Laboratory Manual

HEAT AND MASS TRANSFER LAB

for

B. Tech.
Mechanical Engineering

Department of Mechanical Engineering

Rukmani & Sons

Brij Bhooshan Education Web Portal
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Prepared by

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LABORATORY OBJECTIVE

This course is to introduce the basic principles of heat and mass transfer with emphasis on their analysis and applications to practical engineering problems. On successful completion of this course, you should be able to:

- Identify important thermal processes, and derive the basic expressions for heat conduction, convection and radiation based on the First Law of Thermodynamics.
- Analyze heat transfer using electrical resistance network analogy.
- Determine the steady state and transient temperature distribution in various solid geometries of practical importance.
- Understand the physical significance of dimensionless parameters in convective heat/mass transfer.
- Select and apply the appropriate correlation for different convective heat and mass convection processes.
- Analyze and perform the thermal design of heat exchangers using conventional methods.
- Determine radiation exchange within an enclosure based on the view factor method.
- Analyze mass diffusion in a stationary medium and low rate mass convection based on the analogy between heat and mass transfer.

ABOUT THE LABORATORY

This course is designed to introduce a basic study of the phenomena of heat and mass transfer, to develop methodologies for solving a wide variety of practical engineering problems, and to provide useful information concerning the performance and design of particular systems and processes. A knowledge-based design problem requiring the formulations of solid conduction and fluid convection and the technique of numerical computation progressively elucidated in different chapters will be assigned and studied in detail. As well, to gain experience in designing experiments for thermal systems, the design, fabrication, and experimentation of a thin film heat flux gage will be attempted as part of laboratory requirements.

This laboratory contains the following setups and equipments:

1. Heat Transfer through Composite Wall Apparatus.
2. Critical Radius of Insulation Material Apparatus.
3. Critical Heat Flux Apparatus.
4. Liquid Thermal Conductivity Apparatus.
5. Heat Transfer in Natural Convection Apparatus.
6. Heat Transfer through Pin Fin Apparatus.
7. Heat Transfer in Force Convection Apparatus.
8. Parallel/Counter Flow Heat Exchanger Apparatus.
9. Shell and Tube Heat Exchanger Apparatus.
10. Emissivity Measurement Apparatus.
11. Stefan Boltzman's Apparatus.

GUIDELINES FOR TEACHERS/TECHNICAL ASSISTANTS

1. Know the laboratory: The teacher is expected to understand the layout of laboratory, specifications of equipments/instruments/materials, procedure of experiments, method of working in groups, planning time etc.
2. Ensure that required equipments are in working condition before start of experiment and also keep the operating or instruction/user manuals of equipments/instruments and this laboratory manual available.
3. On the first day of the lab, inform the students about the importance of subject/laboratory, various equipments/instruments that will be used in the lab etc. Also instruct them how to make the practical record file for this lab.
4. Explain the theoretical concepts, relevant to the experiment, to the students before start of each practical.
5. Demonstrate the experiment(s) clearly to the students group-wise.
6. Instruct the students to perform the practical. While taking reading/observation, each student must get a chance to perform or observe the experiment.
7. If the experimental setup has variations in the specifications of the equipment, the teachers are advised to make the necessary changes.
8. Teacher shall assess the performance of students by observation or by asking viva related questions to the students to tap their achievements regarding related knowledge/skills so that students can prepare accordingly.
9. The teacher must check carefully and sign the practical record file of the students periodically.
10. Teacher shall ensure that the industrial/site/plant visits recommended as per the syllabus of laboratory are covered.
11. Teacher should ensure that the respective skills and competencies are developed in the students after the completion of the practical exercise.
12. Teacher may provide additional knowledge and skills to the students albeit not covered in the manual but are expected from students by the industries.
13. Teacher may suggest the students to refer additional related literature of the technical papers, reference books, seminar proceedings etc.
14. Teacher can organize group discussions/brain storming sessions/seminars to facilitate the exchange of practical knowledge amongst the students.

GENERAL PRECAUTIONS AND SAFETY PROCEDURES

1. Teacher/technical assistant must ensure that all the electrical equipments/ instruments are used and periodically performance tested as per manufacturer's recommendations (permissible electrical and ambient temperature ratings).
2. Before use, the electrical equipment, extension cords, power tools etc. must be inspected for any damage (worn insulation, bent/missing pins, etc.). Any equipment found to be damaged or otherwise unsafe must be removed from service.
3. The mains plug of equipments must only be inserted in a socket outlet provided with a protective earth contact.
4. **WARNING**: The protective earth connection inside or outside the equipments/instruments must NEVER be interrupted or tampered. **IT CAN MAKE THE EQUIPMENT DANGEROUS**.
5. If an instrument shows visible damage or fails to perform the intended measurements, it is likely that the protection has been impaired. In such case the instrument must be made inoperative and the necessary repairs should be carried out.
6. Extension cords or power strips must not be plugged into one another so as to increase the overall reach.
7. Report all problems with building electrical systems to the teacher/technical assistant/maintenance for corrective action.
8. In case of any electrical hazard/fire reach out for the nearest fire-extinguisher or sand and use it for putting out the fire. Report immediately to the teacher/ technical assistant nearby.
9. For reasons of safety, every student must come to the laboratory in shoes (covering the whole feet).
10. Avoid wearing garments with loose hanging parts. The students should also ensure that floor around the equipment/machine is clear and dry (not oily) to avoid slipping. Please report immediately to the lab staff on seeing any coolant/oil spillage.
11. The student should take the permission and guidance of the lab staff/teacher before operating any equipment/machine. Unauthorized usage of any machine without prior guidance may lead to fatal accidents and injury.
12. The student will not lean on the equipment/machine or take any kind of support of the machine at any point of time.

INSTRUCTIONS FOR STUDENTS

1. Listen carefully to the lecture and instructions given by the teacher about importance of subject/laboratory, curriculum structure, skills to be developed, information about equipment and instruments, procedure, method of continuous assessment, tentative plan of work in laboratory and total amount of work to be done in the semester/session.
2. Read and understand the theory of each experiment to be performed, before coming to the laboratory.
3. Understand the purpose of experiment and its practical implications. Observe carefully the demonstration of the experiment. When you perform it, organize the work in your group and make a record of all observations.
4. In case of absence, the student must perform the experiment(s) on the next turn or in his/her spare time with permission from the teacher/lab assistant.
5. Student should not hesitate to ask any difficulty faced during conduct of practical/exercise.
6. The student shall study all the questions given in the laboratory manual or asked by the teacher and know the answers to these questions properly.
7. The required instruments/tools will be issued from the laboratory store. They must be returned to the store on the same day at the end of lab hours.
8. Laboratory reports (practical file) should be submitted in a bound file or on A4 size sheets, properly filed, on the next turn completed in all respects i.e. with experiment(s) written, graphs attached (if applicable) and entries made in the list of contents of the file and get them checked from your laboratory teacher. Laboratory reports have associated grades/marks.
9. Student should not bring any food or drink item to the laboratory.
10. Student should develop habit of group discussion related to the experiments/exercises enabling exchange of knowledge/skills.
11. Student shall gain knowledge and develop required practical skills and competencies as expected by the industries.
12. Student shall develop the habit of evolving more ideas, innovations, skills etc. than included in the scope of the manual.
13. Student shall refer technical magazines, proceedings of the seminars; refer websites related to the scope of the subjects and update their knowledge and practical skills.

EXPERIMENT – 1

OBJECTIVE:

To determine the thermal conductivity of a composite structure with different thickness.

APPARATUS USED:

Composite Structure Apparatus

Description of Apparatus:

The apparatus consist of Nicrome heater sandwiched between mica Sheets and placed between two cast iron thick plates. These cast iron plates are placed between identical Bakelite and press wood plates forming a Composite structure of C.I., Bakelite and press wood plates. A screw jack is used to remove the Gap between plates.

Specification of Apparatus:

Bakelite plate diameter	200 mm
Bakelite plate thickness	13 mm
Press wood plate diameter	200 mm
Press wood plate thickness	12 mm
C.I. Plate dia.	200 mm
C.I. Plate thickness	15 mm
Digital Voltmeter	0-230 V
Digital ammeter	0-2 Amps
Heater	Plate type (400 Watt)
Thermocouples	K-type (Cr.Al)

THEORY:

As per Fourier Law

$$\frac{Q}{A} = -K\frac{dt}{dx}$$

$$Q = A \times K\,\frac{dt}{dx}$$

where

d = difference of temperature

A = Area of plate
Q = Heat input in watts
d*x* = Thickness of plate
K = Thermal conductivity of plate

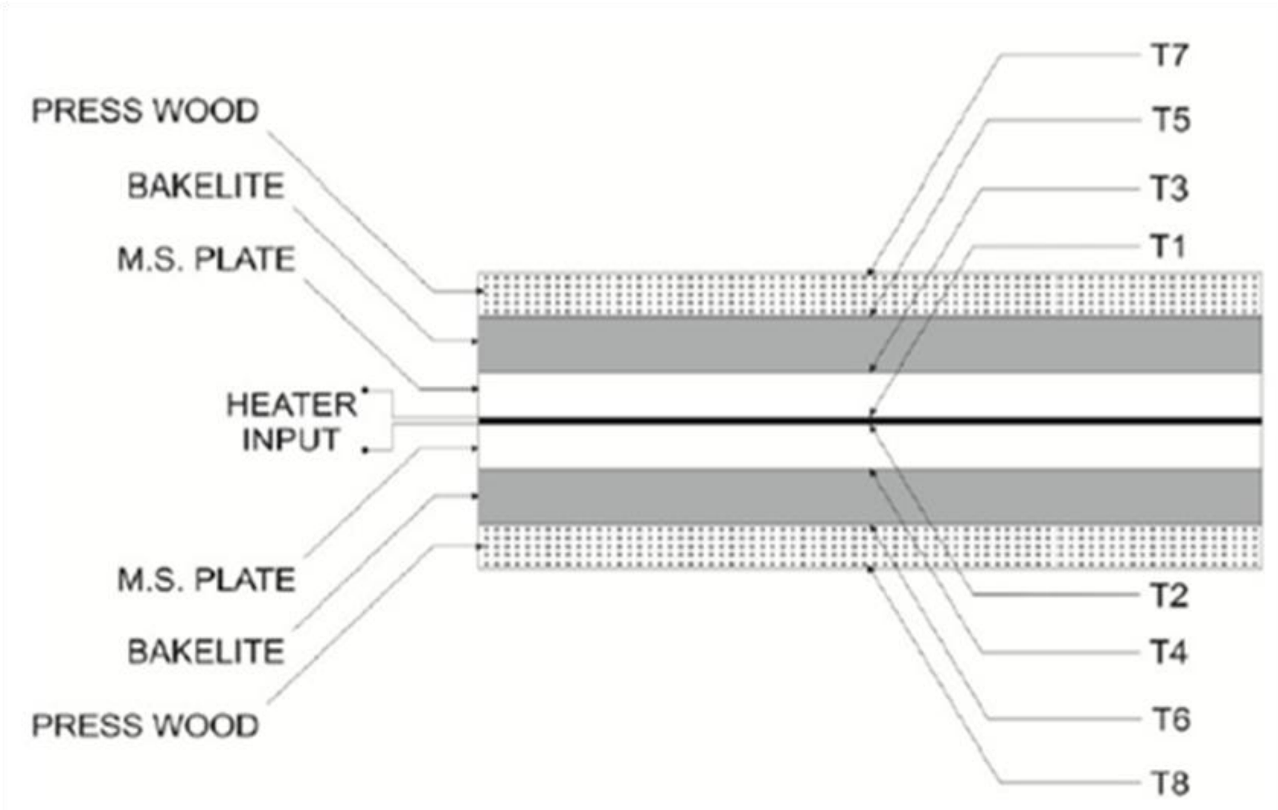

Fig. 1.1 Composite Wall

PROCEDURE:

1. Connect the equipment to power supply.
2. Arrange the plates properly (symmetrically) on both side of heater plate.
3. See that plate is symmetrically arranged on both sides of heater plate (arranged normally).
4. Operate the hand press properly to achieve the steady environmental conditions.
5. Close the box by cover sheet to achieve the environmental conditions.
6. Start the supply of heater. By varying the dimmer stat, adjust the input.
7. Take the readings of all thermocouples at an interval of 10 minutes until steady state is reached.
8. Note down the steady state readings in the observation table.

OBSERVATIONS:

S. No.	V in Volts	'I' in Amp.	T_1 in °C	T_2 in °C	T_3 in °C	T_4 in °C	T_5 in °C	T_6 in °C	T_7 in °C	T_8 in °C
1										
2										
3										
4										

CALCULATIONS:

Considering the composite structure made of different materials and different thickness.

where

Q = V × I = heat input in watt.

A = πd2/4 = Area of plate in m^2

D = diameter of plate

B_1 = Thickness of Bakelite plate

B_2 = Thickness of Press wood plate

B_3 = Thickness of C.I. Plate

$$T_{1(Average)} = \frac{T_1 + T_2}{2}$$

$$T_{2(Average)} = \frac{T_3 + T_4}{2}$$

$$T_{3(Average)} = \frac{T_5 + T_6}{2}$$

$$T_{4(Average)} = \frac{T_7 + T_8}{2}$$

Area of slab = $\pi d^2/4$ = 0.01747m^2

We know,

$$\text{Thermal resistance R} = \frac{T_1 av - T_4 av}{Q}$$

Thermal conductivity of slab 'K'

$$K = \frac{Q \times B}{A(T_1 av - T_4 av)} \text{ Watt/m°C}$$

where $B = B_1 + B_2 + B_3$

RESULT:

The average Thermal Conductivity of Composite structure is…………. watt/m°C.

PRECAUTIONS:

1. Ensure that there is no air gap between plates.
2. Ensure that starting the experiment all the attachment must be properly fitted.
3. Reading should be taken very carefully during practical.

EXPERIMENT – 2

OBJECTIVE:

To determine the Thermal Conductivity of pipe insulation used as Lagged material.

APPARATUS USED:

Lagged pipe Apparatus.

Description of Apparatus:

The apparatus consist of metal cylinder housing inside and electrical heater coil. The Metal cylinder is insulated with asbestos powder. This cylinder is placed in third cylinder and is insulated with sawdust. The ends are covered with thicker Bakelite plate so that end loss will be negligible and the heat flow will be in redial direction only. The Redial temperature distribution within the insulation is measured by six thermocouples placed on respective cylinders.

Specification of Apparatus:

Dia. Of hot plate	170 mm
Liquid depth (ΔX)	16 mm
Digital voltmeter	0-230 V
Digital ammeter	0-2 Amps
Heater	Cartridge type (400 Watt)
Thermocouples	K-type (Cr.Al)

THEORY:

Fourier's Law for steady State radial heat conduction without heat generation is given by

$$Q = \frac{2\pi KL(T_1 - T_0)}{\text{Log}_e({}^{r_0}/_{r_i})}$$

where,

r_1 = Inner radius of pipe in mm
r_0 = Outer radius of pipe in mm
T_1 = Temperature of inner surface in °C
T_0 = Temperature of outer surface in °C
K = Thermal conductivity of the insulating material in W / m°C

Q = Heat flow rate in Watt
L = Length of insulated cylinder in mm

PROCEDURE:

1. Connect the switch to power supply.
2. The heater is put ON. Wattage is maintained at some desired valve.
3. Reading should be taken at regular intervals until steady state is reached.
4. The same procedure is repeated for different wattage of the heater input.

OBSERVATIONS:

S.No.	V (Volts)	I (Amp)	Q = V × I (Watts)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)
1									
2									
3									
4									

CALCULATIONS:

Average of asbestos insulation inner temperature

$$T_1 = \frac{T_1 + T_2}{2}$$

Average of asbestos insulation outer temperature

$$T_m = \frac{T_3 + T_4}{2}$$

Average of sawdust insulation temperature

$$T_o = \frac{T_5 + T_6}{2}$$

Power input $$Q = V \times I$$

$$Q = \frac{2\pi KL(T_1 - T_0)}{\mathrm{Log}_e({}^{r_0}/_{r_i})}$$

or

$$K = \frac{Q Log_e({}^{r_0}/_{r_i})}{2K(T_1 - T_0)}$$

RESULT:

The thermal conductivity of pipe insulation is………………

PRECAUTIONS:

1. The readings should be taken very carefully.
2. Ensure that before starting the experiment all attachments must be properly tight.
3. Ensure heater input is 100 Volt.

EXPERIMENT – 3

OBJECTIVE:

To determine the critical insulation thickness of material.

Apparatus used:

Critical radius of insulation material apparatus

Description of Apparatus:

Standard equipment for the determination of thermal conductivity of insulating powder. The apparatus consists of two thin walled concentric copper spheres. The inner sphere houses the heating coil. The insulating powder (in our case- Chalk Powder) is packed between the two shells. The power supply to the heating coil is adjustable. Fe-Constantan thermocouples are used to measures the temperatures.

Thermocouples 1 to 4 are embedded on the outer surface of the inner sphere and thermocouples 5 to 8 are embedded on the outer shell.

Let, r_i = Radius of inner sphere in meters.

r_o = Radius of outer sphere in meters.

T_i = Average Temperature of the inner sphere in °C

T_o = Average Temperature of the outer sphere in °C

Specification of Apparatus:

Radius	25 mm
Insulating material	Asbestos
Digital voltmeter	0-30 V (AC)
Digital ammeter	0-20 Amps (AC)
Heater	Cartridge type (400 Watt)
Thermocouples	K-type (Fe)

THEORY:

Fourier's Law of Heat Conduction:

Assuming no heat generation, no accumulative of heat and transfer of heat by conduction only at steady state we have,

$$q_x = Q$$

$$q_x = -KA\frac{dT}{dx}$$

where q_x/A is the heat flux in W/m^2 while the quantity dT/dx represents the temp. gradient in x-direction.

Conduction through Hollow Sphere:

Fourier's Law for constant thermal conduction with distance '*dr*', where *r* is the radius of sphere. r_1 is the radius at temp. T_1, and r_2 is the radius at the temp. T_2.

$$\frac{Q}{A} = -K\frac{dT}{dx}; \quad \text{and} \quad A = \pi r^2$$

Integrating above equation from r_1 to r_2.

$$\frac{Q}{4\pi}\int_{r_1}^{r_2}\frac{dr}{r^2} = -K\int_{T_1}^{T_2} dT$$

$$Q = \frac{4\pi K r_1 r_2 (T_1 - T_2)}{(r_1 - r_2)}$$

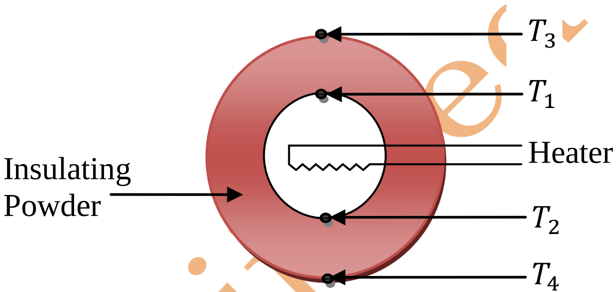

Fig. 3.1 Insulating Powder Conductivity

Insulation:

Covering the surface with another surface with another material of low thermal conductivity in order to prevent excess heat transfer to the surrounding is termed as Insulation. In order to insulate material, it is poor conductor of heat and hence to cover the surface of heat. It is used where excess heat transfer is prevented.

Electrical conductors are almost always good conductor of heat viz. Copper, Aluminum and Silver. & electrical conductors are good heat insulators.

Commonly known heat insulators are Glass, Wood, Window glass, Saw dust, Chalk, Loosely packed or boards of sheet of asbestos.

PROCEDURE:

1. Keep the dimmer-stat at minimum voltage position. Switch ON the electric supply.
2. Adjust the dimmer-stat to supply a maximum 40W to the heating coil. Maintain this constant throughout the experiment.

3. Wait for steady state to be attained.
4. Note down the reading in the observation table as given below.

OBSERVATIONS:

S. No.	V in Volts	'I' in Amp	T_1 in °C	T_2 in °C	T_3 in °C	T_4 in °C
1						
2						
3						
4						

CALCULATIONS:

Formulas used:

$$K = \frac{-VI(r_i - r_0)}{4\pi r_i r_0 (T_i - T_0)}$$

where: K = Thermal conductivity in w/mK.
V = Voltage in volts.
I = Current in Amp.
T_i = Average surface temperature of the inner sphere = $(T_1 + T_2)/2$.
T_0 = Average surface temperature of the outer sphere = $(T_3 + T_4)/2$.

RESULT:

The thermal conductivity of the given insulating powder is =……………w/mK.

PRECAUTIONS:
1. The readings should be taken very carefully.
2. Ensure that before starting the experiment all attachments must be properly tight.
3. Ensure heater input is 100 volt.

EXPERIMENT – 4

OBJECTIVE:

To determine the surface heat transfer coefficient for a vertical tube losing heat by natural convection.

APPARATUS USED:

Natural convection Apparatus

Description of apparatus:

It consists of a steel tube fitted in a rectangular duct in a vertical manner. The duct is open at the top bottom and forms an enclosure and serves as undisturbed surroundings. The side of the duct is made up Perspex for visualization. An electric heating element is kept in the vertical tube for heating the surface of the tube. The temperature of tube is measured by thermo-couples.

Specification of apparatus:

Outer diameter of tube	38 mm
Inner diameter of tube	35 mm
Length of tube	500 mm
Digital voltmeter	0-230 V
Digital ammeter	0-2 Amps
Heater	Band type (400 Watt)
Thermocouples	K-type (Cr.Al)

THEORY:

When a hot body is kept in atmosphere, Heat is transferred by natural convection. The hot air gets heated and rises up due to decrease in density and cold rushes to take place of hot air particle.

PROCEDURE:

1. First we note ambient temperature.
2. Put the supply on and adjust the dimmerstat to get required power input.
3. Wait till steady state is reached.
4. Move the knob and measure the temperature of steel tube at various locations
5. Repeat this procedure after fifteen minutes wait.

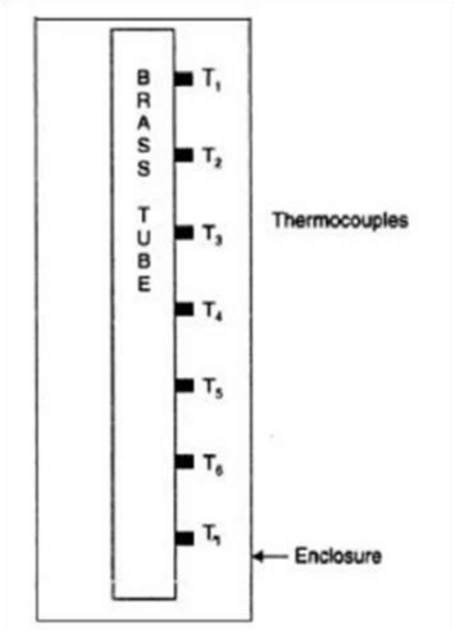

Fig. 4.1 Natural convection

OBSERVATIONS:

S. No.	V (Volts)	'I' (Amp)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	T_7 (°C)	T_8 (°C)
1										
2										
3										
4										

CALCULATIONS:

1. Experimental value h_{exp}

$$h = \frac{Q}{As(t_s - t_a)}$$

where,

h = Average heat transfer coefficient W/m^{2}K
Q = Heat transfer rate in watt
t_s= Average surface temperature in °C
t_o = Ambient temperature in °C
A_s = Area of heat transferring surface in m^2

$$t_s = \frac{t_1 + t_2 + t_3 + t_4 + t_5 + t_6 + t_7 + t_8}{8}$$

2. Theoretical value h_{th}

For laminar flow:

$$Nu = 0.59\,(Gr.\,Pr)^{1/4} \text{ for } (10^4 < Gr.\,Pr < 10^9)$$

All the properties are evaluated at mean film temp.

$$T_f = \frac{t_s - t_a}{2}$$

$$Gr = \frac{t^3 \beta g \Delta t}{\nu^2}$$

where, $\beta = 1/t_f$

$$Nu = \frac{hL}{K}$$

At film temp. t_f find the properties (Pr, ν and K) from the property table of air.

RESULT:

1. Experimental value of convective heat transfer coefficient $h_{exp.}$ = ……….
2. Theoretical value of convective heat transfer coefficient $h_{th.}$ = ………….

PRECAUTIONS:

1. The readings should be taken carefully.
2. Ensure that the readings have been taken after attaining the steady state condition.
3. Ensure that nothing should be kept on the top of the duct.

EXPERIMENT – 5

OBJECTIVE:

To study the variation-of temperature along the length of pin-fin forced convection and to determine

(i) The value of heat transfer Co-efficient under forced convection condition
(ii) Effectiveness of pin-fin

APPARATUS USED:

Pin- Fin Apparatus.

Specification of Apparatus:

Pin Fin material	Brass, mild-steel & aluminum (One each)
No. of thermocouples	08
Length of fin	100 mm
Diameter of Fin	12.7 mm
Dimmer state	2 amp
Orifice dia.	25 mm

THEORY:

The heat transfer from a heated surface to the ambient is

$$Q = h \times A \times \Delta T$$

where

h = Heat transfer coefficient
ΔT = temperature difference
A = Area of cross- section of Fin

To increase the rate of heat transfer through convection either we can increase hot. In some cases it is not possible to increase the value of heat transfer coefficient and temperature difference and the alternative is to increase the surface area of heat transfer. The surface area is increased by attaching extra material in the form of rod on the surface. The extra material attached is called extended surface or fin.

Temperature distribution and heat transfer along the length of Fin is:

$$\frac{T - T_1}{T_2 - T_1} = \frac{\cosh m(L - X)}{\cosh ml}$$

where

T = Temperature at any instant °c
T_1 = Ambient temperature °c
T_2 = Body temperature in °c
L = Length of fin in meter

$$m = \sqrt{\frac{h \times p}{K \times Ac}}$$

h = Heat transfer coefficient between fin surface and surroundings
P = Perimeter of fin.
K = Thermal conductivity of fin.
A_c = Area of X-section of fin.
T_s = Average temperature in °C

Therefore, Heat flow rate

$$q_c = \sqrt{h_c} \times P \times K \times Ac(T_s - T_1)$$

'Effectiveness of Fin is defined as the ratio of heat transfer with fin to the-heat transfer from the surface without fin'

$$\text{Effectivness} = \frac{\tanh (mL)}{m \times L}$$

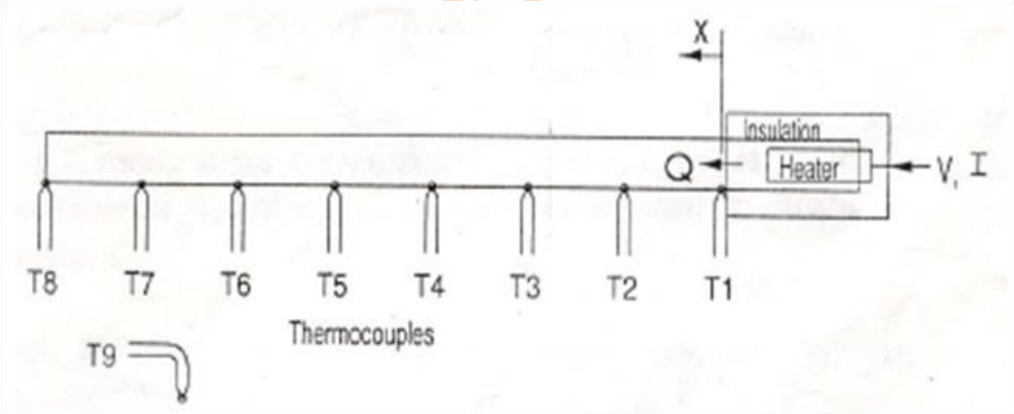

Fig. 5.1 Schematic of experimental set-up

PROCEDURE:

1. Connect the electric switch to the electric power supply
2. Keep the thermocouple selector 1knob to zero position.
3. Switch on the blower.
4. Ensure that reading should be noted after stabilization.
5. Note the difference of level of manometer after few seconds.

OBSERVATIONS:

S. No.	V (Volts)	'I' (Amp)	$H_w = (h_1 - h_2)$ (mm)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	T_7 (°C)	T_8 (°C)
1											
2					.						
3											
4											

CALCULATIONS:

Difference of manometer reading h_w	=	$h_1 - h_2$
Height of air column H_a	=	$\rho_w \times h_w / \rho_a$ in meter
where		
Density of air ρ_a	=	1.16 kg/m^3
Density of water ρ_w	=	1000 kg/m^3
Discharge of air Q	=	$C_d \times A \sqrt{2g} H_a$ in m^3/sec
Given C_d	=	0.6
Area of Orifice in mm^2	=	A

$$\text{Velocity of Air} = \frac{\text{Discharge of air } Q}{\text{Area of pipe}} \text{ m/sec}$$

$$\mu = 171 \times 10^{-6}$$

d is the diameter of fin in meters

Reynold No. = Velocity of air × dia. of Fin / u

Nusett No. = $Nu = 0.615\,(Re)^{0.466}$ 40 c Re < 4000

$Nu = 0.174(Re)^{0.618}$ 4000 < Re < 40000

$$Nu = hd/K$$

$$h = Nu \times k_{air}/d \quad K_{air} = 0.0285$$

$$m = \sqrt{h \times P / KAc}$$

where $P = \pi d^2$

$$A_c = \frac{\pi d^2}{4}$$

$$\text{Effectivness} = \frac{\tanh(mL)}{mL}$$

RESULT:

1. The heat transfer coefficient = ……………………….
2. Effectiveness Pin-fin = ……………………….

PRECAUTIONS:

1. Ensure that readings should be taken after its stability.
2. Before starting the practical all the -electric connections should be properly tight.
3. Ensure that after completing the practical dimmer. Must be in Zero position.

EXPERIMENT – 6

OBJECTIVE:

To determine the Critical heat flux of Nichrome wire for different bulk temperature of water.

APPARATUS USED:

Nichrome wire, Glass Container filled with water etc.

Description of Apparatus:

It consists of half cut glass container filled with water. The heating surface of a Nichrome wire completely submerged in Water. There is another heater submerged in water to initially heat the water up to the required temperature to study the critical heat flux phenomenon at various bulk temperatures. The temperature of water is measured with the help of thermometer. Electrical supply to the test heating wire.

Specification of Apparatus:

Diameter of Nichrome wire	0.3mm
Length of Nichrome wire	65mm

THEORY:

When a heat is added to a liquid from submerged solid surface which is at a temperature higher than the saturation temperature of water or liquid. It is usual part of change of phase referred to pool boiling. The boiling curve can be divided into three regions.

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

The region of natural convection occurs at low temperature difference. Heats transfer from heated surface to the liquid in its causes the liquid to be superheated.

As the same temperature difference increases, nucleate boiling starts. In this region it is observed that bubbles start to form at certain locations in heated surfaces.

Region II consists of two parts - In the first part, the bubble formed are very few in number. They gets condensed in the liquid and do not reach the free surface. In the IInd part the rate of bubble formation is more. So the bubbles rises above up to the free surface and finally enters in region III. The formation of bubbles is so high that they start to coalesce and blanket the surface with vapor film, Hence the heat flux decreases. Now again increasing the temperature excess minimizes the effect of insulation blanket and heat flux goes on increasing up to burn out point. At burn out point the wire gets melted.

PROCEDURE:

1. Fill the pure water in the glass container. So that bulk heater is submerged in water.
2. Start bulk heater and note down the temperature of water.
3. Wait for some time to obtain desired bulk temperature.
4. Switch off the bulk heater.
5. Now, start test heater and increase dimmer-stat slowly as go on increasing the dimmer.
6. Note down voltage & current.
7. At certain point Nichrome wire melts.
8. Move the dimmer knob to zero position and switch off the test heater.
9. Repeat the procedure for different bulk temperature.

OBSERVATIONS:

S.No.	Bulk temp in t°C	Voltage 'V' in volt	Current 'I' in Amp	Heat flux in watt/m²	Remark
1					
2					
3					
4					

CALCULATIONS:

Diameter of Nichrome wire (d) = 0.3 mm
Length of Nichrome wire (L) = 65 mm
Surface Area (A) = $\pi \times d \times l$

$$\text{Heat flux} = \frac{V \times I}{A} \text{watt/m}^2$$

where

V = Voltmeter reading
I = Ammeter reading

RESULT:

The critical heat flux for different bulk temperature is……… watt/m^2

PRECAUTIONS:

1. Put sufficient water in the glass container.
2. After Nichrome wire melt immediately switch off test heater
3. The reading V, I and T should be noted very frequently at critical point.
4. Do not increase the bulk temperature above 90°C.

EXPERIMENT – 7

OBJECTIVE:

To determine the effectiveness and overall heat transfer coefficient for counter flow heat exchanger.

APPARATUS USED:

Counter flow heat exchanger apparatus, Geyser, Flow measuring flasks etc.

Description of Apparatus:

It consist of a concentric tube hot water is obtained from an electric geyser and it flows through inner tube and cold water flow through Annular pipe and come from same end but flow in opposite direction. In this Exchanger this can be done by operating different valves provided to measure using stop watch and flask. In the outer tube is provided with insulation to minimize the heat loss to the surroundings.

Specification of Apparatus:

Inner tube (Cu) diameter	10 mm
Inner tube (Cu) length	1575 mm
Outer tube (G.I.) diameter	28 mm
Outer tube (G.I.) length	1350 mm
Thermocouple	K-type (Fe)
Temperature indicator	Digital (0-999°C)
Length of heat exchanger	1.5 meter
Measuring jar	500 cc (Plastic body)
Geycer	Instant type (3 kW, 1 Lit.)

THEORY:

In counter flow heat exchanger the change in the direction of fluid results in counter flow. The two fluids enter at each end, flow in the opposite direction and leave at opposite end.

PROCEDURE:

1. To obtain counter flow, keep the valves $V_1$and V_2 open positioned and V_2 and V_4 closed positioned.

2. Adjust flow rates on hot side and cold side exactly to those use in parallel flow run.
3. Check the temperature at an interval of 10 minutes till the steady state reached.
4. Check the flow rates and try to keep them constant as per initially obtained parallel flow run.

OBSERVATIONS:

S. No.	Hot water Inlet Temp. in °C.(T_{hi})	Hot water Outlet Temp. in °C.(T_{he})	Cold water inlet Temp. in°C.(T_{ci})	Cold water Outlet Temp. in °C. (T_{ce})	Hot water flow rate (m_h)	Cold water flow rate (m_c)
1						
2						
3						
4						

CALCULATIONS:

First we find Log mean Temperature difference

$$L.M.T.D = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)}$$

$$\theta_1 = t_{hi} - t_{ce}$$

$$\theta_2 = t_{he} - t_{ci}$$

$$q_h = m_h C_{ph}(t_{hi} - t_{he})$$

$$q_c = m_c C_{pc}(t_{ce} - t_{ci})$$

Thus

$$q_{actual} = \frac{q_h + q_c}{2}$$

Now we can find Overall heat transfer Co-efficient

$$U = \frac{q_{actual}}{A \times LMTD}$$

$$L.M.T.D = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)}$$

$$A_i = \pi \times d_i \times L$$

where,

d_i = Inner diameter of pipe in mm
L = Length of Pipe in mm

Therefore,

$$\text{effectivness of heat Exchanger } \varepsilon = \frac{q_{actual}}{q_{max}}$$

$$= \frac{q_{actual}}{C_{min}(Th_i - Tc_i)}$$

Where C_{min} = Minimum of m_hC_{ph} or m_hC_{pc}

RESULT: In case of Counter flow heat exchanger

1. LMTD………………………
2. The overall heat transfer Co-efficient U is ………………………
3. The effectiveness is ………………………

PRECAUTIONS:

1. Ensure that before starting practical all connection of apparatus should be properly tight.
2. Reading should be taken very carefully.
3. Give sufficient time to boil the water.

EXPERIMENT – 8

OBJECTIVE:

To determine the effectiveness and overall heat transfer coefficient for parallel flow heat exchanger.

APPARATUS USED:

Parallel flow heat exchanger apparatus, Geyser, Flow measuring flasks etc.

Description of Apparatus:

It consists of a tube, in tube heat exchanger which can operate as parallel flow heat exchanger. Hot water obtained from an electric geyser is flowing through the inner Cu tube and is coming out at the end of heat exchanger. Cold water flows through the annular pipe fitted concentric with inner tube. When cold water and hot water enters at the same end the arrangement is called parallel flow arrangement.

Specification of Apparatus:

Inner tube (Cu) diameter	10 mm
Inner tube (Cu) length	1575 mm
Outer tube (G.I.) diameter	28 mm
Outer tube (G.I.) length	1350 mm
Thermocouple	K-type (Fe)
Temperature indicator	Digital (0-999°C)
Length of heat exchanger	1.5 meter
Measuring jar	500 cc (Plastic body)
Geycer	Instant type (3 kW, 1 Lit.)

THEORY:

In parallel flow heat exchanger, the two fluids enter at one end flow in the same direction and leave at other end.

PROCEDURE:

1. In the parallel flow run, allow water from supply line to flow through the inner tube and is required.
2. Adjust flow rates on hot side and cold water side. However note down the exact flow rate carefully by using measuring flask and stopwatch.

3. Take the initial temperature reading from the given four thermometers.
4. When heater gets off start water supply.
5. Note down the temperatures and check the flow rates and adjust to the critically fixed rates by minor adjustments if required.

OBSERVATIONS:

S. No.	Hot water Inlet Temp. in °C.(T_{hi})	Hot water Outlet Temp. in °C.(T_{he})	Cold water inlet Temp. in°C. (T_{ci})	Cold water Outlet Temp. in °C. (T_{ce})	Hot water flow rate (m_h)	Cold water flow rate (m_c)
1						
2						
3						
4						

CALCULATIONS:

First we find Log mean Temperature difference

$$L.M.T.D = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)}$$

$$\theta_1 = t_{hi} - t_{ci}$$

$$\theta_2 = t_{he} - t_{ce}$$

$$q_h = m_h C_{ph}(t_{hi} - t_{he})$$

$$q_c = m_c C_{pc}(t_{ce} - t_{ci})$$

Thus

$$q_{actual} = \frac{q_h + q_c}{2}$$

Now we can find Overall heat transfer Co-efficient

$$U = \frac{q_{actual}}{A \times LMTD}$$

$$L.M.T.D = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)}$$

$$A_i = \pi \times d_i \times L$$

where,

d_i = Inner diameter of pipe in mm

L = Length of Pipe in mm

Therefore,

$$\text{effectivness of heat Exchanger } \varepsilon = \frac{q_{actual}}{q_{max}}$$

$$= \frac{q_{actual}}{C_{min}(Th_i - Tc_i)}$$

Where C_{min} = Minimum of $m_h C_{ph}$ or $m_h C_{pc}$

RESULT:

In case of Parallel flow heat exchanger

(i) LMTD………………………

(ii) The overall heat transfer Co-efficient U is ………………………

(iii) The effectiveness is ………………………

PRECAUTIONS:

1. Ensure that before starting practical all connection of apparatus should be properly tight.
2. Reading should be taken very carefully.
3. Give sufficient time to boil the water.

EXPERIMENT – 9

OBJECTIVE:

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

APPARATUS USED:

Stefan's Boltzmann apparatus, Water tank.

Description of Apparatus:

1. Stainless steel tank of about 360 mm diameter and 550 mm depth provided with an immersion heater coil of about 2 kw capacities.
2. Heat is controlled by the thermostat.
3. Thermocouples are fitted at different locations on the enclosure to sense inside surface temperature.
4. Test disc with black surface and a thermocouple fitted at the centre
5. The temperature indicator to read the temperature of enclosure and the disc.

Specification of Apparatus:

Diameter of the disc	20 mm
Thickness of the disc	15 mm
Mass of the disc	0.098 kg
Specific heat of material C_p	380 g/kg°c
Thermocouple	K-type (Cr.Al)
Heater	Immersion type (400 Watt)

THEORY:

Stefan's Boltzmann law state that the thermal radiation heat flux emitted from a black surface is proportional to The fourth power of the absolute temperature of the surface.

$$E_b \propto T^4$$

$$E_b \propto T^4$$

where ,

T = Absolute surface temperature.

E_b = the emissive power of black surface

PROCEDURE:

1. Fill the steel tank with water more than half of its capacity.
2. Set the thermostat at about desired temperature.
3. Check the leakage of current and make proper earthling connecting.
4. Wait till the temperature of water reach the set valve heater' will get off automatically at set point.
5. Record the test disc temperature.
6. Introduce the test disc, item the position with thermocouple leads connected to the temperature indicator and record time in seconds when temperature indicator shows change in temperature.

OBSERVATIONS:

S. No.	Time of rise in temp. in second.	T_1 in °C	T_2 in °C	T_3 in °C	T_4 in °C	T_5(initial) in °C	T_5(final) in °C
1							
2							
3							
4							

CALCULATIONS:

$$t_s = \frac{t_1 + t_2 + t_3 + t_4}{4} \text{ in °C}$$

$$\text{Area of disc} = \pi \times \frac{d^2}{4} \text{ in m}^2$$

$$\sigma = \frac{m \times Cp(T_{5final} - T_{5initial})}{A \times (T_s^4 - T_{sfinal}^4)} \text{w/m}^2\text{K}^4$$

RESULT:

1. The experimental value of Stefan's Boltzmann constant is σ = ...
2. The actual value of Stefan's Boltzmann constant is $\sigma = 5.67 \times 10^{-8}$ w/m²K⁴

PRECAUTIONS:

1. Ensure that before starting practical all connection of apparatus should be properly tight.
2. Reading should be taken very carefully.
3. Ensure that no water is available in the hemisphere before starting the practical.

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