta}{dx^2} - m^2\theta(x) = 0$$

Where $m^2 = \dfrac{hP}{k_{brass}A}$

$\theta(x) = T_x - T_a$

Since h, P, K_{brass} and A are constant for a given rod with fixed power input, therefore m^2 must be a const.

Assuming that the diameter of the pin is small in comparison with its length then heat loss at the tip can be assumed to be negligible (at the tip x=L). $\dfrac{d\theta(x)}{dx} = 0 \; at \; x = L$

Therefore: $\dfrac{\theta(x)}{\theta} = \dfrac{T_x - T_a}{T_1 - T_a} = \dfrac{\cosh m(L-x)}{\cosh mL}$

Note that the magnitude of the temperature gradient decreases with increasing x. This trend is a consequence of the reduction in the conduction heat transfer with increasing x due to continuous convection and radiation losses from the fin surface.

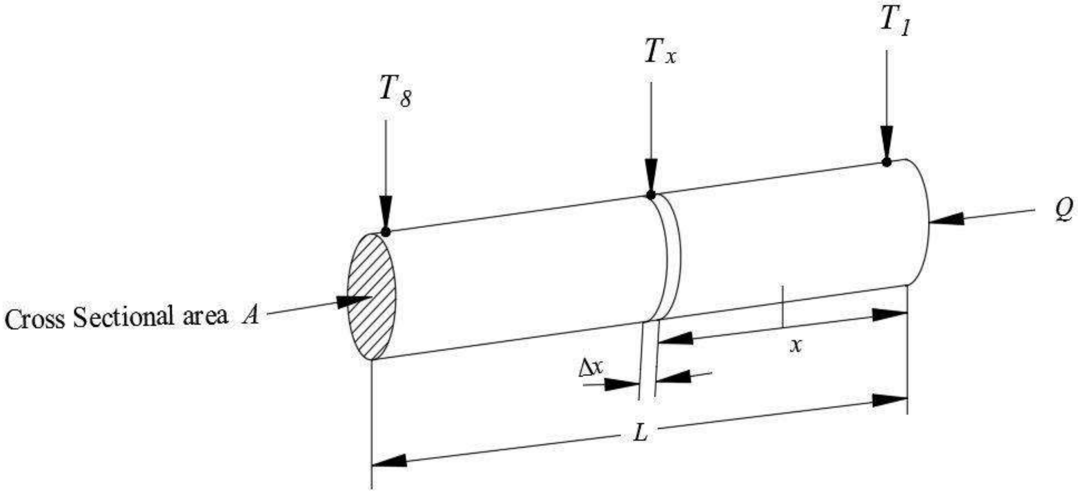


Figure 1: Geometrical Description of Experimental Setup

Part 2:

The total heat loss from the rod can be calculated as follows:

$Q_{tot} = hA_s(T_s - T_a)$ (W)

Where the heat transfer coefficient (HTC) h is the combined coefficient due to natural convection and radiation, i.e. $h = h_c + h_r (Wm^{-2}K^{-1})$

and $A_s = \pi DL$ (Total area of the extended surface)

where: L = Length of the rod (distance from T_1 to T_8) = 35 cm

Note: The distance between each thermocouple thermocouple is 5 cm starting from 0.0 cm at T_1.

T_s = Average surface temperature of the rod (averaged from temperature T_1 to T_8)

T_a = Ambient air temperature (T_9)

$$Nu_c = \frac{h_c D}{k} = CRa_D^n$$

Where: $Ra_D = \dfrac{\beta g(T_s - T_a)D^3}{\upsilon_a}$

Ra_D	C	n
$10^{-10} – 10^{-2}$	0.675	0.058
$10^{-2} – 10^{2}$	1.02	0.148
$10^{2} – 10^{-4}$	0.85	0.188
$10^{4} – 10^{7}$	0.48	0.25
$10^{7} – 10^{12}$	0.125	0.333

The average radiative heat transfer coefficient can be calculated as follows:

$$h_r = \sigma \varepsilon F \left(\frac{T_s^4 - T_a^4}{T_s - T_a} \right)$$

Where: σ = Stefan Boltzmann constant = 5.67×10^{-8} ($Wm^{-2}K^{-4}$)

ε = Emissivity of the surface ≡ 0.85 and view factor F=1

Part 3:

Then the thermal conductivity of the material is given as: $k_{brass} = \dfrac{hP}{m^2 A}$

Where Perimeter of fin $(P) = \pi D$

Cross sectional area of the pin $(A) = \dfrac{\pi D^2}{4}$

Equipment Set-up

Before proceeding with the exercise ensure that equipment has been prepared as follows: Locate the HT15 Extended Surface Heat Transfer Accessory alongside the HT10X Heat Transfer Service Unit on a suitable bench. Since heat transfer from the extended surface relies on natural convection and radiation to the surroundings, the accessory must be located away from draughts or source of radiation

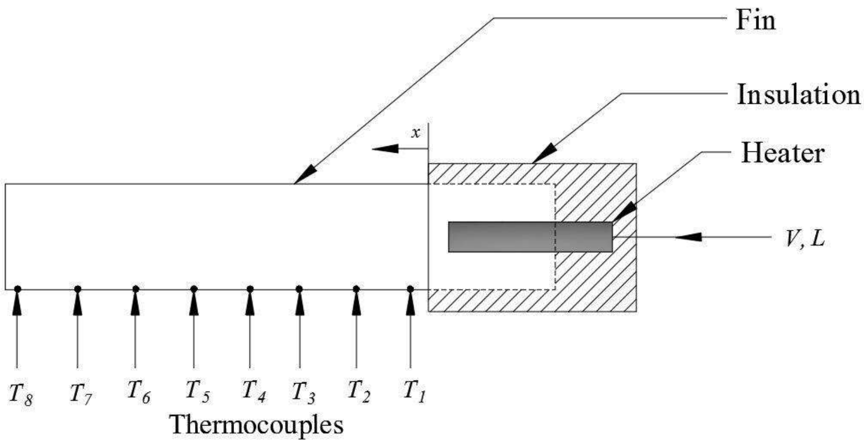


Figure 2: Schematic diagram of experimental setup

Connect the nine thermocouples on the HT15 to the appropriate sockets on the front of the service unit. Ensure that the labels on the thermocouples leads *(T1 – T9)* match the labels on the sockets.Set the voltage control potentiometer to minimum (anticlockwise) and selector switch to manual then connect the power lead from the HT15 to the socket marked O/P 3 at the rear of the service unit.

Procedure

Switch on the main switch.

Set the heater voltage to 20 Volts with the help of voltage control potentiometer.

Monitor temperature T_1 regularly and when T_1reaches 80°C, reduce the heater voltage to 9 Volts (the initial higher setting will reduce the time taken for the temperature on the rod to stabilize).

Allow the temperature to stabilize till steady state reached.

Record the voltage and current supplied to the heater.

Record the temperature at each position along the rod (T_1 *to* T_8) and ambient air temperature (T_9).

Set the heater voltage to 12 and 16 volts and follow the above steps

Observation Tables

Measurement for 9 V										
Heater Voltage *V* (V) : Heater current *I* (A) : Heater Power *Qin* (W) :										
Thermocouple Description	numbers	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
	Location (*m*)									
Temperature T_x(°C)	Time1									
	Time2									
	Time3									

Measurement for 12 V										
Heater Voltage (V) : Heater current (A) : Heater Power (W) :										
Thermocouple Description	Number	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
	Location (m)									
Temperature T_x (°C)	Time1									
	Time2									
	Time3									

Measurement for 16 V										
Heater Voltage *V* (V): Heater current *I* (A): Heater Power *Qin* (W):										
Thermocouple Description	Number	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
	Location (m)									
Temperature T_x (°C)	Time1									
	Time2									
	Time3									

Results and Calculations

Perform the results and calculation based on the recorded data as per formulas mentioned above.

Part I.

- Find the value of constant *'m'* using any iterative technique for thermocouple T_1 to T_8 (the initial guess for the value of *'m'* can be taken 8.0).
- Calculate the theoretical temperature T_x at each point along the rod using average value of '*m*'.
- Estimate the cumulative influence of the experimental errors on your calculated values for 'm' and measured values for T_1 to T_9, *x* and *L*.
- Plot measured surface temperature T_x from experiment and theoretical temperature profile (calculated using average value of '*m*') against position *x* (in same plot) along the extended surface clearly showing the data points on the plot.

Part II.

- Compare the measured power Q_{in} to the heater with the calculated heat loss Q_{tot} from the rod.

Part III.

- Compare the measured thermal conductivity with the suggested thermal conductivity for brass rod k_{brass} = 121 $Wm^{-2}K^{-1}$.

Discussion on Results

Discuss about your findings in the results and explain/ provide reasons for deviations of the experimental results with the theoretical/analytical solution/s.

Conclusions

Conclude the experimental results obtained in the experiments

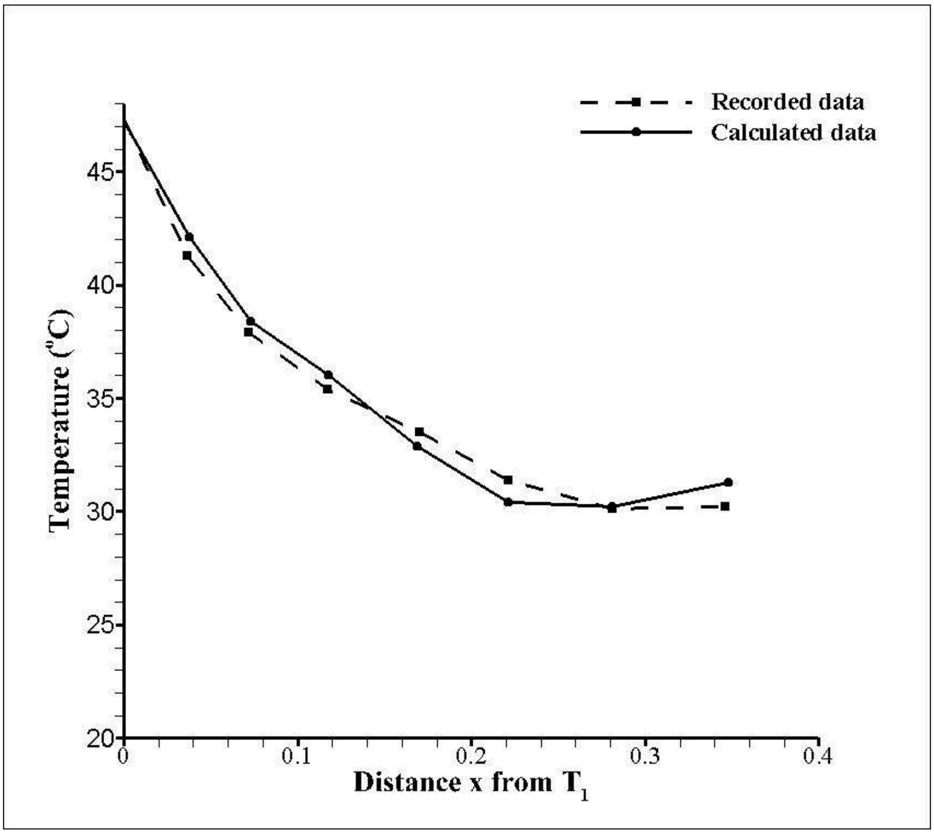


Figure 3: Temperature vs distance distribution curve

Experiment No. 5 (a)

Heat transfer in natural convection

Objective

To determine the natural convection heat transfer coefficient for the vertical cylindrical tube which is exposed to the atmospheric air and losing heat by natural convection.

Theory

There are certain situations in which the fluid motion is produced due to change in density resulting from temperature gradients, which is the heat transfer mechanism called as free or natural convection. Natural convection is the principal mode of heat transfer from pipes, refrigerating coils, hot radiators etc. The movement of fluid in free convection is due to the fact that the fluid particles in the immediate vicinity of the hot object become warmer than the surrounding fluid resulting in a local change of density. The warmer fluid would be replaced by the colder fluid creating convection currents. These currents originate when a body force (gravitational, centrifugal, electrostatic etc.) acts on a fluid in which there are density gradients. The force which induces these convection currents is called a buoyancy force which is due to the presence of a density gradient within the fluid and a body force. Grashoff number (Gr) plays a very important role in natural convection.

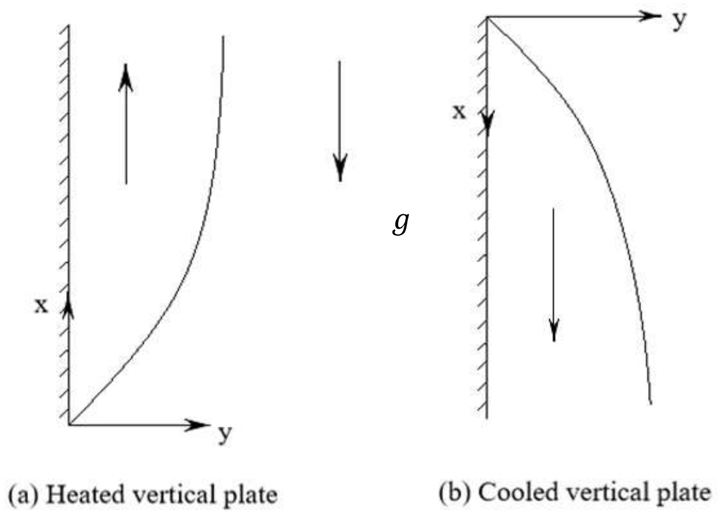


Figure 1: Natural convection flow pattern

In contrast to the forced convection, natural convection phenomenon is due to thetemperature difference between the surface and the fluid is not created by any external agency.

The test section is a vertical, open ended cylindrical pipe dissipating heat from the internal surface. The test section is electrically heated imposing the circumferentially and axially constant wall heat flux. As a result of the heat transfer to air from the internal surface of the pipe, the temperature of the air increases. The resulting density non-uniformity causes the air in the pipe to rise. The present experimental setup is designed and fabricated to study the natural convection phenomenon from a vertical cylinder in terms of the variation of the local heat transfer coefficient and its comparison with the value which is obtained by using an appropriate correlation.

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, rises up due to the decrease in its density and the cold surrounding fluid rushes in to take its place. The process is continuous and heat transfer takes place due to the relative motion of hot and cold particles.

The heat transfer coefficient is given by

$$h = \frac{q}{A_s(T_s - T_a)} \quad (1)$$

Where,

h is Average surface heat transfer coefficient,

q is Heat transfer rate,

A_s isArea of heat transferring surface,

T_s is Average surface temperature (°C),

T_a isAmbient temperature in the duct (°C) $= T_8$,

And

$$T_s = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7}{7} \quad (2)$$

The surface heat transfer coefficient of a system transferring heat by natural convection depends on the shape, dimensions and orientation of the body, the temperature difference between the hot body and the surrounding fluid and fluid properties like k, μ, p etc.

The dependence of h on all the above mentioned parameters is generally expressed in terms of nondimensional groups, as follows:

$$\frac{hL}{k} = A\left[\left\{\frac{g\beta\Delta TL^3}{\nu^2}\right\}\left\{\frac{\mu C_P}{k}\right\}\right]^n \qquad (3)$$

Here,

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

Grashoff Number $Gr = \frac{g\beta\Delta TL^3}{\nu^2}$

Prandtl Number $\Pr = \frac{\mu C_P}{k}$

A and n are constants depending on the shape and orientation of the heat transferring surface.

L is a characteristic dimension of the surface,

k is the thermal conductivity of the fluid,

ν is the kinematic viscosity of the fluid,

μ is the dynamic viscosity of the fluid,

C_P is the specific heat of the fluid,

β is the coefficient of volumetric expansion of the fluid,

g is the acceleration due to gravity at the place of experiment,

$\Delta T = T_s - T_a$ (°C)

For gases,

$$\beta = \frac{1}{T_f + 273}\ \text{K}^{-1}$$

Where, T_f is mean film temperature

$$T_f = \frac{T_s + T_a}{2}\ (°\text{C})$$

For a vertical cylinder losing heat by natural convection, the constants A and n of equation (3) have been determined and the following empirical correlations have been obtained:

$$Nu = \frac{h_{th} L}{k} = 0.59(Gr \cdot \Pr)^{.25},\ 10^4 < Gr \cdot \Pr < 10^9 \qquad (4)$$

$$Nu = \frac{h_{th} L}{k} = 0.59(Gr \cdot \Pr)^{1/3},\ 10^9 < Gr \cdot \Pr < 10^{12} \qquad (5)$$

Here L is the length of cylinder and h_{th} is theoretical heat transfer coefficient. All the properties of the fluid are evaluated at the mean film temperature T_f.

Apparatus

The apparatus consists of a stainless steel tube fitted in a rectangular duct in a vertical fashion. The control panel for the natural convection apparatus is shown in figure 2. The heat input to the heater is measured by an ammeter and a voltmeter and is varied by a Dimmerstat. The temperatures of the vertical tube are measured by seven thermocouples (T_1 to T_7) and are marked on the Temperature Indicator Switch of the instrument panel as shown in Figure 2. One more thermocouple is used to measure ambient temperature. The schematic of the natural convection apparatus is shown in figure 2& 3.

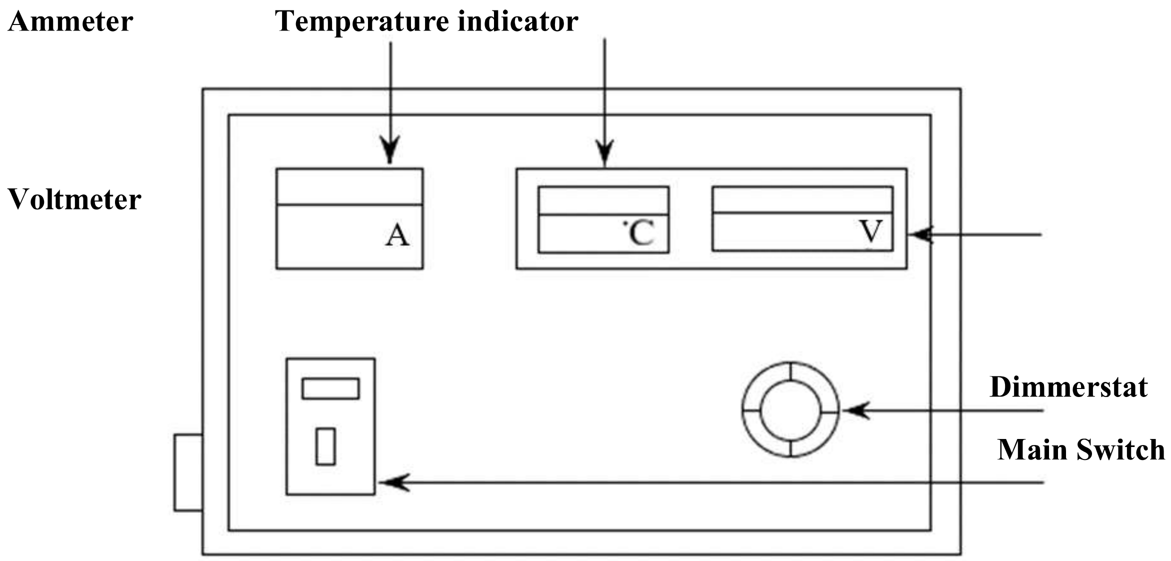


Figure 2: Control Panel for Natural Convection Apparatus

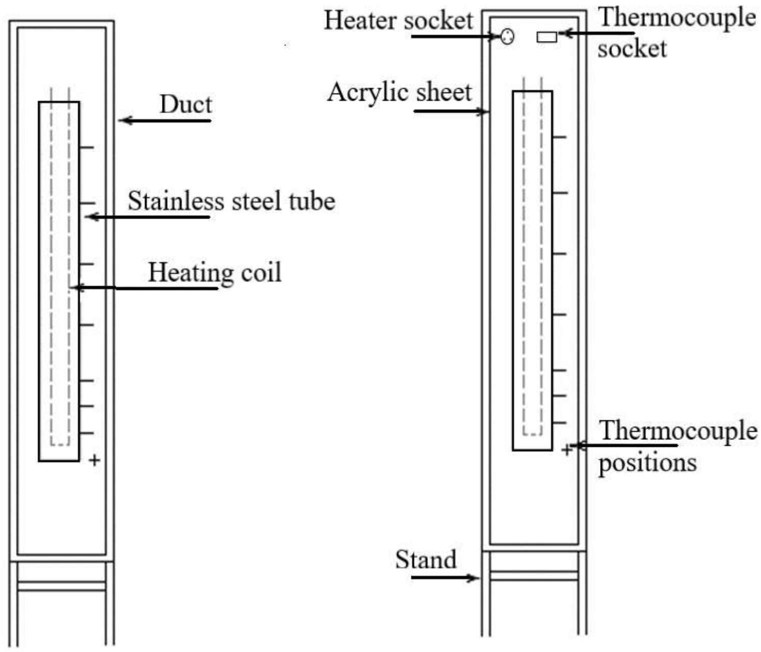


Figure 3: Schematic diagram of Natural Convection

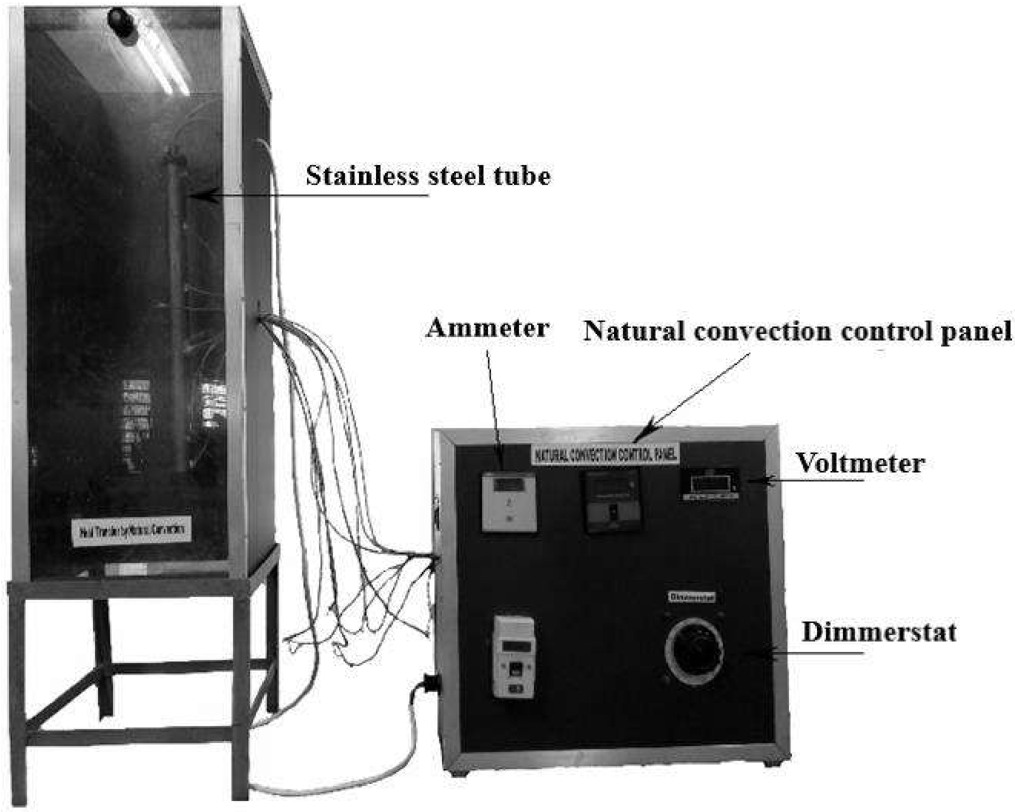


Figure 3(b): Image of Experimental Setup(Natural Convection) in Heat Transfer Lab

The duct is open at the top and the bottom forms an enclosure which serves the purpose of undisturbed surroundings. One side of the duct is made up of perspex for visualization. An electric heating element is kept in the vertical tube which internally heats the tube surface. The heat is lost from the tube to the surrounding air by natural convection. The vertical cylinder with the thermocouple positions is shown in Figure 4.

Heating element

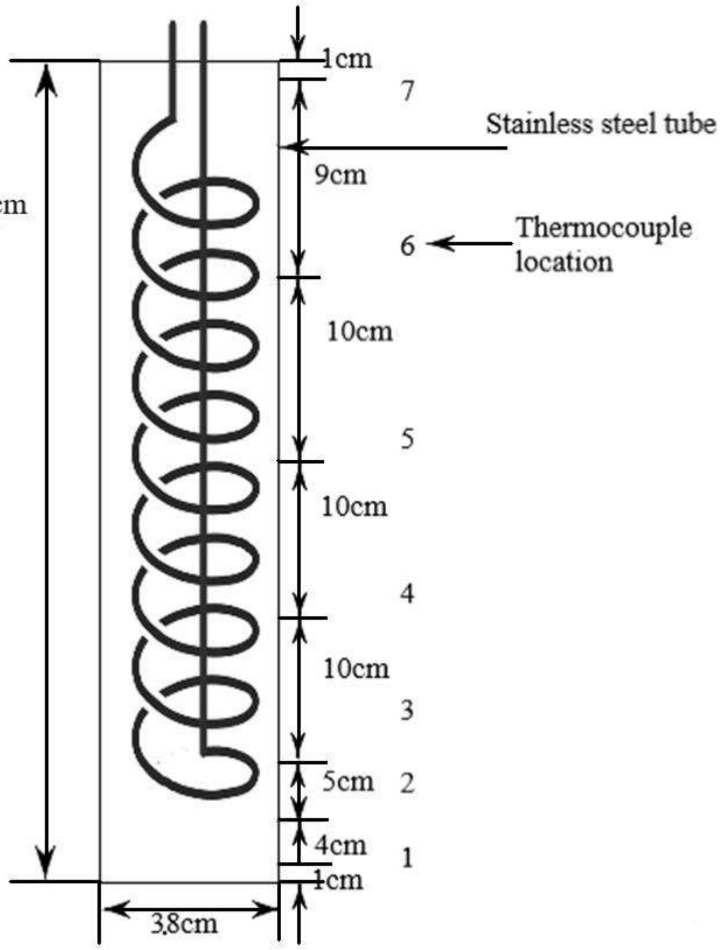
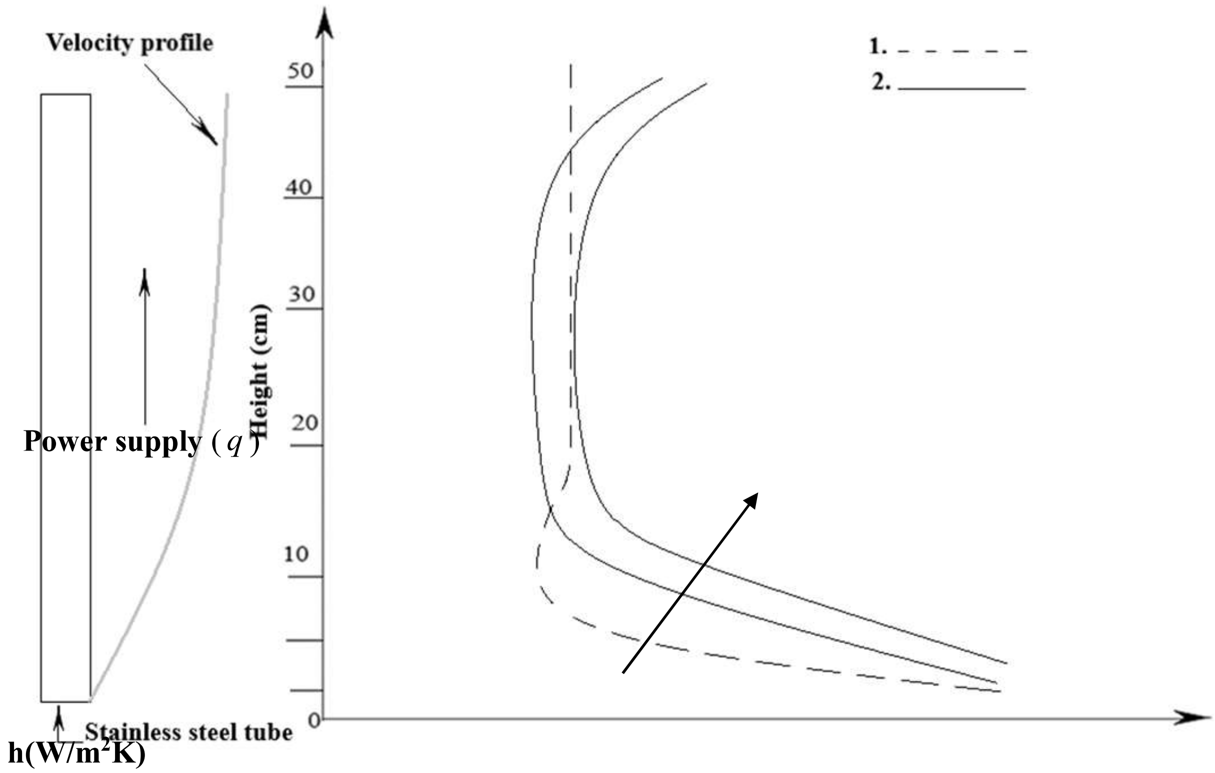


Figure 4: Thermocouple positions in the vertical cylinder

While the possible flow pattern and the expected variation of local heat transfer coefficient are shown in Figure 5. The tube has been polished to minimize the radiation losses.



1. showing the curve obtained from empirical correlations.
2. showing the curve obtained from experimental data.

Figure 5: Variation of the heat transfer coefficient (h) along the height of the tube in free air flow and dependence of this variation on the nature of flow.

Specifications

1. Diameter of the tube (d) is 38 mm.
2. Length of the tube (L) is 500 mm.
3. Duct size (20cm x 20cm x 100cm).
4. Number of the thermocouples 8.
5. Thermocouple number 8 reads the Ambient Temperature and is kept in the duct.

6.Temperature Indicator 0-300(°C). Multi-channel type calibrated from iron constantan Thermocouples with compensation of ambient from 0-50(°C).

7. Ammeter
8. Voltmeter
9. Dimmerstat

Experimental procedure

1 .Switch on the supply and adjust the Dimmerstat to obtain the required heat input (say40W, 60 W, 70 W).

2. Monitor the temperature T_1 to T_8 every five minutes till steady state is reached.

3. Wait till the steady state is reached. This is confirmed from temperature readings (T_1 to T_7). If they remain steady and do not register a change of more than 1°C per hour.

4. Measure the surface temperature at various points(T_1 to T_7)

5. Note the ambient temperature is T_8.

6. Repeat the experiment for different heat inputs (say 40W, 60W, 70W) by varying Dimmerstat position.

Precautions

1. Switch off the ceiling fan before giving supply to set-up. This is to ensure the natural Convection heat transfer environment.
2. Adjust the temperature indicator to ambient level by using compensation screw before Starting the experiment (if needed).
3. Keep dimmerstat to zero volt position and increase it slowly.
4. Operate the changeover switch of temperature indicator gently from one position to Other, i.e. from position 1 to 8 position.

Calculations

1. Calculate the value of average surface heat transfer coefficient.

   Average heat transfer coefficient,

$$h_{avg} = \frac{q}{A_s(T_s - T_a)}\left(\frac{\mathrm{W}}{\mathrm{m^2K}}\right)$$

Where, q = rate of heating= $V \cdot I$ (W)

A_s = surface area of vertical cylinder rod, $A_s = \pi \cdot d \cdot L(\mathrm{m}^2)$

T_s = Average surface temperature (°C)

$$T_s = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7}{7} \ (°C)$$

T_a = ambient temperature T_8 (°C)

2. Calculate the value of local heat transfer coefficient and plot the graph between the local heat transfer coefficient and along length of the rod.

3. Compare the experimental value of natural heat transfer coefficient with theoretical value obtained by using the correlations (4) and (5).

Experiment No. 5 (b)

Calibration of Thermocouples

Objective:

To calibrate the thermocouples

Theory:

A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming electrical junctions at differing temperatures. A thermocouple produces a temperature-dependent voltage a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature. The temperature of a substance is a function of the intensity of vibration of its atoms and molecules.

Thermoelectricity is a major method of measuring temperature of bodies. The basic theory behind this is that a small voltage is generated when two different metals are joined together. This is known as Seebeck effect or thermoelectric effect. The magnitude of the voltage is generated depends on the temperature of the junction. The junction can therefore be used as a temperature transducer, converting temperature into voltage. This type of temperature transducer is called a thermocouple.

The voltages V1 and V2 at the two junctions oppose each other and any current in the circuit is due to the voltage difference V1-V2 which will be due to temperature difference between the two junctions (shown in figure below).

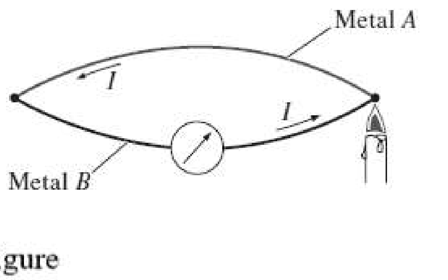


Figure
When one of the junctions of two dissimilar metals is heated, a current I flows through the closed circuit.

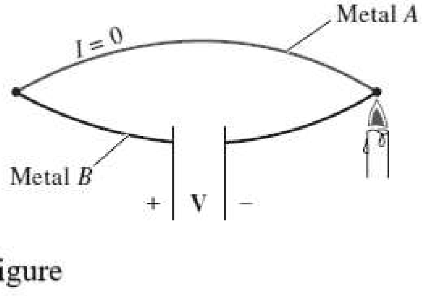
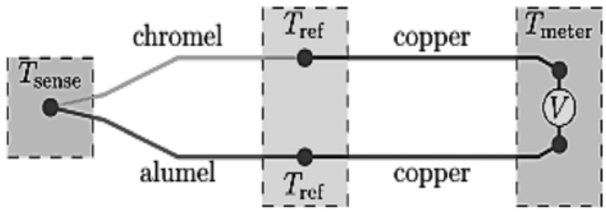


Figure
When a thermoelectric circuit is broken, a potential difference is generated.

Principle of operation:

In 1821, the German physicist Thomas Johann Seebeck discovered that when different metals are joined at the ends and there is a temperature difference between the joints, a magnetic field is observed. The magnetic field he observed was later shown to be due to thermo-electric current. The Seebeck effect is responsible for the behavior of thermocouples, which are used to approximately measure temperature differences. The magnitude of the voltage depends on the types of wire being used. Generally, the voltage is in the microvolt range.



K-type thermocouple (chromel-alumel) is shown

Types of thermocouples:

Commonly used thermocouple metal combinations

1. J-Type: (Iron-constantan),
2. K-Type: (Chromel-alumel)

Apparatus:

Field Metrology Well (9143) is designed to be stable and reliable heat source that can be used in the laboratory. The special built-in features make (FMW- 9143) extremely adaptable. The exclusive voltage compensation allows the technical experts to plug into mains power with voltage from 90V to 250V AC without degradation to the instrument. The range of ambient temperature compensation is (13º C to 33º C). The gradient temperature compensation keeps the axial gradient within the specification over the entire temperature range of the instrument and over the specified guaranteed operating temperature range.

These combined features along with the rugged design, light weight and small size make this instrument ideal for the applications of thermocouple calibrator.

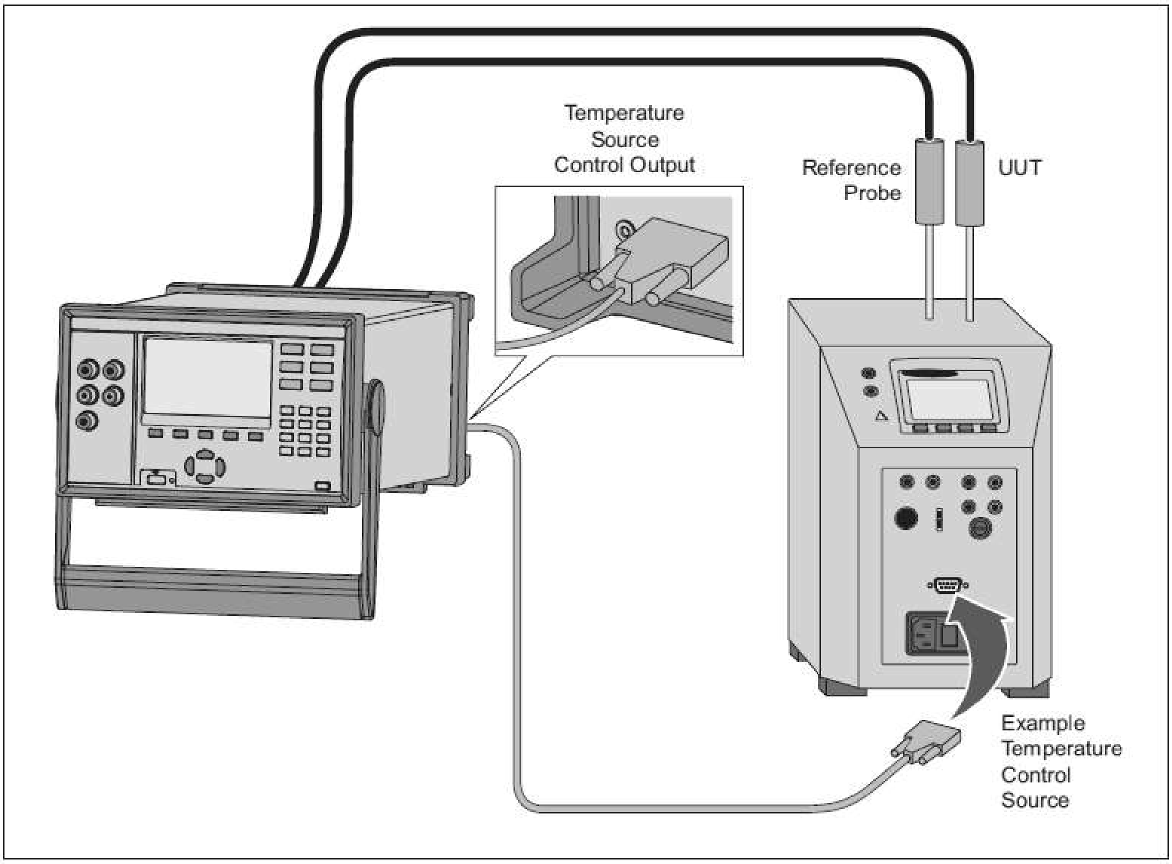
The unique safety features make this the safest heat source available. The unique air flow design keeps the probe and instrument cool and protecting the user from the heat effects.

The Block temperature indicator shows the user when the Well temperature is above 50º C and letting the user know when it is safe to remove the insert or move the instrument.

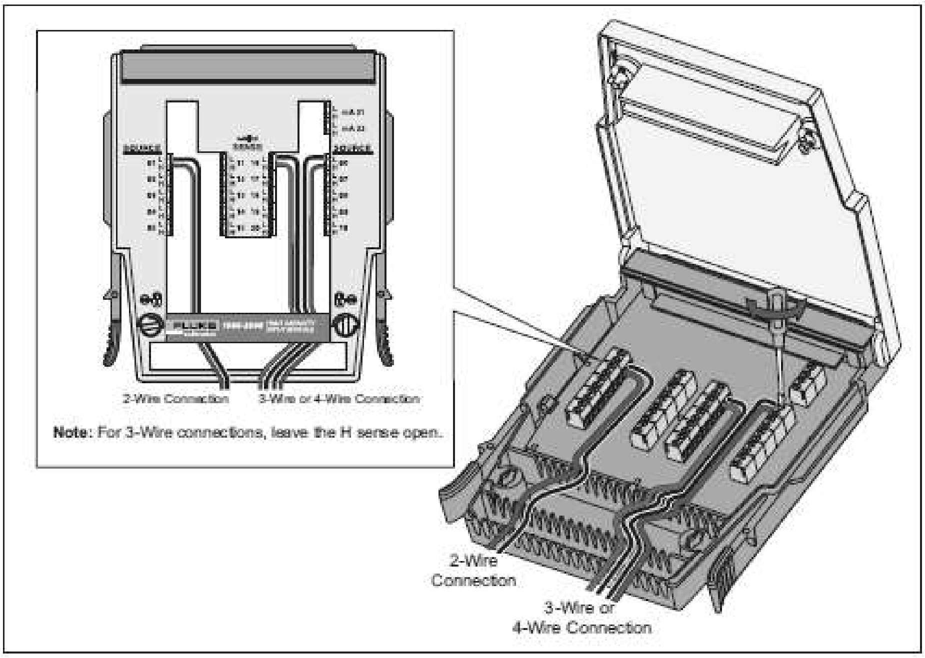
The LCD display continuously shows many useful operating parameters including the block temperature, the current set point, block stability, and the heating and cooling status.

The instrument is rugged in design and special features make them ideal for the field or laboratory with the proper use. The instrument provides continued accurate calibration of the temperature.

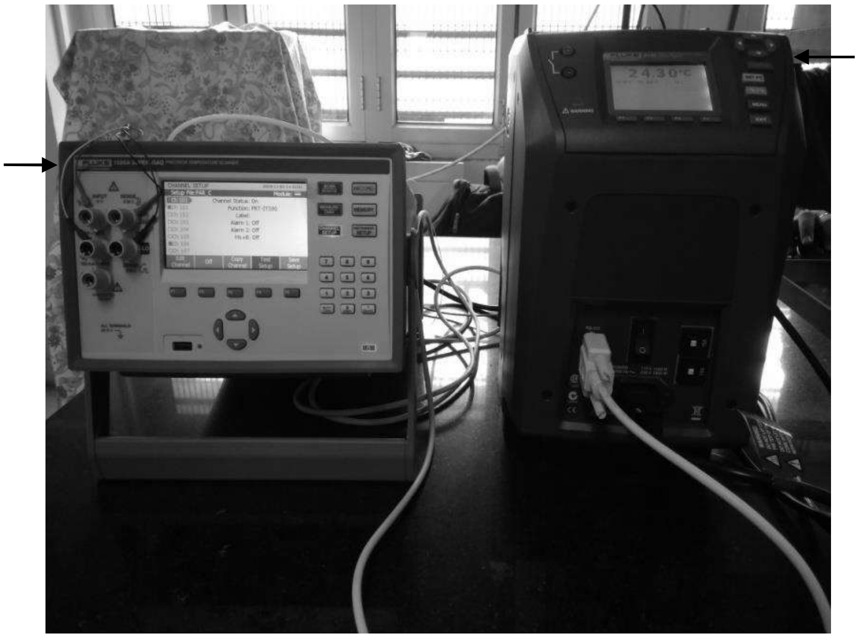
Before the use of the instrument, the user should be familiar with the warnings, caution and operating procedures of the calibrator.



Wire diagram of Thermocouple Calibration System



Thermocouples Input Module



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Thermocouple Calibration System

Procedure:

1. Switch on the Field Metrology Well (FMW) – 9143 & Temperature scanner – 1586 A
2. Measure the initial temperature from the FMW- 9143
3. Set the temperature 30º C in FMW – 9143 and press the enter key thereafter the heating of the dry well will begin and the temperature will rise up from ambient to 30º C.
4. When the dry well will reach to the temperature of 30º C. The buzzer of the FMW- 9143 will beep. It is a signal that the system is reaching to the steady state.
5. Let continue the heating process/ Let the instrument as it is till it will get the steady state. The steady state may come after 10-12 minutes of buzzer beep.
6. After getting the steady state, press the SCAN/Monitor key of the temperature scanner - 1586. Let the process on till 4-5 minutes. Thereafter, display of the temperature scanner – 1586 will show the value of the measured temperature and the corresponding value of the emf.
7. Note the readings of the measured temperatures and the emf from the temperature scanner – 1586.
8. Don't stop the system or don't press any key of the experiment during the above process.
9. Do follow the same procedure from S.N. (01) to S.N. (08) for the second measurement of the temperature and the emf.
10. Repeat the experiment and take the measurements at 40, 50, 60, 70, 80, 90 and 95º C.
11. Measure the emf value w.r.t. each reading of thermocouple
12. Draw the plot (Tmeas - Tamb) vs emf.

Technical Specifications:

1. Temperature range: Ambient to 350º C
2. Mains voltage: 220 to 240 Volts
3. Frequency: 50/60 Hz
4. Power: 1800 Watt
5. Immersion (Well) depth: 150 mm (5.9 In)
6. Insert outer diameter (OD): 25.3 mm (1.00 In)
7. Size (H*W*D): 290 mm x 185 mm x 295 mm
8. Weight: 7.3 Kg
9. Ambient temperature: 27º C
10. Ambient relative humidity (ARH): 0 to 90%

Precautions:

1. Don't turn off the instrument unless the temperature of FMW – 9143 will reach down to 40 ºC.
2. Don't touch any wire/ thermocouple wires, when the instrument is in running condition.
3. Make sure that the thermocouple beads are properly made.
4. Thermocouple beads should not be in contact to each other inside of the FMW – 9143.
5. Ensure that there is no any loose connection in the experimental set up.