Experiment 1

Measurement of Thermal Conductivity of a Metal (Brass) Bar

Introduction:

Thermal conductivity is a measure of the ability of a substance to conduct heat, determined by the rate of heat flow normally through an area in the substance divided by the area and by minus the component of the temperature gradient in the direction of flow: measured in watts per meter per Kelvin

Symbol K is used for denoting the thermal conductivity

According to the Fourier Law of thermal conductivity of place wall

$$Q \infty A \frac{dT}{dx}$$

Or $Q = -KA \frac{dT}{dx}$

Where

Q = heat flow (by conduction rate) through the material

A = The section through which heat flows by conduction

$\frac{dT}{dx}$ = the temperature gradient at the section

The proportionality constant K is a transport property known as thermal conductivity (W/mk) and is a characteristics of the wall material. It provided an indication of the rate at which energy is transferred by diffusion process. It depends on the physical structure of matter, atomic and molecular , which is related to the state of matter. The minus sign is consequence of the fact that heat is transferred in the direction of decreasing temperature.

The generalized heat conduction equation for constant thermal conductivity in Cartesian co-ordinate is:

$$\frac{d^2T}{dx^2} + \frac{d^2T}{dy^2} + \frac{d^2T}{dz^2} + \frac{q}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

T = temperature distribution at the location x,y,z (ºC)

x,y,z = co-ordinates

q = internal heat generation rate per unit volume (W/m^3)

k = thermal conductivity of the material (W/mK)

α = Thermal diffusivity (=k/ρc) of the material (m^2/s)

t = time , s

Some assumptions that are given can be followed to simplify the generalized equation:

1. Heat flow is one-dimensional i.e. temperature, varies along x-direction only. This is achieved by putting insulation on the circumferential surface of the specimen.
2. End effect is negligible
3. The specimen material is isotropic
4. There is no internal heat generation in specimen
5. Steady state is achieved before final data recorded

So, the simplified form of the generalized equation is,

$$\frac{d^2T}{dx^2} = 0$$

When the steady state is attained the following boundary conditions are considered:

(i) At x = 0; $T = T_0$
(ii) At x = L; $T = T_L$

Using these boundary conditions we get the solution of the differential equation as :

$$\frac{T - T_0}{T_L - T_0} = \frac{x}{L}$$

Where,

T = temperature of the section at distance x (ºC)

T_0 = temperature at section where x = 0 (ºC)

T_L = temperature at section where x = L (ºC)

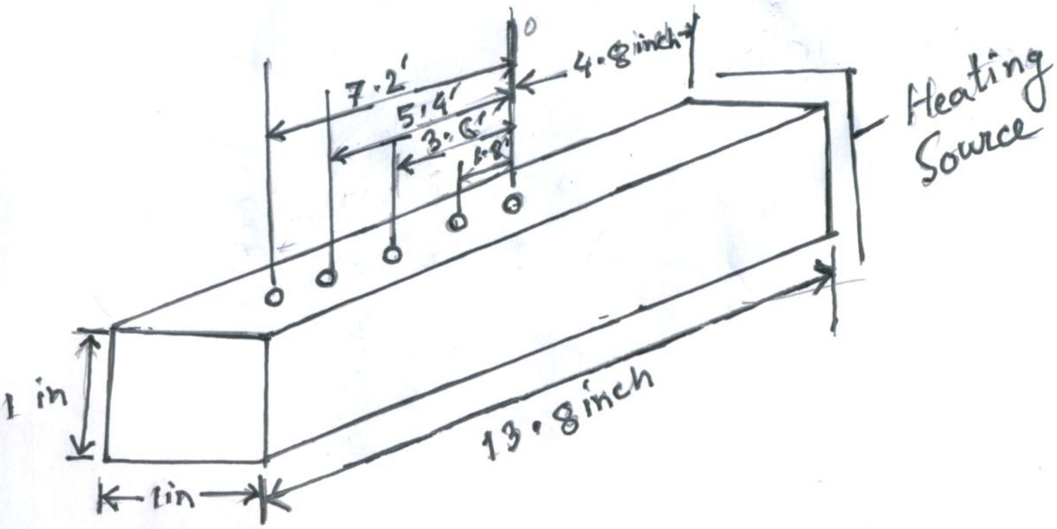
X = Distance of the section of measurement from the section at x = 0, (m)

L = Distance between sections at x = 0 and x = L , (m)

In this experiment a Brass rod is heated by nicrome wire surrounding the brass bar at one side. The brass bar was properly insulated is such a way that heat flow remain one dimensional to the other end of the rod for heat conduction study with a view to fulfilling the following objectives:

(i) To plot temperature vs. distance curve from experimental measurements.
(ii) To plot temperature vs. distance curve from theoretical analysis.
(iii) To determine thermal conductivity of the metal specimen.

Experimental Set up:



Operation procedure

1. Check the room temperature by an analog thermometer and then calibrate the digital thermocouples.
2. Start the experiment by switching on the Veriac and make suitable heating at the end of the brass bar by nicrome wire.
3. Carefully measure the distance from one thermocouple to another thermocouple or the positions of the thermocouples.
4. After every 10 minutes take the reading of every thermocouples along with the reading of water inlet and outlet.
5. Continue this until the steady state has come.
6. It will take too long time to come steady state. So, take the reading of every thermocouple after ten minutes and draw the curves.

7. If two or more than two consecutive curves show that slopes are similar or equal (carefully follow the shape of the curve); then we can consider the heat flux through the brass bar is constant at that time.
8. Take the reading of the water inlet and outlet.
9. Draw the curves of Temperature vs. distance for both experimental case and theoretical case
10. Find the thermal conductivity of the metal Bar.
11. Find the mass flow rate of the water.

Data Table:

Time → (minutes) Positions ↓	10	20	30	40	50	60	70	80	90	100	110	120
0 inch												
1.8 inch												
3.6 inch												
5.4 inch												
7.2 inch												

Time → (minutes) Positions ↓	130	140	150	160	170	180	190	200	210	220	230	240
0 inch												
1.8 inch												
3.6 inch												
5.4 inch												
7.2 inch												

Collected Data and Calculation:

1. Heat Flow Rate, Q

Heat flow rate through the specimen, Q is equal to the amount of heat carried away by the flowing water. Heat carried away by the flowing water is calculated from:

$$Q = m_w C_w \Delta T_w$$

m_w = mass flow rate of water in Kg/s
C_w = specific heat of water, 4120 J/Kg-K and
ΔT_w = Rise in temperature of flowing water, K

2. Plots:

- Plot experimentally measured temperature (T_e) against distance and evaluate dT/dx
- Plot the theoretically calculated temperature (T_t) against distance.

3. Thermal conductivity, K

Evaluate thermal conductivity K from:

$$Q = -KA\,\frac{dT}{dx} = m_w C_w \Delta T_w$$

4. Theoretical temperature , T_t

Evaluate theoretical temperature (T_t) from $\frac{T-T_0}{T_L-T_0} = \frac{x}{L}$ and plot (T_t) against distance x.

Discussions:

- Briefly explain the Experimental temperature distribution plot (Temperature vs. Distance) plot.
- Is there any deviation in the values of thermal conductivity obtained in two observations during the experiment? If yes, why?
- What is the actual value of thermal conductivity of Brass at the temperature that was maintained during the experiment? Is there any discrepancy between the actual and the experimental value? If yes, why?
- Explain the variation in the Experimental temperature distribution and theoretical temperature distribution plot, if there is any

Conclusion

- Comment on the thermal conductivity of Brass obtained in the experiment

Experiment 2

Study of Heat Transfer by Natural Convection from a Horizontal Cylinder

Introduction

An extended surface is commonly used in reference to a solid that experiences energy transfer by conduction within its boundaries, as well as energy transfer by convection to its surroundings. The extended surface is most often utilized in quick removal of heat. The rate of heat removal by convection from surfaces is increased by increasing the surface area for heat transfer by using extended surfaces called fins. A fin with a cylindrical shape and high aspect ratio (length/diameter) is called a pin fin.

Fins are often used seen in engine cooling, electrical appliance such as in a computer power supply or substation transformers, etc.

The generalized equation for one dimensional heat transfer through extended surfaces may be written as:

$$\frac{d^2T}{dx^2} = m^2(T - T_\infty)$$

Where, $m^2 = \frac{hp}{kA}$

T = T(x) , Temperature at a section in the fin which is at a distance x from the base wall

T_∞ = Temperature of the fluid surrounding the fin

h = heat transfer coefficient between the surface of the fin and the surrounding fluid (W/m^2 k)

k = Thermal conductivity of the fluid

A = Cross sectional area of the metal bar or fin

With the following assumptions:

- The fin material having no external heat generation
- One dimensional conduction exist only along the fin
- The system is steady state
- Radiation loss is neglected
- The base temperature is fixed
- Natural convection conditions are maintained

The solution of the aforementioned differential equation depends on the choice of boundary conditions. Three different boundary conditions are set below will be considered.

Case-1: The fin is very long and the temperature at the end of fin is essentially that of the surrounding fluid

Case-2: The fin is finite length but its tip is insulated.

Case-3: The fin is of finite length and heat loses by convection from its end

For case 1: the solution becomes

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-mx}$$

For case 2: The solution becomes

$$\frac{T - T_\infty}{T_0 - T_\infty} = \frac{Cosh\ [m(L - x)]}{\cosh mL}$$

For case 3: The solution becomes

$$\frac{T - T_\infty}{T_0 - T_\infty} = \frac{Cosh\ [m(L - x)] + (h/mk) \sinh[m(L - x)]}{\cosh mL + (h/mk) \sinh mL}$$

Where

T$_o$ = temperature of the base wall of the fin

L = length of the fin

x = distance of the fin section from the base wall where the temperature is being measured

The amount of heat transfer involved in these 3 cases may be given by the following expressions:

Case 1: $Q_1 = \sqrt{hpkA}\ (T_o - T_\infty)$

Case 2: $Q_2 = \sqrt{hpkA}(T_o - T_\infty) \tanh mL$

Case 3: $Q_1 = \sqrt{hpkA}(T_o - T_\infty) \frac{\sinh\ mL + \left(\frac{h}{mk}\right) \cosh\ mL}{\cosh\ mL + \left(\frac{h}{mk}\right) \sinh\ mL}$

To indicate the heat transfer performance of a fin, two parameters are defined as below :

1. **Fin efficiency** : defined as the ratio of actual heat transferred to heat which would be transferred if the entire fin area were at base wall temperature

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

2. **Fin effectiveness:** defined as the ratio of heat transfer from the wall after adding fin to the heat transfer from the wall before adding fin

$$\eta_f = \frac{\tanh mL}{\sqrt{hA/kP}}$$

The specific objectives of this experiment are as follow:

- To plot the temperature distribution along the fins.
- To plot $\frac{T-T_\infty}{T_0-T_\infty}$ against $\frac{x}{L}$ to show the temperature distribution along the fins in non-dimensional form for both experimental and theoretical considerations using tree different boundary conditions stated before.
- To estimate heat transfer under all conditions.
- To estimate fin efficiency and fin effectiveness.

Experiment Set-up:

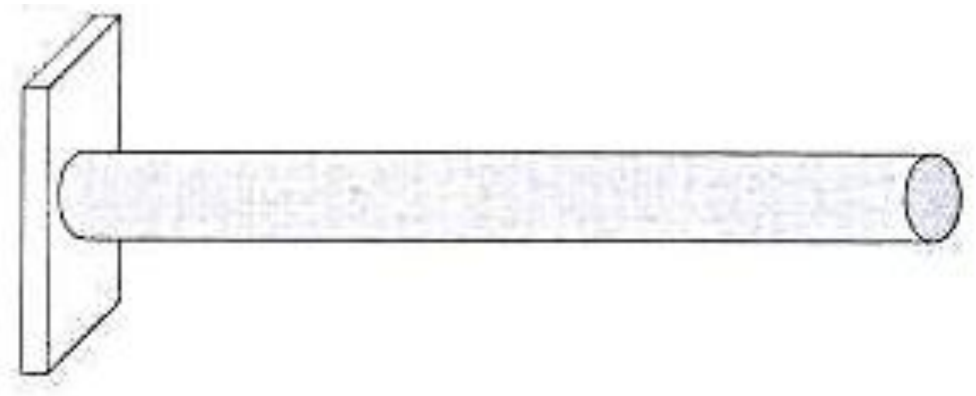


Fig: Pin fin

Thermal conductivity of the stainless steel is 16.26 W/m-K

Procedure:

1. Record room temperature and that is the surrounding fluid temperature
2. Maintain natural convection condition as far as possible during the experiment and collection of data
3. Switch on the heater and adjust the watt setting for heating purpose
4. Take the initial readings at the different positions of pin fin
5. Take the reading of the same position after 10 minutes.
6. If possible then repeat this same experiment for the second watt setting.
7. Plot the temperature distribution along the fins
8. Plot $\frac{T-T_\infty}{T_0-T_\infty}$ against $\frac{x}{L}$ to show the temperature distribution along the fins in non-dimensional form for both experimental and theoretical considerations.
9. Find the effectiveness and efficiency if this metal bar is considered as fin
10. Find the experimental errors and find how to minimize that.
11. Discuss the nature of true experimental and theoretical results you get from the graph and through calculations

Data collection table:

Watt setting	Time (minutes)	Position of thermocouples (mm)	Reading of temperature ℃	$\frac{T-T_\infty}{T_0-T_\infty}$ from experiment	$\frac{T-T_\infty}{T_0-T_\infty}$ from Theory		
					Case-1	Case-2	Case-3
	0	0					
		7.5					
		19.5					
		31.5					
		43.5					
		55.5					
		67.5					
	10	0					
		7.5					
		19.5					
		31.5					
		43.5					
		55.5					
		67.5					
	20	0					
		7.5					
		19.5					
		31.5					
		43.5					
		55.5					
		67.5					
	30	0					
		7.5					
		19.5					
		31.5					
		43.5					
		55.5					
		67.5					
	40	0					
		7.5					
		19.5					
		31.5					
		43.5					
		55.5					
		67.5					
	50	0					
		7.5					

		19.5					
		31.5					
		43.5					
		55.5					
		67.5					

Calculations:

Diameter of rod, D = 13 mm

Length of fin, L = 72 mm

Thermal conductivity of the material, K =

Heat transfer coefficient between in surface and surrounding fluid h = 10 W/m^2K

- Find $\frac{T-T_\infty}{T_0-T_\infty}$ from experiment and from the theoretical conditions
- Find Fin efficiency and effectiveness for different cases

Experiment-3
Free Convection and Forced Convection

Introduction

In most applications, a 'heat sink' cools a critical component such as an engine cylinder head or electronic component. Therefore, a suitable and simple comparison of the surfaces is to apply a fixed input power and airflow (natural), while measuring surface temperature. The surface that reaches the highest surface temperature will be the least effective at transferring heat to air. Therefore, the surface that reaches the lowest temperature will be the most effective at transferring heat to air. We have here three find apparatus like pin fin, surface fin and open surface.

Free Convection

This is when the heat transfers from the object under the influence of fluid (air) density changes. The heat energy around the object causes the air density around the surface of the object to decrease. The reduced density air is more buoyant than the surrounding air and rises, transporting the heat energy away naturally. In normal conditions, gravity is the main force affecting buoyancy and therefore convection. However, where the object forms part of a rotating machine, centrifugal force can be a driving force for convection.

Forced Convection

This is when an external force moves air around or across the surface. The movement of air transports the heated air away from the object. The higher the air velocity, the faster it transports heat away from the object.

Thermal Conductivity of Air (k_{air})

Some materials (including fluids) are better heat conductors than others; their chemical and atomic structure affects the rate of heat transfer. This effect is its thermal conductivity (k). It is a measure of how quickly heat energy travels along a unit length of material of a unit cross-sectional area. The thermal conductivity of air increases almost linearly with temperature over the range O to 100°C.

Thermal inertia or thermal mass:

$$Q = mc\Delta T$$

From this equation it is clear that when you have two objects of same material, the one with the largest mass needs more heat energy to rise its temperature. Inversely, when two object of same material but of different mass have the same temperature, the object with the largest mass could contain or store more heat energy than a smaller mass.

In terms of heat flow therefor, a larger mass takes more time to reach a given temperature than smaller mass when supplied at the same rate. Again, inversely a larger mass takes more time to lose energy than a smaller mass when the loss is at the same rate. It has a larger thermal inertia.

In Mechanical engineering, a flywheel helps to store energy (mechanical inertia) and help damp outtransient changes in demand. In electronic engineering, a capacitor helps to store charge and help damp out transient changes in current in voltage. In thermodynamics, a large thermal mass helps to store heat energy to help damp out transient changes temperatures or heat supply.

Objective:

- To compare the maximum temperature each surface reaches for a given input power when in freeconvection.
- To compare the maximum temperature each surface reaches for a given input power when in forced convection.

Procedure:

1. Remove the fan from the top of the duct in case of free convection test.
2. Fit your chosen heat transfer surface.
3. Create a blank results table
4. Increase the power to 15 Watts.
5. Wait for the temperatures to stabilize while readjusting the power if necessary and record the maximum temperature each surface reaches. Under free convection, it may take up to 30 minutes for temperatures to stabilize.
6. Record the inlet (ambient temperature).
7. Switch off the heater and allow the surface to cool down to near ambient temperature.
8. Repeat the experiment for the other heat transfer surfaces.
9. In case of forced convection,first make sure fan speed is at zero.
10. Switch on the heater and set it to 15-Watts power.
11. Wait for the temperatures to stabilize and then take readings of the surface and inlet temperatures.
12. Increase the fan speed to give an air velocity of approximately 2 m/s
13. Wait for temperatures to stabilize and take readings of surface and inlet temperatures.
14. Switch off the heater and allow the surface to cool down to near ambient temperature (use the fan to help cool down the surface if necessary).
15. Repeat the experiment for the other heat transfer surfaces.

Schematic:

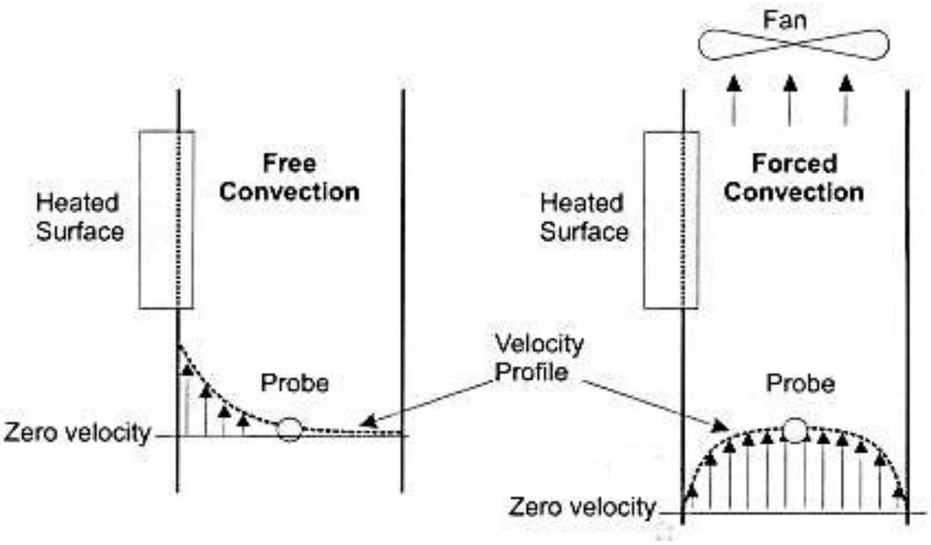


Fig: Free and Forced convection velocity profile

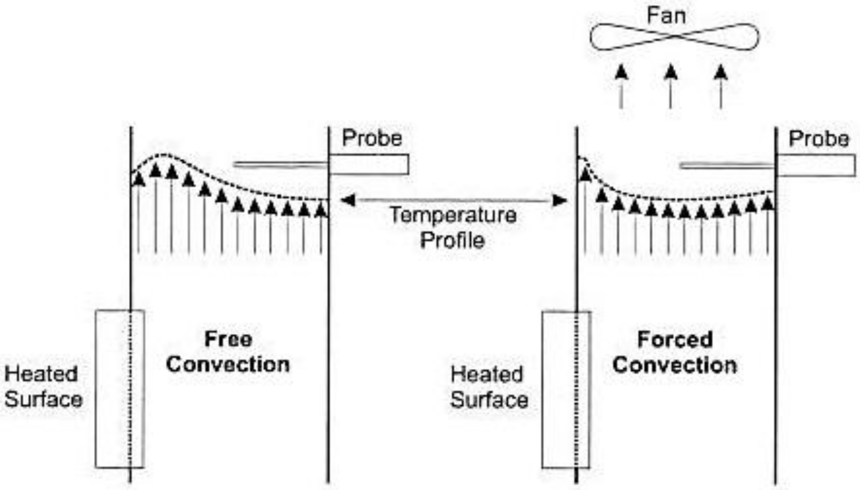


Fig: Free and Forced convection temperature profile

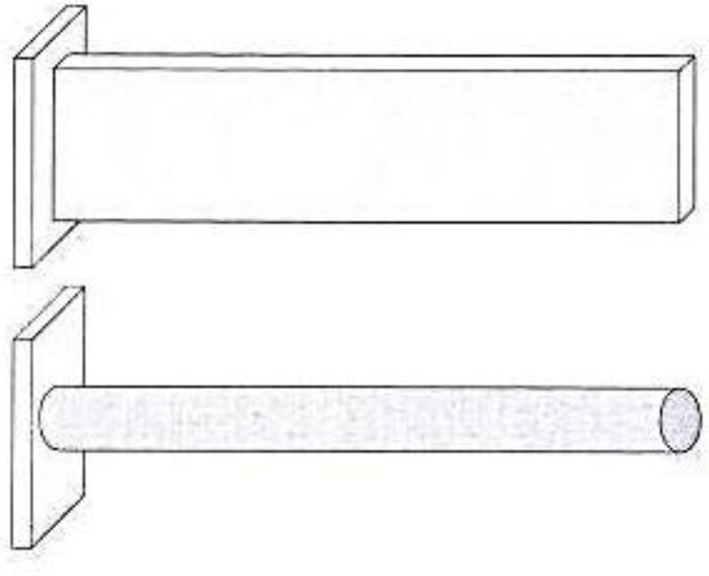


Fig: Fin and Pin

Data Table:

Free convection :

Power = 15W			
Heat Transfer Surface	**T_2**	**T_1**	**Difference (T_S-T_{in})** (°C)
	Surface Temperature T_s(°C)	**Duct Inlet (ambient) temperature T_{in}** (°C)	
Finned			
Pinned			

Forced convection :

Power = 15W **Fan velocity =**			
Heat Transfer Surface	**T_2**	**T_1**	**Difference (T_S-T_{in})** (℃)
	Surface Temperature T_s(℃)	**Duct Inlet (ambient) temperature T_{in}** (℃)	
Finned			
Pinned			

Schematic:

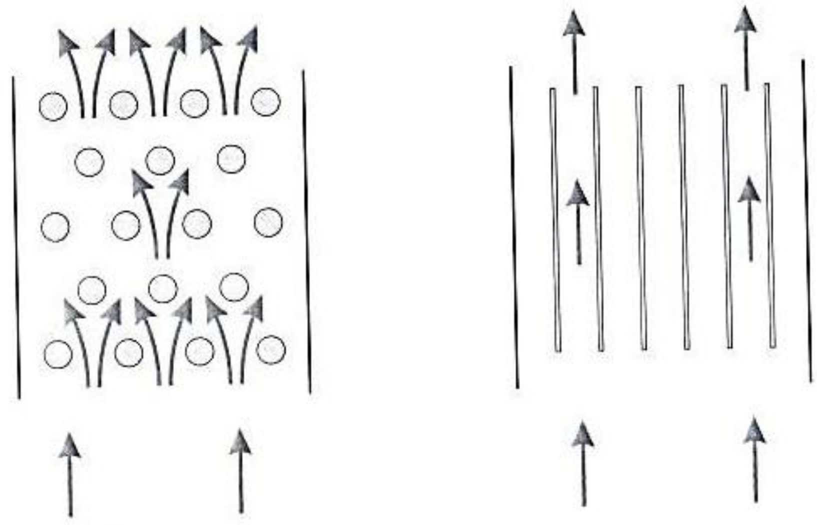


Fig : Compressed air flow over finned and pinned surface

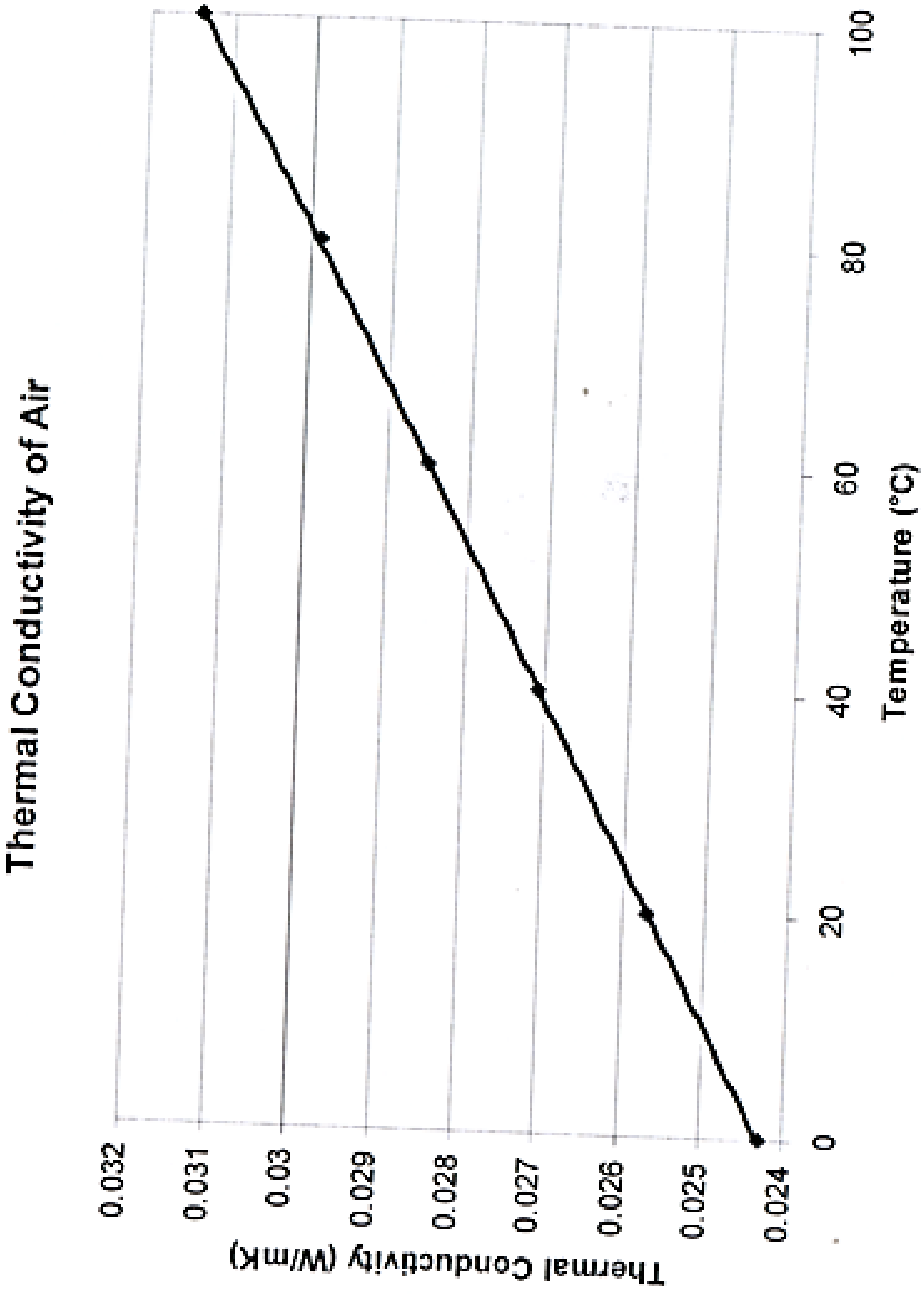
Data Sheet:

Heat Transfer Surface: **Power = 15W** **Fan velocity =**			
Air velocity (m/s)	**T_2**	**T_1**	**Difference (T_S-T_{in})** (℃)
	Surface Temperature T_s(℃)	**Duct Inlet (ambient) temperature T_{in}** (℃)	

Result Analysis

- What does the chart say about temperature and velocity?
- Which surface has the coolest temperature for any given air velocity?
- Free convection and forced convection
- Which surface created greater temperature difference in free and forced convection?
- Why thermal conductivity of air rises with increasing temperature
- Discuss about the results you got for free convection and forced convection

Thermal Conductivity of Air:



Experiment 4

Heat Transfer Coefficient and Nusselt Number

Introduction

Earlier experiments compare performance of the surfaces in free and forced convection by measuring surface temperature. However, a more scientific test needs calculations of coefficients that show the effectiveness of heat transfer. In this case, the convective heat transfer coefficient and Nusselt number are important. The earlier experiments showed that forced convection gives better results than free convection. This experiment quantifies this more scientifically for the flat plate.

Under natural (free) convection, flat/vertical fins have similar performance and allow better heat transfer to the surrounding air than vertical/horizontal fins (this is not true for forced convection). When used as a heat sink for electrical applications, a vertical/horizontal finned surface has as much as 70% less efficiency than a flat/vertical or vertical/vertical surface in free convection. Note however, that even a vertical/horizontal finned surface transfers heat better than a simple flat surface, due to the extended surface area of its fins.

Heat transfer coefficient: Heat transfer coefficient is a material’s ability to conduct heat to another material. Convective heat transfer occurs between the surface of a material and a moving fluid. Typical values of heat transfer to air are:5 to 25 W/m^{2}K in free convection and 10 to 200 W/m^{2}K in forced convection

$$h_c = \frac{Q}{A_s * T_m}$$

Where T$_m$= logarithmic mean temperature and Q is the heat flow from the surface to air.

$$T_m = \frac{T_{out} - T_{in}}{\ln \frac{T_s - T_{in}}{T_s - T_{out}}}$$

Nusselt Number (Nu):

A Nusselt number applies to heat transfer. It is a dimensionless value of the ratio of convective to conductive heat transfer across a boundary. It can also give an indication of convective flow - a low number (near to 1) shows that flow is laminar; while a high number (greater than 100) shows that flow is turbulent.

$$Nu = \frac{h_c \times L}{K_{air}}$$

Where L is the length of the surface over which the air moves (for the flat plate, this is simply the length of the plate).

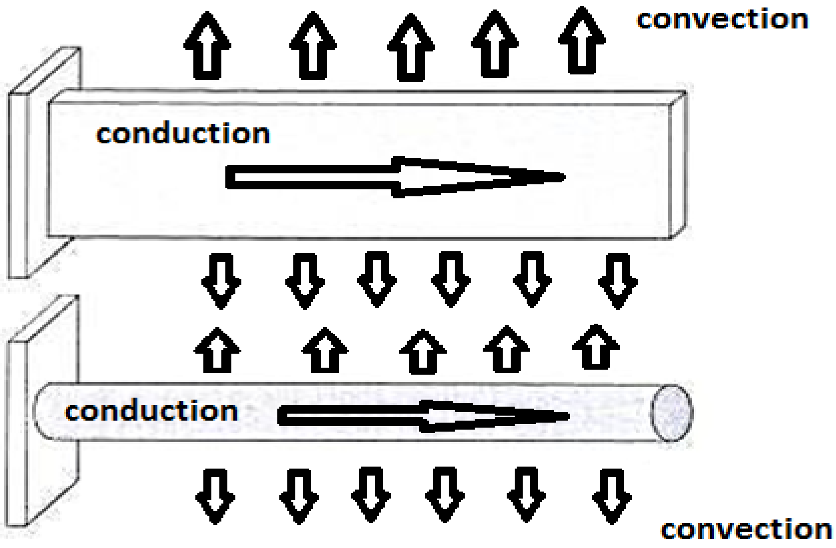
Objectives

- To show how to find a value for heat coefficient and Nusselt number for a heat transfer surface in a duct for both free and forced convection.

Procedure

1. Make sure the duct is vertical, as this will affect your results.
2. Remove the fan from the top of the duct for free convection
3. Fit the flat heat transfer surface
4. Create a blank results table
5. Set the heater to 20 Watts.
6. Move the duct traverse probe so it reads 0 (zero) so that its tip touches the opposite wall of the duct at this position. Now move it to the 1 mm position.
7. Wait for the temperatures to stabilize and then take readings of the surface, inlet and outlet (duct probe) temperatures.
8. Either choosing to move in equal steps (if you have time) or larger stepstake readings of the temperatures across the duct using the traverse. Stop when you reach 74 mm (the tip is almost fully retracted into the near sidewall of the duct at this point). Recheck the inlet and surface temperatures as you do this.
9. For forced convection, repeat the experiment with the fan fitted and airflow of 3 m/s

Schematic:



Data Table:

For Free Convection

Duct Traverse Probe Position (mm)	T_1	T_2	T_3	T_S-T_{in} (℃)	T_P-T_{in}(℃)
	Ambient Temperature (Probe) T_{in}(℃)	Heat Transfer Surface Temperature T_S(℃)	Duct Traverse Probe Temperature T_P (℃)		

For Forced Convection

Duct Traverse Probe Position (mm)	T_1	T_2	T_3	T_S-T_{in} (℃)	T_P-T_{in} (℃)
	Ambient Temperature (Probe) T_{in} (℃)	Heat Transfer Surface Temperature T_S(℃)	Duct Traverse Probe Temperature T_P (℃)		

Results Analysis

For each set of results (free and forced):

1. Produce a chart of T_p-T_{in}, to see the outlet temperature profile with respect to inlet (this allows for changes in ambient temperature).
2. Find T_{out} using simple averaging.
3. Find average values for the other temperature readings.
4. Use T_{out} and the average readings to find the logarithmic mean temperature difference T_m,using given equation.
5. Use this to find the heat transfer coefficient (h_c) (assuming heat flow to the air is equal to the power applied).
6. Find the thermal conductivity (k_{air}) for air at the average inlet temperature.
7. Use your values of h_c and k_{air} to find the Nusselt number.
8. Compare your values with those given in the theory.

Experiment 5

The Effect of Varying Flow Rate in parallel and Counter flow

Introduction

The heat exchanger is a simple shell and tube type heat exchanger. It has two tubes one inside the other. The outer tube is shell. The inner tube carries the water from the hot circuit of the service module; the outer tube carries the water from the cold circuit. Heat transfer between the two tubes. Parallel and Counter flow arepossible in this heat exchanger module but not the cross flow

This heat exchanger is in two equal parts with extra thermocouples at the midpoint.

Parallel flow:

When the direction of flow for the both hot water and cold water is same then it is called parallel flow

Counter flow:

When the detection of flow for the hot water is just opposite of cold fluid then it is called counter flow

Some common terminology:
The mean temperature efficiency and heat transfer coefficient give more useful results for comparison between heat exchangers.

The ***temperature efficiency*** of the ***hot*** circuit of the Heat Exchanger is the ratio of the temperature change in the hot circuit, divided by the difference between the maximum and minimum temperatures of the hot and cold circuits:

$$\eta_H = \frac{T_{H1} - T_{H2}}{T_{H1} - T_{C1}} \times 100\ \%$$

The ***temperature efficiency*** of the ***cold*** circuit of the Heat Exchanger is the ratio of the temperature change in the cold circuit, divided by the difference between the maximum and

$$\eta_C = \frac{T_{C2} - T_{C1}}{T_{H1} - T_{C1}} \times 100\ \%$$

The ***mean temperature efficiency*** of the two circuits is the average efficiency of them both:

$$\eta = \frac{\eta_H + \eta_C}{2}$$

Logarithmic Mean Temperature Difference (LMTD)

This is a measure of the heat driving force that creates the heat transfer. It is a logarithmic average of the temperature difference between the hot and cold circuits at each end of the heat exchanger.

$$LMTD = \frac{(T_{H2} - T_{C2}) - (T_{H1} - T_{C1})}{\ln\left(\frac{T_{H2} - T_{C2}}{T_{H1} - T_{C1}}\right)}$$

Heat Transfer Coefficient (U)

This is the overall heat transfer coefficient for the wall and boundary layers. It is a measure of how well the heat exchanger works. A good heat exchanger will give a high coefficient;therefore, this value is important to engineers.

$$U = \frac{Q_e}{A \times LMTD}$$

Mean heat transfer area A = 0.02 m^2

Heat Transfer and Energy balance (Q, $Q_e$and Q_a)

The subscript 'e' represents here emission and 'a' represents here absorption. Here the heat is emitted from the hot water and the cold water is absorbing heat energy.

Commonly we know that $Q = m \times C_p \times \Delta T$

And mass flow rate, m = $\rho \times V$

ρ = density and V = volumetric flow rate

Heat emitted by the hot water is$Q_e = \rho_H \times V_H \times C_{pH} \times \Delta T_H$And heat absorbed by the cold water is$Q_a = \rho_C \times V_C \times C_{pC} \times \Delta T_C$

Density and specific heat must be measure at the average temperature of inlet and outlet.

In ideal heat exchanger, the heat emitter by the hot water must be equal to the heat absorbed by the cold water but practically it is not. There are some losses in the surroundings.

$Q_e = Q_a \pm$ Losses or gain from surroundings

Heat balance Coefficient, $C_{EB} = \frac{Q_a}{Q_e}$

If there are gain from Surrounding then $Q_a > Q_e$.In these the energy balance coefficient may be greater than 1.

Objective

- To show how different cold flow rates affect the performance of the heat exchanger in both parallel flow and counter flow connection (hot flow rate and heater temperature are fixed).
- Temperature vsposition graphs for both the counter flow and cross flow
- Calculation of power emitted , power absorbed , mean temperature efficiencies and energy balance for parallel and counter flow
- Find LMTD and over all heat transfer coefficient (U) for each flow rate.

Procedure:

1. Connect and set up your heat exchanger
2. Press the solenoid valve at the hot water system for filling water inside the tank. Stop pressing when the full green lamp is on.
3. Switch off the inlet regulator for hot circuit.
4. Start heater and set the heater tank temperature at 60 °C
5. After achieving that temperature stop the heater and open the inlet regulator (hand operated flow control valve). Start the pump immediately. Set the flow of the hot water circuit 3 L/min and the cold-water circuit 3 L/min.
6. Allow at least five minutes for the heat exchanger temperatures to stabilize. Generally the temperature at the inlet of the hot water circuit is low and then start increasing and after sometime the temperature will begin to fall. It is because the thermocouple at the inlet need some time and also continuous flow for stabilization. So the temperatureT_{H1}at the beginning of experiment start rising but as the cold water is also taking some heat so after giving a peak temperature it will begin to fall again.
7. Record the hot water inlet temperature T_{H1} ,Hot water outlet temperature $T_{H2}$and a middle hot circuit temperature T_{H3}. Also record the readings of cold water inlet temperature T_{C1} and cold water outlet temperature T_{C2} and the cold water circuit middle temperature T_{C3}. Take all the temperature at the peak of T_{H1}
8. Follow the procedure for differentflow rate in case of cold-water flow.
9. Apply the same procedure for counter flow.

Experimental set up :

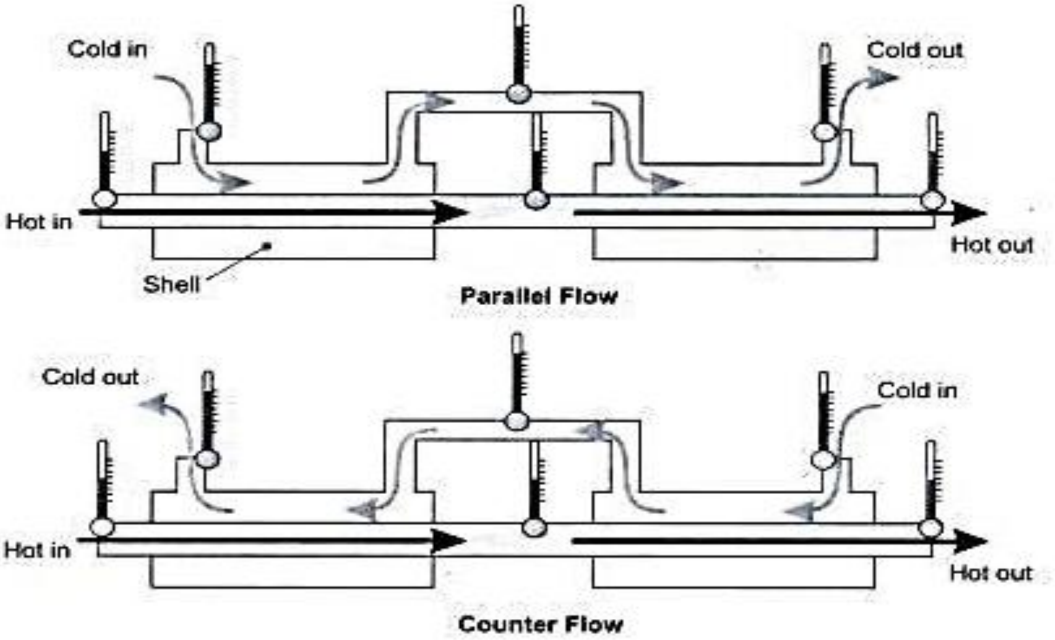


Fig: Counter flow and parallel flow for concentric shell and tube heat exchanger

Data Sheet:

Data Table 1:

<table>
<tr><td colspan="13">Parallel flow connection
Ambient tank temperature :
Heater thank temperature :</td></tr>
<tr><th>Test</th><th>Hot Flow L/min</th><th>Cold flow L/min</th><th>T_{H1}</th><th>T_{H2}</th><th>ΔT_H</th><th>Average T_H</th><th>T_{H3}</th><th>T_{C1}</th><th>T_{C2}</th><th>ΔT_C</th><th>Average T_C</th><th>T_{C3}</th></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Data Table 2:

<table>
<tr><td colspan="13">Counter flow connection
Ambient tank temperature :
Heater thank temperature :</td></tr>
<tr><th>Test</th><th>Hot Flow L/min</th><th>Cold flow L/min</th><th>T_{H1}</th><th>T_{H2}</th><th>ΔT_H</th><th>Average T_H</th><th>T_{H3}</th><th>T_{C1}</th><th>T_{C2}</th><th>ΔT_C</th><th>Average T_C</th><th>T_{C3}</th></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Calculation Table:

Table 1:

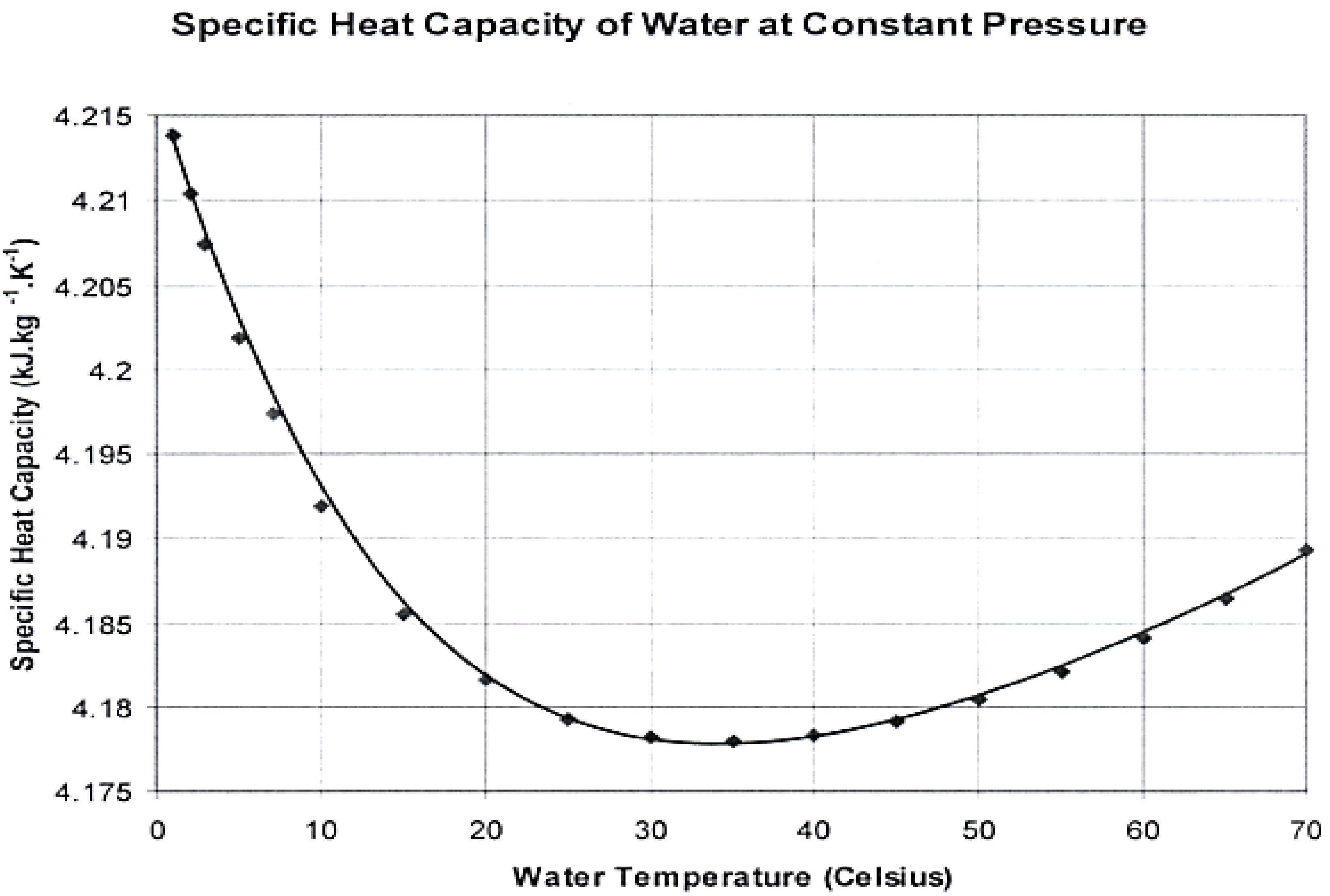
Parallel Flow												
Test	η_H	η_C	η	ρ_H	ρ_C	**C_{PH}**	**C_{PC}**	**Q_e**	**Q_a**	**C_{EB}**	**LMTD**	**U**
1												
2												
3												
4												

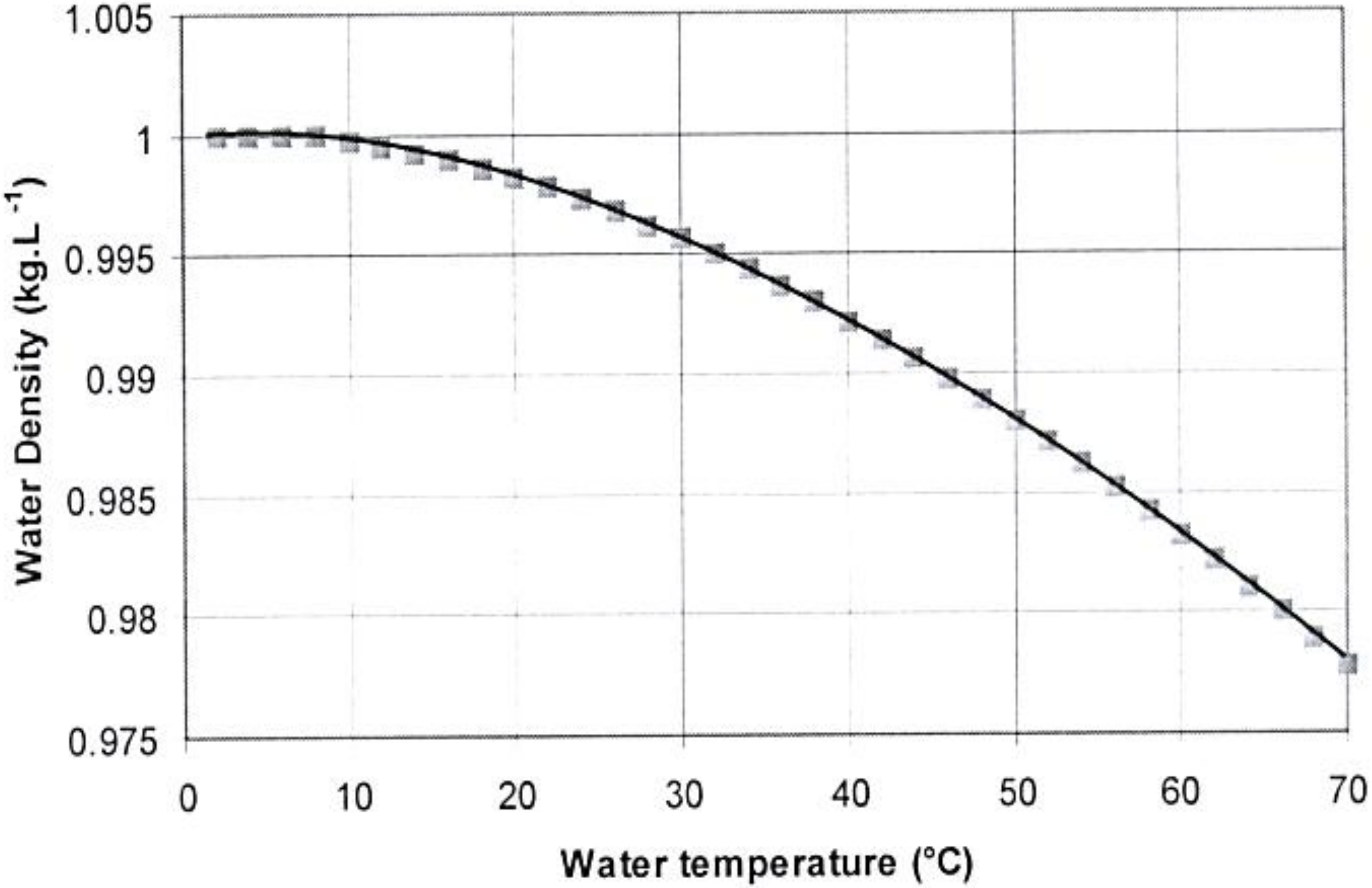
Table 2:

Counter Flow												
Test	η_H	η_C	η	ρ_H	ρ_C	**C_{PH}**	**C_{PC}**	**Q_e**	**Q_a**	**C_{EB}**	**LMTD**	**U**
1												
2												
3												
4												

Result Analysis:

- Discuss the deviation in results of counter and parallel flow
- Write about the losses in surroundings


Specific Heat Capacity of Water at Constant Pressure
Specific Heat Capacity (kJ.kg -1.K-1)
4.215
4.21
4.205
4.2
4.195
4.19
4.185
4.18
4.175
0
10
20
30
40
50
60
70
Water Temperature (Celsius)



Water Density

Experiment 6

The Effect of Varying Temperature in parallel and Counter flow

Objective

- To show how different cold flow rates affect the performance of the heat exchanger in both parallel flow and counter flow connection (hot flow rate and heater temperature are fixed).
- Temperature vs position graphs for both the counter flow and cross flow for different temperatures.
- Calculation of power emitted , power absorbed , mean temperature efficiencies and energy balance for parallel and counter flow
- Find LMTD and over all heat transfer coefficient (U) for each flow rate.

Data Sheet:

Data Table 1:

Parallel flow connection
Hot water flow rate:2.86 L/s
Cold water flow rate:1.43
Ambient tank temperature :
Heater tank temperature :

Test	Heater Set Temperature	T_{H1}	T_{H2}	ΔT_H	Average T_H	T_{H3}	T_{C1}	T_{C2}	ΔT_C	Average T_C	T_{C3}
1	60	57.8	54.9				31.3	33.2			
2	55	54.1	52.2				31.3	32.9			
3	50	48.8	47.6				31.3	32.4			
4											

Data Table 2:

<u>Counter flow connection</u> **Hot water flow rate:2.87** **Cold water flow rate:1.43** **Ambient tank temperature :** **Heater tank temperature :**											
Test	**Heater Set Temperature**	**T_{H1}**	**T_{H2}**	**ΔT_H**	**Average T_H**	**T_{H3}**	**T_{C1}**	**T_{C2}**	**ΔT_C**	**Average T_C**	**T_{C3}**
1	**60**	**58.7**	**55.9**				**31.3**	**33.9**			
2	**55**	**54.3**	**53.8**				**31.3**	**33.2**			
3	**50**	**49.8**	**47.7**				**31.3**	**33.0**			
4											

Calculation Table:

Table 1:

Parallel Flow												
Test	η_H	η_C	η	ρ_H	ρ_C	**C_{PH}**	**C_{PC}**	**Q_e**	**Q_a**	**C_{EB}**	**LMTD**	**U**
1												
2												
3												
4												

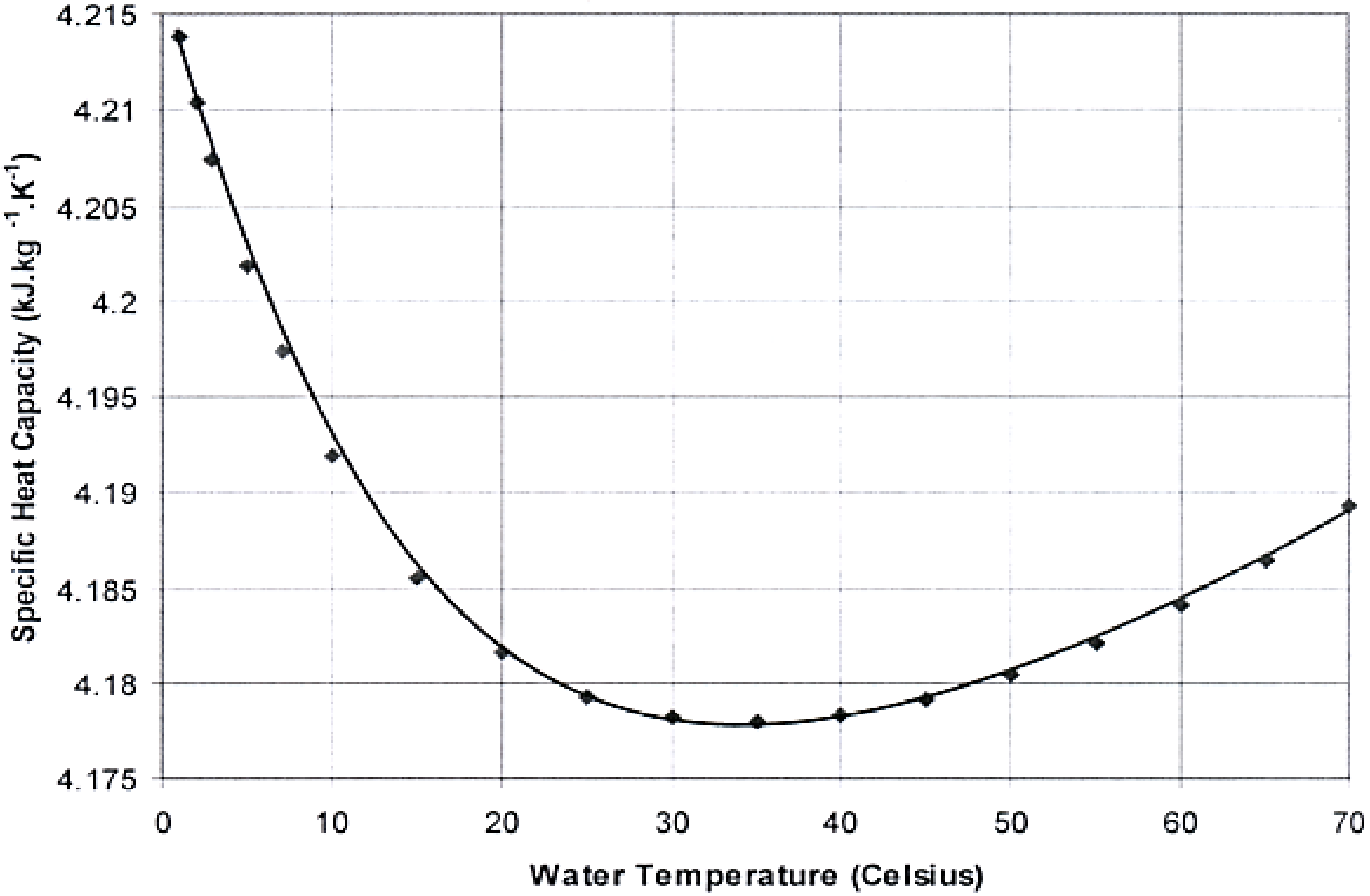
Table 2:

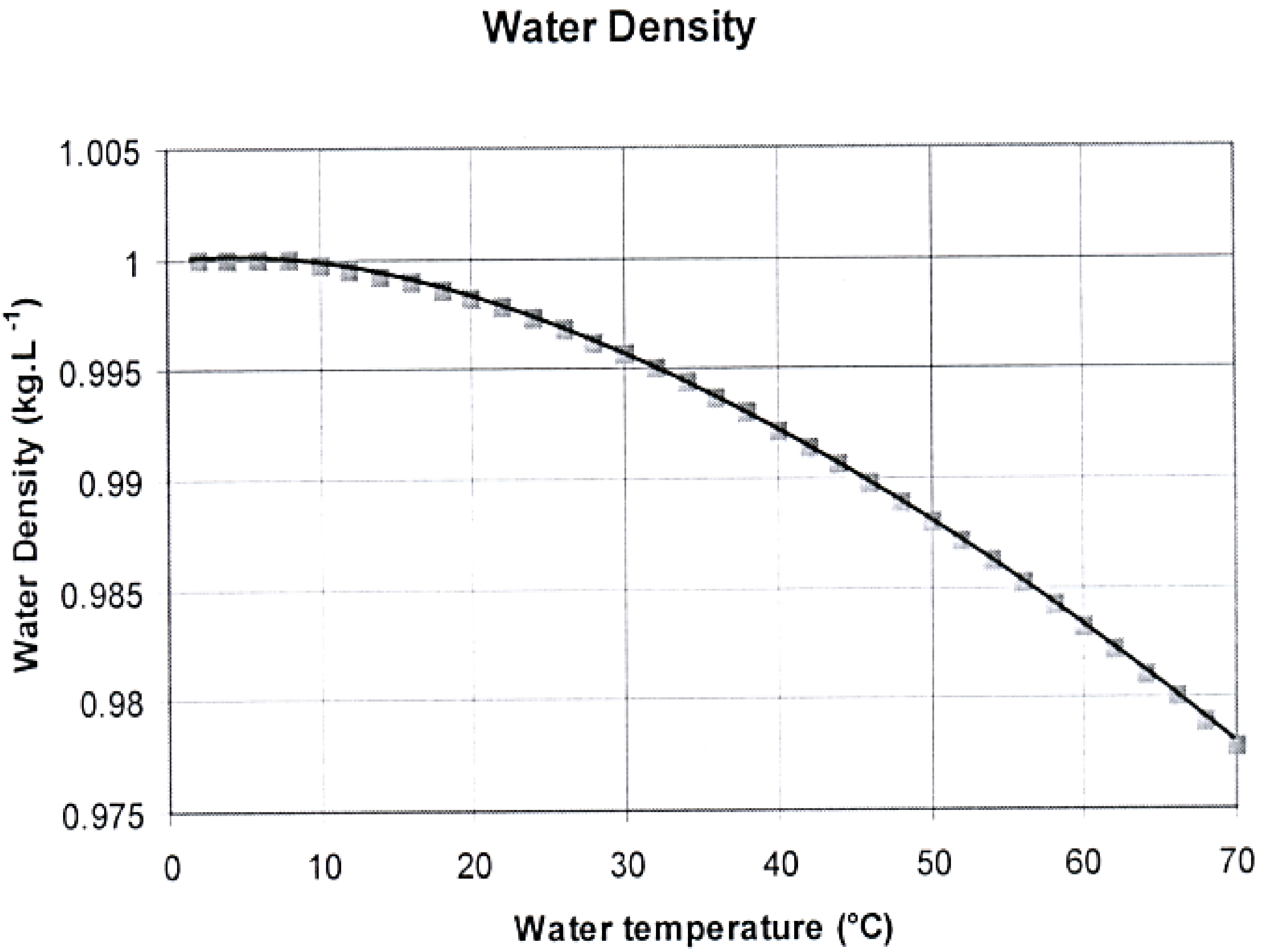
Counter Flow

Test	η_H	η_C	η	ρ_H	ρ_C	C_{PH}	C_{PC}	Q_e	Q_a	C_{EB}	LMTD	U
1												
2												
3												
4												

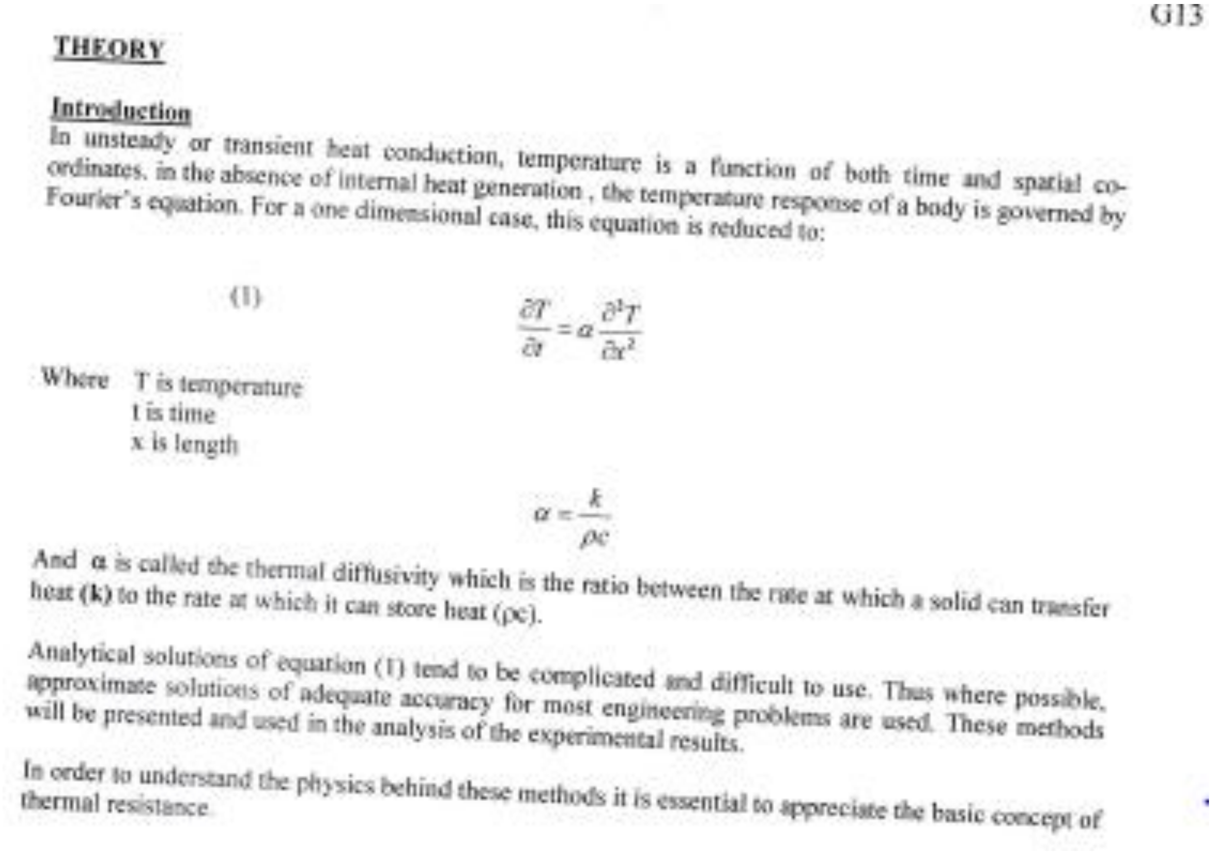
Result Analysis:

- Discuss the deviation in results of counter and parallel flow
- Write about the losses in surroundings


Specific Heat Capacity of Water at Constant Pressure


Water Density
Water Density (kg.L -1)
1.005
1
0.995
0.99
0.985
0.98
0.975
0
10
20
30
40
50
60
70
Water temperature (°C)

Experiment – 08: Transient Heat Transfer Analysis



G13

THEORY

Introduction

In unsteady or transient heat conduction, temperature is a function of both time and spatial co-ordinates. in the absence of internal heat generation , the temperature response of a body is governed by Fourier's equation. For a one dimensional case, this equation is reduced to:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \qquad (1)$$

Where T is temperature
t is time
x is length

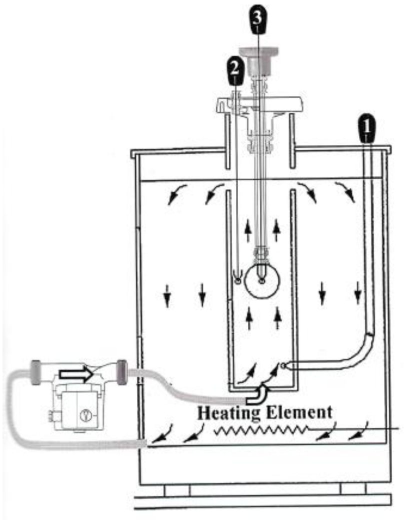
$$\alpha = \frac{k}{\rho c}$$

And α is called the thermal diffusivity which is the ratio between the rate at which a solid can transfer heat **(k)** to the rate at which it can store heat (ρc).

Analytical solutions of equation (1) tend to be complicated and difficult to use. Thus where possible, approximate solutions of adequate accuracy for most engineering problems are used. These methods will be presented and used in the analysis of the experimental results.

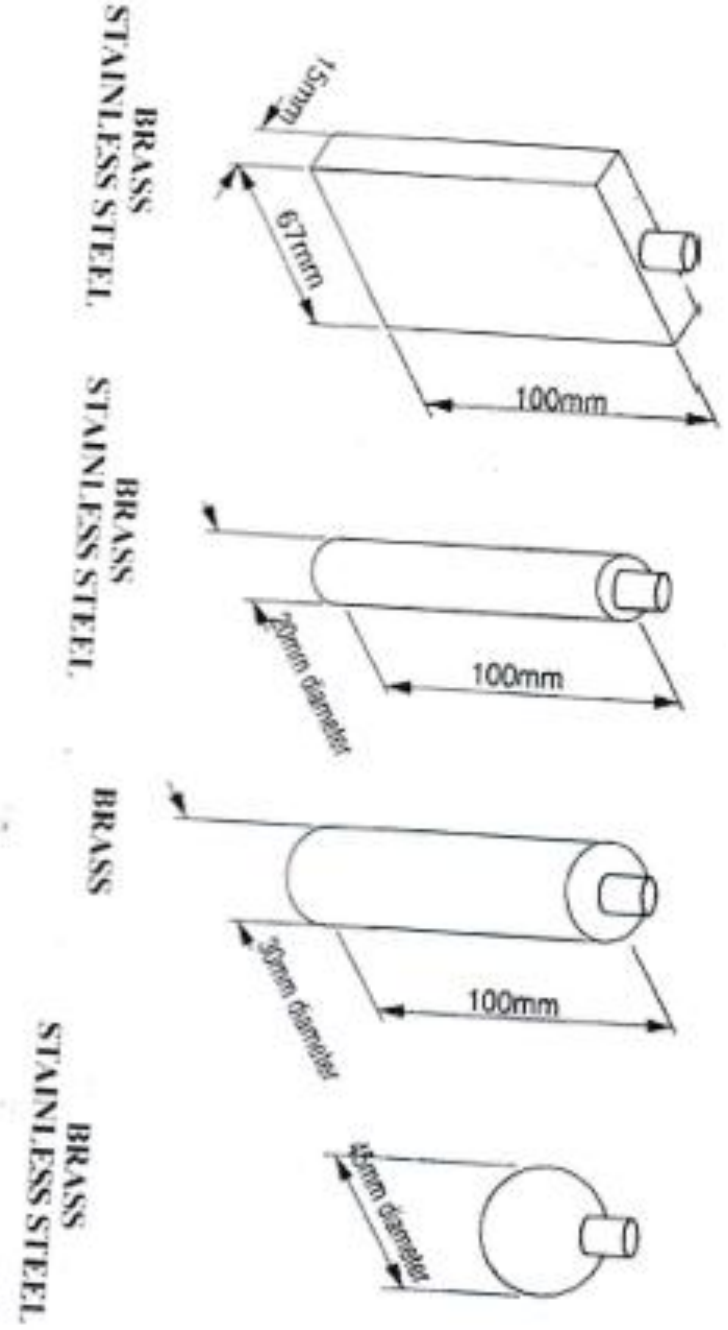
In order to understand the physics behind these methods it is essential to appreciate the basic concept of thermal resistance.

Experimental Set Up:



H112G SCHEMATIC ARRANGEMENT

Sample Object



Low Biot Number ($Bi < 0.1$)

A Biot number less than 0.1 indicates that the conduction thermal resistance is practically negligible compared with the convection resistance. In this case the temperatures T_1 and T_2 (in Figure G7) are approximately the same and the solid is assumed to have a uniform temperature. The transient thermal response of such a system can be obtained by consideration of the changes in the internal energy of the system expressed in terms of the changes of the assumed uniform temperature.

This approximation is called the ***Lumped Thermal Capacity*** method.

the governing equation in this case is determined from the energy balance between the heat transfer by convection through the surface and the change in the internal energy of the solid.

$$\rho v c \frac{\partial T}{\partial t} = hA\left(T - T_\infty\right) \quad (6)$$

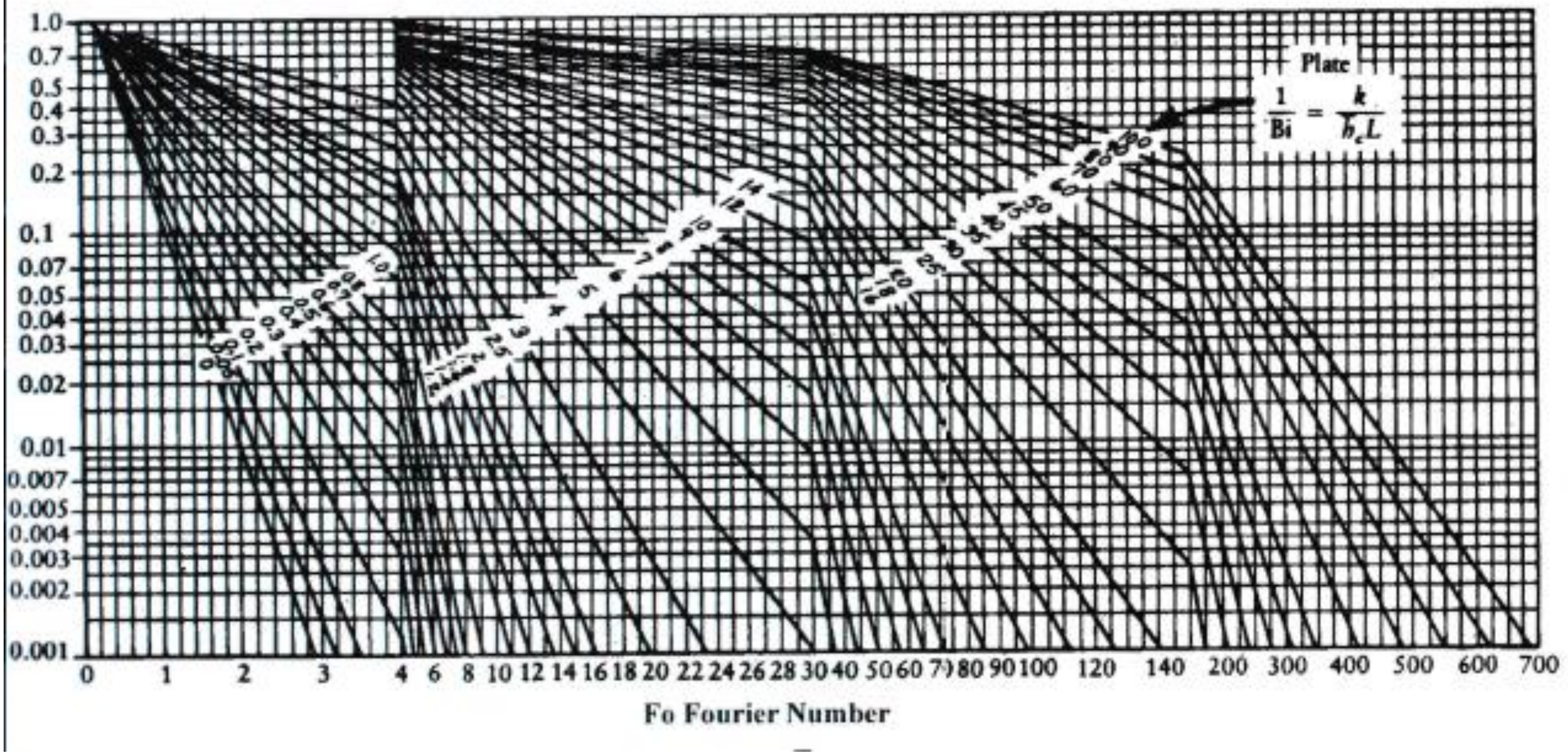
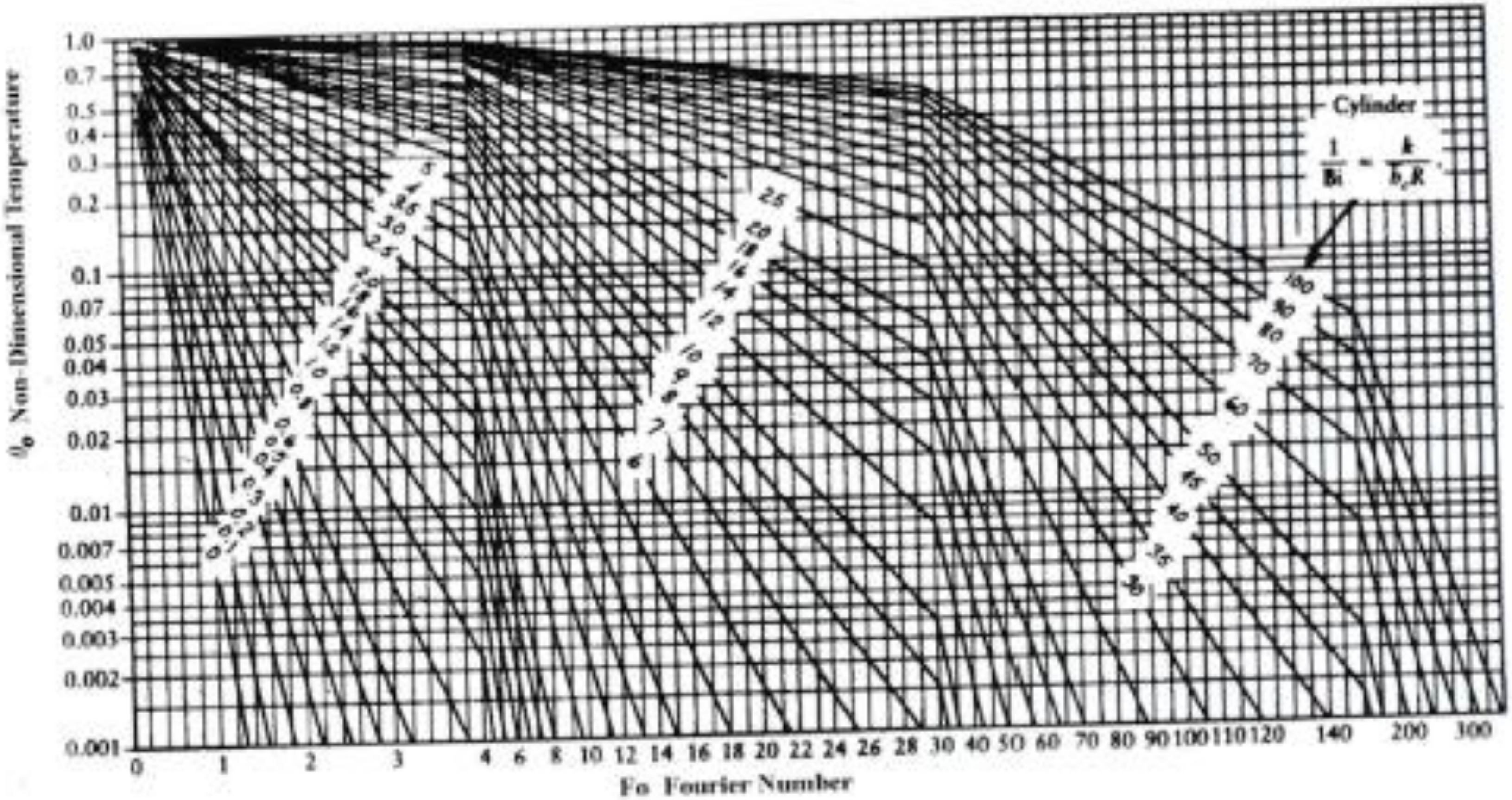
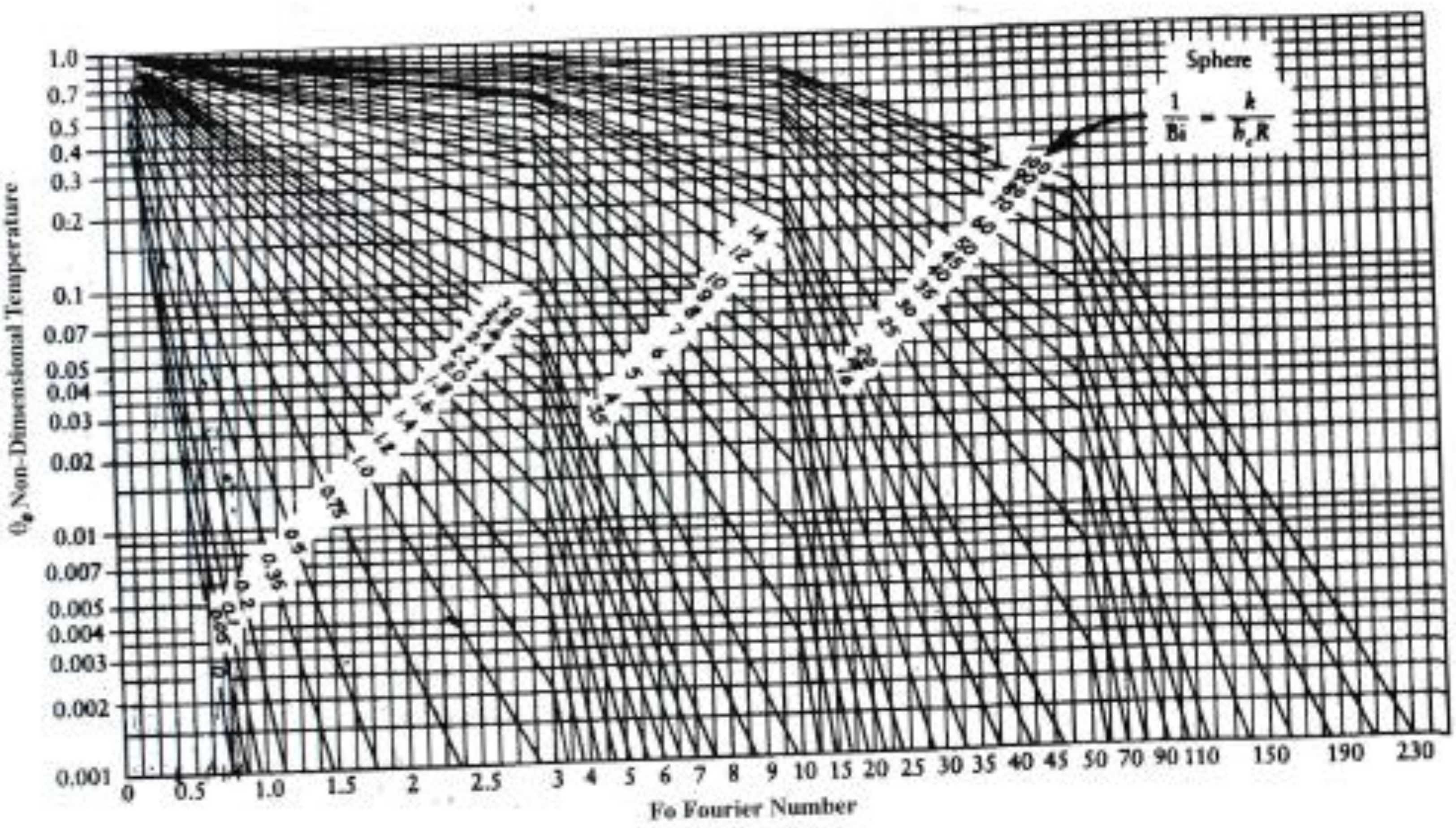


Plate
$\frac{1}{\mathrm{Bi}} = \frac{k}{h_c L}$
1.0
0.7
0.5
0.4
0.3
0.2
0.1
0.07
0.05
0.04
0.03
0.02
0.01
0.007
0.005
0.004
0.003
0.002
0.001
0
1
2
3
4
6
8
10
12
14
16
18
20
22
24
26
28
30
40
50
60
70
80
90
100
120
140
200
300
400
500
600
700
Fo Fourier Number
0
0.05
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1.0
2.5
3
4
5
6
7
8
9
10
12
14
16
18
20
25
30
35
40
45
50
60
70
80
90
100


θ0 Non-Dimensional Temperature
1.0
0.7
0.5
0.4
0.3
0.2
0.1
0.07
0.05
0.04
0.03
0.02
0.01
0.007
0.005
0.004
0.003
0.002
0.001
0
1
2
3
4
6
8
10
12
14
16
18
20
22
24
26
28
30
40
50
60
70
80
90
100
110
120
140
200
300
Fo Fourier Number
Cylinder
1/Bi = k/(h_c R)
0
0.1
0.2
0.3
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
3.5
4
6
7
8
9
10
12
14
16
18
20
25
30
35
40
45
50
60
70
80
90
100


Sphere
$\frac{1}{Bi} = \frac{k}{h_c R}$
θ_o Non-Dimensional Temperature
1.0
0.7
0.5
0.4
0.3
0.2
0.1
0.07
0.05
0.04
0.03
0.02
0.01
0.007
0.005
0.004
0.003
0.002
0.001
0
0.5
1.0
1.5
2
2.5
3
4
5
6
7
8
9
10
15
20
25
30
35
40
45
50
70
90
110
150
190
230
Fo Fourier Number
0.05
0.1
0.2
0.35
0.5
0.75
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
3.5
4
5
6
7
8
9
10
12
14
16
18
20
25
30
35
40
45
50
60
70
80
90
100