File No:

SRI KRISHNA INSTITUTE OF TECHNOLOGY, BENGALURU

COURSE PLAN

Academic Year 2019 – 20

Program:	B E
Semester :	6/A
Course Code:	17MEL67
Course Title:	Heat Transfer Lab
Credit / L-T-P:	2/ 1-0-2
Total Contact Hours:	30
Course Plan Author:	APPESE S D

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Table of Contents

17MEL67: Heat Transfer Lab

A. LABORATORY INFORMATION

1. Lab Overview

Degree:	BE	*Program:*	ME
Year / Semester :	3 / 6	*Academic Year:*	2019-20
Course Title:	Heat Transfer Lab	*Course Code:*	17MEL67
Credit / L-T-P:	2 / 1-0-2	*SEE Duration:*	180 Minutes
Total Contact Hours:	30 Hrs	*SEE Marks:*	60
CIA Marks:	40	*Assignment*	1
Course Plan Author:	Mr. Appese S D	*Sign*	Dt:
Checked By:	Mr. Naveen Kumar P	*Sign*	Dt :

2. Lab Content

Unit	Title of the Experiments	Blooms Level
	Part-A	
1	Determination of Thermal Conductivity of a Metal Rod.	L3
2	Determination of Overall Heat Transfer Coefficient of a Composite wall	L3
3	Determination of Effectiveness on a Metallic fin.	L3
4	Determination of Heat Transfer Coefficient in a free Convection	L3
5	Determination of Heat Transfer Coefficient in a Forced Convention Flow through a Pipe.	L3
6	Determination of Emissivity of a Surface.	L3
7	Analysis of steady and transient heat conduction, temperature distribution of plane wall and cylinder using Numerical approach (ANSYS/CFD package).	L3
	Part-B	
1	Determination of Steffan Boltzmann Constant.	L3
2	Determination of LMDT and Effectiveness in a Parallel Flow and Counter Flow Heat Ex-changers.	L3
3	Experiments on Boiling of Liquid and Condensation of Vapour.	L3
4	Performance Test on a Vapour Compression Refrigeration	L3
5	Performance Test on a Vapour Compression Air – Conditioner	L3
6	Experiment on Transient Conduction Heat Transfer.	L3
7	Determination of temperature distribution along a rectangular and circular fin subjected to heat loss through convection using Numerical approach (ANSYS/CFD package)	L3

3. Lab Material

Unit	Details	Available
1	Text books	
	M. Necati Ozisik, Heat Transfer – A Basic Approach, McGraw Hill, New York,2005.	In Lib
2	Incropera, F. P. and De Witt, D. P., Fundamentals of Heat and Mass Transfer, 5th Edition, John Wiley and Sons, New York, 2006.	In Lib
3	Holman, J. P., Heat Transfer, 9th Edition, Tata McGraw Hill, New York, 2008.	In Lib/Dept Lib

4. Lab Prerequisites: Performance Test on a Vapour Compression Refrigeration

SNo	Course Code	Course Name	Topic / Description	Sem	Remarks
1	17ME33	Basic thermodynamics	Fundamentals, Work and Heat Interactions	3	-
2	15MEL57	Fluid mechanics	Fluid properties, Fluid flows, variation in fluid flows, turbulent and laminar flow.	4	-

5. General Instructions

S No	Forced convection systems applicable for extremely high temperatures for functions Instructions	Remarks
1	Observation book and Lab record are compulsory.	
2	Students should report to the concerned lab as per the time table.	
3	After completion of the program, certification of the concerned staff in-charge in the observation book is necessary.	
4	Student should bring a notebook of 100 pages and should enter the readings /observations into the notebook while performing the experiment.	
5	The record of observations along with the detailed experimental procedure of the experiment in the Immediate last session should be submitted and certified staff member in-charge.	
6	Should attempt all problems / assignments given in the list session wise.	
7	It is responsibility to create a separate directory to store all the programs, so that nobody else can read or copy.	
8	When the experiment is completed, should disconnect the setup made by them, and should return all the components/instruments taken for the purpose.	
9	Any damage of the equipment or burn-out components will be viewed seriously either by putting penalty or by dismissing the total group of students from the lab for the semester/year	
10	Completed lab assignments should be submitted in the form of a Lab Record in which you have to write the algorithm, program code along with comments and output for various inputs given	

6. Lab Specific Instructions

S No	Specific Instructions	Remarks
1	Students must attend the lab classes with ID cards and in the prescribed uniform.	
2	Students must check if the components, instruments and machinery are in working condition before setting up the experiment.	
3	Power supply to the experimental set up/ equipment/ machine must be switched on only after the faculty checks and gives approval fording the experiment. Students must start to the experiment. Students must start doing the experiments only after getting permissions from the faculty.	
4	Students may contact the lab in charge immediately for any unexpected incident sand emergency	
5	The apparatus used for the experiments must be cleaned and returned to the technicians, safely without any damage	
6	Make sure, while leaving the lab after the stipulated time, that all the power connections are switched off	

B. OBE PARAMETERS

1. Lab / Course Outcomes

S no	CO s	Teach. Hours	Instr Method	Assessment Method	Blooms' Level
CO1	Perform experiments to determine the thermal conductivity of a metal rod	6	Demonstration, Video, chalk and Board	Practical record and IA test	L3
CO2	Conduct experiments to determine convective heat transfer coefficient for free and forced convection and correlate with theoretical values.	6	Demonstration, Video, chalk and Board	Practical record and IA test	L3
CO3	Estimate the effective thermal resistance in composite slabs and efficiency in pin-fin	6	Demonstration, Video, chalk and Board	Practical record and IA test	L3
CO4	Determine surface Emissivity of a test plate	6	Demonstration, Video, chalk and Board	Practical record and IA test	L3
CO5	Estimate performance of a refrigerator and effectiveness of fin	6	Demonstration, Video, chalk and Board	Practical record and IA test	L3
-	**Total**	**30**	**-**	**-**	**-**

2. Lab Applications

S No	Application Area	Level
1	Air conditioning, Fins in all system, Fans, refrigerator, Engine Radiators, cooling heat pipes in electronic Appliances,	L3
2	To compute the heat flux at any location, compute the thermal stress, design of insulation thickness, chip temperature calculation, heat treatment of metals.	L3
3	Buildings, Mechanical systems, Refrigeration, Spacecraft, Automotive	L3
4	Metallurgy, heat treating process applications.	L3
5	2-D study state heat conduction equation is applied in CFD analysis(Finite difference and finite element method)	L3
6	Solar flat plate collector, water heating process (solar pond), photo voltaic cell.	L3
7	To compute the heat flux at any location, compute the thermal stress, design of insulation thickness, chip temperature calculation, heat treatment of metals.	L3
8	Forced convection systems applicable for extremely high temperatures for functions	L3
9	Establishing temperature distribution within building, determining heat loss calculations, ventilating and air-conditioning system.	L3
10	Boiling and condensation knowledge is applicable to calculate critical heat flux, and condensation rate in heat transfer problems.	L3
11	LMTD and NTU methods for analysis of heat ex-changers.	L3
12	Buildings, Mechanical systems, Refrigeration, Spacecraft, Automotive	L3

3. Articulation Matrix

(CO – PO MAPPING)

-	Course Outcomes	Program Outcomes												
#	COs	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12	Level
CO1	Perform experiments to determine the thermal conductivity of a metal rod	√	√	-	-	-	-	-	-	√	-	-	-	L3
CO2	Conduct experiments to determine convective heat transfer coefficient for free and forced convection and correlate with theoretical values.	√	√	-	-	-	-	-	-	√	-	-	-	L3
CO3	Estimate the effective thermal resistance in composite slabs and efficiency in pin-fin	√	√	-	-	-	-	-	-	√	-	-	-	L3
CO4	Determine surface Emissivity of a test plate	√	√	-	-	-	-	-	-	√	-	-	-	L3
CO5	Estimate performance of a refrigerator and effectiveness of fin	√	√	-	-	-	-	-	-	√	-	-	-	L3

4. Mapping Justification

Mapping		Mapping Level	Justification
CO	**PO**	**-**	**-**
CO1	PO1	L2	Knowledge of engineering fundamentals is required to understand the thermal conductivity .
CO1	PO2	L3,L4	Analyzing problem in thermal conductivity of a given metal rods.
CO1	PO9	L3	Individual work, mapping
CO2	PO1	L2	Knowledge of engineering fundamentals is required to understand the temperature difference between different layers of composite walls.
CO2	PO2	L3,L4	Analyzing overall heat transfer coefficient in a different composite walls.
CO2	PO9		Individual work, mapping
CO3	PO1	L2	Knowledge of temperature difference is required to understand thermal resistance.
CO3	PO2	L3,L4	Analyzing surface heat transfer coefficient for a fin loosing heat by forced convection.
CO3	PO9	-	Individual work, mapping
CO4	PO1	L2	Knowledge of modes of heat transfer is required to understand convective heat transfer coefficient
CO4	PO2	L3,L4	Analyzing heat transfer inn liquids and gasses.
CO4	PO9	-	Individual work, mapping
CO5	PO1	L2	Knowledge of Newtons law of cooling is required to understand rate of convective heat transfer.
CO5	PO2	L3,L4	Analyzing solid surface to fluid layer by conduction.
CO5	PO9	-	Individual work, mapping

C. COURSE ASSESSMENT

1. Course Coverage

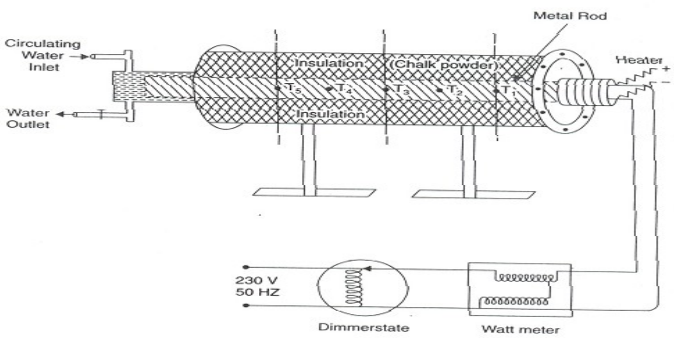
Unit	Title	Teaching Hours	No. of question in Exam							Levels
			CIA-1	CIA-2	CIA-3	Asg-1	Asg-2	Asg-3	SEE	
	PART-A									
1	Determination of Thermal Conductivity of a Metal Rod.	03	1	-	-	-	-	-	1	L3
2	Determination of Overall Heat Transfer Coefficient of a Composite wall	03	1	-	-	-	-	-	1	L3
3	Determination of Effectiveness on a Metallic fin.	03	1	-	-	-	-	-	1	L3
4	Determination of Heat Transfer Coefficient in a free Convection	03	1	-	-	-	-	-	1	L3
5	Determination of Heat Transfer Coefficient in a Forced Convention Flow through a Pipe.	03	1	-	-	-	-	-	1	L3
6	Determination of Emissivity of a Surface.	03	1	-	-	-	-	-	1	L3
7	Analysis of steady and transient heat conduction, temperature distribution of plane wall and cylinder using Numerical approach (ANSYS/CFD package).	03	-	-	-	-	-	-	1	L3
	PART-B									
1	Determination of Steffan Boltzmann Constant.	03	1	-	-	-	-	-	1	L3
2	Determination of LMDT and Effectiveness in a Parallel Flow and Counter Flow Heat Ex-changers.	03	1	-	-	-	-	-	1	L3
3	Experiments on Boiling of Liquid and Condensation of Vapour.	03	1	-	-	-	-	-	1	L3
4	Performance Test on a Vapour Compression Refrigeration	03	1	-	-	-	-	-	1	L3
5	Performance Test on a Vapour Compression Air – Conditioner	03	1	-	-	-	-	-	1	L3
6	Experiment on Transient Conduction Heat Transfer.	03	1	-	-	-	-	-	1	L3
7	Determination of temperature distribution along a rectangular and circular fin subjected to heat loss through convection using Numerical approach (ANSYS/CFD package)	03	1	-	-	-	-	-	1	L3
-	**Total**	**42**								-

2. Continuous Internal Assessment (CIA)

Evaluation	Weight age in Marks	CO	Levels
CIA Exam – 1	30	CO1, CO2, CO3, CO4,CO5	L3
Assignment – 1	5	CO1, CO2, CO3, CO4,CO5	L3
Other Activities – define – Slip test	5	CO1 to CO5	L3
Final CIA Marks	**40**	**-**	**-**

D. EXPERIMENTS

Experiment 01: Determination of Thermal Conductivity of a Metal Rod.

-	**Experiment No.:**	1	**Marks**		**Date Planned**		**Date Conducted**	
1	Title	Determination of Thermal Conductivity of a Metal Rod						
2	Course Outcomes	Perform experiments to determine the thermal conductivity of a metal rod						
3	Aim	To determine the thermal conductivity of the given metal rod						
4	Material / Equipment Required	Metal rod, Heater, Rota-meter, Thermocouples, Power supply panel, etc.						
5	Theory, Formula, Principle, Concept	Thermal conductivity is a physical property of a material and depends on the chemical composition of the substance, the phase (solid, liquid or gas) in which it exists, its crystalline structure if a solid, the temperature and pressure to which it is subjected, and whether or not it is homo-genetic material.						
6	Procedure, Program, Activity, Algorithm, Pseudo Code	1. Note down the specifications of the equipment. 2. Switch on the mains, Heater and maintain a steady water flow, say 0.5 LPM to 1LPM through the rota-meter. 3. Set the temperature to a particular safe value through Dimmer stat. 4. After steady state conditions are established (around 20 minutes), record the temperatures of Thermocouples along the rod T_2 – T_7 and T_8 (water inlet) and T_9 (water outlet) temperatures. 5. Repeat the experiment for various input conditions (V and I) to obtain the thermal conductivity of the rod at the corresponding average temperatures in each case.						
7	Block, Circuit, Model Diagram, Reaction Equation, Expected Graph							

8 Observation Table, Look-up Table, Output

Sl. no	Mass flow rate		Volt	Amp	room temp	Surface temp. of metal rod						Water temp.		Q_{theo} V × I (W)	Q_{act} (W)	Thermal conductivity k (W/m-k)
	lpm	Kg/s	'V'	'I'	T_1	T_2	T_3	T_4	T_5	T_6	T_7	inlet T_8	ourlet T_9			

9 Sample Calculations

- 1. Heat input rate, Q_{th} = V *x* I (W)
- Where V = Voltage. (Volts)
- I = Current (amps)

2. Heat absorbed by water, $Q_{act} = m\, C_p\, (T_8 - T_9)$

- Where m = mass flow rate of water. (Kg/s)
- C_p = specific heat of water = 4.178 (KJ/ kg –K)
- $(T_8 - T_9)$ = difference between of water at inlet and outlet.(K)

3. Area of cross section of metal rod, $A = \frac{\pi . d^2}{4}$ = ________ m^2

- d = Diameter of the rod in. m.

4. Plot the graph of temperature T v/s distance X (Fig 1.2), from the best fitting straight line for temperatures T_2, T_3, T_4, T_5, T_6 and T_7, Average temperature gradient (slope). $\frac{dT}{dX}$ is calculated.

5. Heat transfer through metal rod is given by $Q_{act} = -kA \frac{dT}{dX}$

Hence, $k = -\frac{Q_{act}}{A \frac{dT}{dX}}$

Where k = Thermal conductivity

A = Area of cross section of metal rod.

$\frac{dT}{dX}$ = slope from graph T vs L

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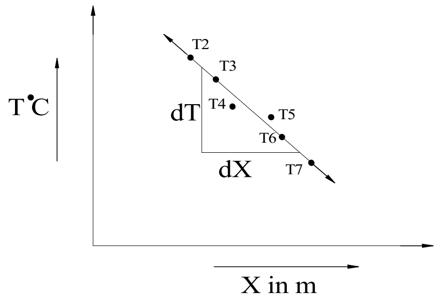
10	Graphs, Outputs	
11	Results & Analysis	The thermal conductivity of given material was found to be k = _____W/ m-K. **Point for Discussion** Compare the experimental value of k with the standard value at the average temperature of the set of observations. Is there any specific reason why the water jacket is circulated on one end of the rod. Comment on it.
12	Application Areas	Air conditioning, Fins in all system, Fans, refrigerator, Engine Radiators, cooling heat pipes in electronic Appliances,
13	Remarks	
14	Faculty Signature with Date	

Experiment 02 : Determination of Overall Heat Transfer Coefficient of a Composite wall

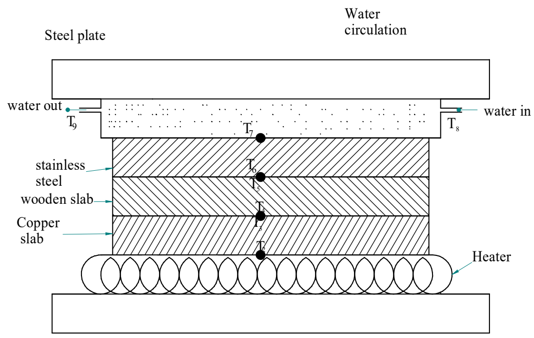
-	**Experiment No.:**	2	**Marks**		**Date Planned**		**Date Conducted**	
1	Title	Determination of Overall Heat Transfer Coefficient of a Composite wall						
2	Course Outcomes							
3	Aim	To Determine the overall heat Transfer coefficient of a composite wall						
4	Material / Equipment Required	Given Composite wall, Heater, Set of Thermocouples, Power Supply panel, Channel Temperature Indicator and necessary connections.						
5	Theory, Formula, Principle, Concept	The composition of two or more materials of different thermal conductivity arranged in series or parallel is called composite material (wall).Many engineering applications of practical utility involve heat transfer through composite materials. Consider for example, the wall of a refrigerator, hot cases; cold storage plants hot water tanks, etc., which always have some kind of insulating material between the inner and outer walls. The procedure for solving one-dimensional, steady state heat conduction problems for composite systems comprising parallel plates, coaxial cylinders or concentric spheres. It will be assumed that the parallel layers in the composite system are in perfect thermal contact or the resistance due to interface contact is negligible, i.e, the temperature continuous at the interface of two layers in contact.						

6 Procedure, Program, Activity, Algorithm, Pseudo Code

- Switch on the mains and console.
- Set the water flow rate to 1-2 lpm (Fixed).
- The heat input to the heater is fixed for any desired value.
- After steady state is reached, average temperature of the slabs at the inter faces are noted.
- By varying the heat input to the system through variac, different sets of readings can be obtained.

  Repeat the above operations for given Heat inputs.

7 Block, Circuit, Model Diagram, Reaction Equation, Expected Graph



8 Observation Table, Look-up Table, Output

Sl No	Voltage 'V' Volts	Current 'I' Amps	Temperatures (^{0}C)							Water inlet temperature T_8(^{0}C)	Water outlet temperature T_9(^{0}C)
			T_1	T_2	T_3	T_4	T_5	T_6	T_7		

9 Sample Calculations

(a) Heat flow through composite wall Q = V x I. (W)

$$Q = \frac{k_1 A_1 (T_2 - T_3)}{L_1} = \frac{k_2 A_2 (T_4 - T_5)}{L_2} = \frac{k_3 A_3 (T_6 - T_7)}{L_3} \quad ....(1)$$

k_1= Thermal conductivity of Mild steel. L_1 = thickness of Mild Steel.

k_2 = Thermal conductivity of Wood. L_2 = thickness of wood.

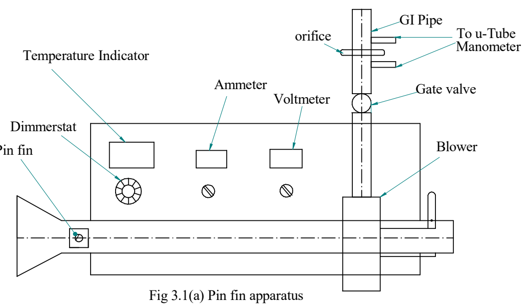
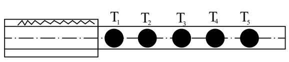
k_3 = Thermal conductivity of copper. L_3 = thickness of copper.

From equation..(1)

		$k_1 = \dfrac{QL_1}{A_1(T_2 - T_3)}$, Where A= $\dfrac{\pi . d^2}{4}$ d = Diameter of the slab $k_2 = \dfrac{QL_2}{A_2(T_4 - T_5)}$, $A_1 = A_2 = A_3 = A$. $k_3 = \dfrac{QL_3}{A_3(T_6 - T_7)}$, (b) Overall heat transfer coefficient (U_o) $1/U_o = \dfrac{L_1}{k_1} + \dfrac{L_2}{k_2} + \dfrac{L_3}{k_3}$, $(\dfrac{W}{m^2 - K})$
10	Graphs, Outputs	**Result:** The Overall heat transfer co-efficient of given composite slab was found to be U_0 = _____W/ m-K. **Points for discussion:-** 1) Comment on the experimental set up,its validity and accuracy. 2) Overall heat transfer co-efficient can also be calculated without the requirement of intermediate temperatures. comment on it.
11	Results & Analysis	
12	Application Areas	To compute the heat flux at any location, compute the thermal stress, design of insulation thickness, chip temperature calculation, heat treatment of metals.
13	Remarks	
14	Faculty Signature with Date	

Experiment 03: Determination of Effectiveness of a Metallic fin.

-	Experiment No.:	3	Marks		Date Planned		Date Conducted	
1	Title	Determination of Effectiveness on a Metallic fin.						
2	Course Outcomes	Estimate the effective thermal resistance and efficiency in pin-fin						
3	Aim	To determine the efficiency and effectiveness of the fin by natural convection and forced convection using pin fin apparatus.						
4	Material / Equipment Required	The experimental set up consists of a blower unit having a rectangular duct inside which the pin fin is fitted. One end of the pin fin is connected to heater. Five Thermocouples are embedded on the fin surface. Blower along with the orifice is used to measure flow of air through the duct. Input to heater is given through dimmer stat and measured by voltmeter and ammeter. Air flow is controlled by the gate valve and is measured with the help of orifice meter and the manometer fitted on the board.						
5	Theory, Formula,	(i) Fins are extended surfaces which are used to increase the rate of heat transfer						

	Principle, Concept	between a surface and the adjacent fluid. Fins are classified into three viz. angular fins, straight fins and pin-fins. Angular fins are fixed to cylindrical surfaces, straight fins and pin fins are fixed to plane surfaces. Fins are used in I.C. Engines, Compresses, Radiation, Heat exchanges etc. (ii) Natural convection is the heat transfer between a surface and adjacent fluid particles due to the macroscopic motion of fluid particles, set up by buoyancy effect resulting from the density difference caused by their temperature difference, (iii) Fin effectiveness is the ratio of heat transfer with the fin to the heat transfer without fin, It is denoted by, Γ = $\dfrac{\tanh(ml)}{\sqrt{\dfrac{h.A}{k_f.P}}}$. (iv) Fin efficiency is the ratio of heat lost from the fin to the heat that would be lost when the entire surface of the fin is under base temperature, it is given by η = $\dfrac{\tanh ml}{ml}$.
6	Procedure, Program, Activity, Algorithm, Pseudo Code	*(a) Natural Convection:* 1. Switch on the supply and adjust the variac to obtain the required heat input. 2. Note down the following readings after reaching the steady state: (i) Voltmeter reading 'V' volts (ii) Ammeter reading 'A' amps (iii) Thermocouples readings (T_1 to T_6)^{0}C. 3. Repeat the procedure for different heat inputs and tabulate the readings. *(b) Forced Convection:* 1. Switch on the supply and adjust the variac to obtain the required heat input. 2. Start the blower, set the manometer head as required. 3. Note down the following readings after reaching the steady state: (i) Voltmeter reading 'V' volts (ii) Ammeter reading 'A' amps (iii) Thermocouples readings (T 1 to T 6)^{0}C. (iv) Manometer reading ‘h’ cm. Repeat the procedure for different heat inputs and tabulate the readings
7	Block, Circuit, Model Diagram, Reaction Equation, Expected Graph	 Fig 3.1(a) Pin fin apparatus  Fig 3.2(b) Pin fin enlarged

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8 Observation Table, Look-up Table, Output

Sl. No.	Voltage (V) Volts	Current amps	Power Q=VI Watts	Temperature at different point in the outer surface of cylinder (ºC)						h_{the} W/m^2-K	η_{the} (%)	η_{exp} (%)	ε
					T_2	T_3	T_4	T_5	T_6				

9 Sample Calculations

(1) Experimental Efficiency of pin fin(η_{exp})

The efficiency of the pin fin experimentally is given by

$$\eta_{exp} = \frac{Q_{fin}}{(Q_{fin})_{max}}$$

Where, Q_{fin} = V x I, W

$(Q_{fin})_{max} = h_{exp}.A_S.(T_s - T_a) + \sigma.A_S.(T_s^4 - T_a^4)$, W

But, $h_{exp} = Q_{fin} / \{A_s (T_s - T_a)$

$A_S = \pi.d.l.$ (m^2)

(2) Theoretical Efficiency of pin fin(η_{the})

$$\eta_{the} = \frac{\tanh ml}{ml}$$

Where, $m = \sqrt{\frac{h.P}{k_f.A}}$

h = heat transfer coefficient of fin

P = Perimeter of fin (πD)

k_f = thermal conductivity of pin fin = 110 ($\frac{W}{m-K}$)

A= Area of fin = $\frac{\pi.d^2}{4}$, (d = Diameter of the pin fin, m), m^2

l = Length of pin fin, m

To find heat transfer coefficient of fin(h)

1) Film temperature, $T_f = \frac{Ts + Ta}{2}$ (°C)

Where, T_s = Surface temperature of the cylinder = $\frac{T_2+T_3+T_4+T_5+T_6}{5}$ (K)

$T_a = T_1$, ambient temperature (K)

Properties of air at the film temperature (T_f) is obtained from data book, hence determine

Kinematic viscosity, v = Thermal conductivity, k =

Prandtl number, Pr =

(ii) Grassoff number Gr = $\frac{g.\beta.\Delta T.d^3}{\nu^2}$

Where,

β = Co-efficient of thermal expansion = $\frac{1}{(T_f+273)}$. (K^{-1})

$\Delta T = T_f - T_1$. (K)

d = Diameter of the pin fin. (m)

v = Kinematic viscosity. (m^2/s) ×

∴ Ra. No= Gr *x* Pr =

From heat transfer Data hand book corresponding to this value of Rayleigh number Ra, the nusselt number(Nu) is given by

Forced convection systems applicable for extremely high temperatures for functions

For $10^{-1} < Gr \times Pr < 10^4$, $Nu = 0.68 + \frac{0.67 \times (Gr \times \Pr)^{0.25}}{\left\{1+\left[\frac{0.492}{\Pr}\right]^{0.5625}\right\}^{0.444}}$

For $10^4 < Gr \times Pr < 10^9$, $Nu = 0.59\,(Gr \times x\,Pr)^{0.25}$

For $10^9 < Gr \times Pr < 10^{12}$, $Nu = 0.13\,(Gr\,x\,Pr)^{0.33}$

Hence,

$Nu = \frac{h.l}{k}$. Or

$h = \frac{Nu.k}{l}$.

Where, $h = h_{the}$ = natural heat transfer co-efficient, ($\frac{W}{m^2-K}$)

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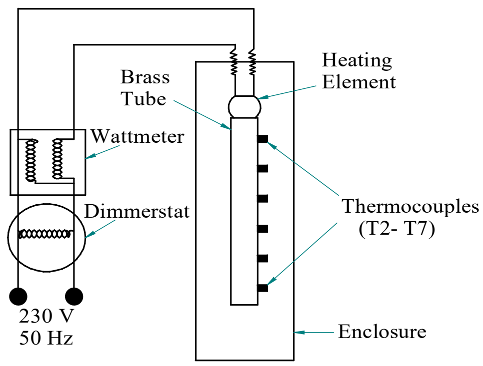
		(3) Effectiveness of Fin, $\varepsilon = \dfrac{\tanh(ml)}{\sqrt{\dfrac{h.A}{k_f.P}}}$
10	Graphs, Outputs	
11	Results & Analysis	**Result:-** *free convection* h_{the} = ______ , η_{exp} = _______ , ε = ______ *forced convection* h_{the} = ______ , η_{exp} = _______, ε = ______ **Points for discussion:-** (1) If the readings are taken when the steady state is yet to be reached,how will the accuracy of the results will be affected. (2) From the observations taken in this experiment, explain how would you determine the thermal conductivity of the material of the fin.
12	Application Areas	Buildings, Mechanical systems, Refrigeration, Spacecraft, Automotive
13	Remarks	
14	Faculty Signature with Date	

Experiment 04 :Determination of Heat Transfer Coefficient in a free Convection

-	**Experiment No.:**	4	**Marks**		**Date Planned**		**Date Conducted**	
1	Title	Determination of Heat Transfer Coefficient in a free Convection						
2	Course Outcomes	Conduct experiments to determine convective heat transfer coefficient						
3	Aim	To determine Heat Transfer Coefficient in a free Convection						
4	Material / Equipment Required	The apparatus consists of a brass tube fitted in a rectangular duct in a vertical position. The duct is open at the top and bottom and forms an enclosure and serves the purpose of undisturbed surrounding. An electric heating element is kept in the vertical tube which in turn heats the tube surface. The heat is lost from the tube to the surrounding air by natural convection. The temperature of the vertical tube is measured by six Thermocouples. The heat input to the heater is measured by an Ammeter and a Voltmeter and is varied by a dimmer stat. The tube surface is polished to minimize the radiation losses.						
5	Theory, Formula, Principle, Concept	natural convection is the mode of heat transfer from hot radiators, refrigerating coils etc. It is heat transfer between a surface and adjacent fluid particles due to the macroscopic motion of fluid particles, set up by buoyancy effect resulting from the density difference caused by their temperature difference. The heat transfer rate (Q) in free convection is given by Newton's law of cooling given by $Q = hA_s(T_s - T_\infty)$ Where, A_s - Surface area. (m^2)						

<table>
<tr><td></td><td></td><td>(T_s - T_∞) - Temperature difference between the surface and fluid. (K)
h - Heat transfer co-efficient (usually 5 to 25 ($\frac{W}{m^2 - K}$) for natural convection for air)</td></tr>
<tr><td>6</td><td>Procedure, Program, Activity, Algorithm, Pseudo Code</td><td>1. Switch on the electric heater and adjust the auto transformer.
2. Wait for steady state to be reached.
3. Note down the required readings like Voltage, Current and Thermocouples readings
$T_2 - T_7$ along the rod
4. Calculate heat transfer co-efficient for natural convection.
5. Also determine the heat transfer co-efficient using the empirical relation compare
the values.</td></tr>
<tr><td>7</td><td>Block, Circuit, Model Diagram, Reaction Equation, Expected Graph</td><td>


</td></tr>
<tr><td>8</td><td>Observation Table, Look-up Table, Output</td><td>
<table>
<tr><td rowspan="2">Sl. No.</td><td rowspan="2">Voltage (V) Volts</td><td rowspan="2">Current amps</td><td rowspan="2">Power Q=VI Watts</td><td colspan="8">Temperature at different point in the outer surface of cylinder (°C)</td><td rowspan="2">Manometer Readings H_w= (h_1+ h_2) x 10^{-3}, m</td><td colspan="2">Heat transfer co-efficient W/m²-K</td></tr>
<tr><td>T1</td><td>T_2</td><td>T_3</td><td>T_4</td><td>T_5</td><td>T_6</td><td>T_7</td><td>T_8</td><td>h_{exp}</td><td>h_{the}</td></tr>
</table>
</td></tr>
</table>

9 Sample Calculations

I. *Experimental Method*

Experimental heat transfer co-efficient, $h_{exp} = \dfrac{Q}{A_S(T_S - T_a)}$.

Where

Q = Rate of heating, = V x I, watts.

A =πdl,

Where,

d = Diameter of cylinder rod. (m)

l = length of cylinder. (m)

II. Analytical (Theoretical) Method

(i) Film temperature, $T_f = \dfrac{T_S + Ta}{2}$. (°C)

T_s = Surface temperature of the cylinder = $\dfrac{T_2 + T_3 + T_4 + T_5 + T_6 + T_7 + T_8}{7}$ (ºC)

T_a = ambient temperature. (ºC)

Properties of air at the film temperature (T_f) is obtained from data book, hence determine

Kinematic viscosity, v = Thermal conductivity, k =

Prandtl number, Pr =

(ii) Grassoff number Gr = $\dfrac{g.\beta.\Delta T.l_c^3}{\nu^2}$

Where,

β = Co-efficient of thermal expansion = $\dfrac{1}{(T_f + 273)}$. (K^{-1})

ΔT = $T_f - T_1$. (K)

l_c = characteristic length = length of the vertical cylinder . (m)

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

Ra.No = Gr *x* Pr =

From heat transfer Data hand book corresponding to this value of Rayleigh number Ra, the nusselt number(Nu) is given by

For 10^{-1} < Gr *x* Pr < 10^4, search a suitable correlation from data hand book.

For 10^4 < Gr *x* Pr < 10^9, Nu = 0.59 (Gr × Pr)$^{0.25}$

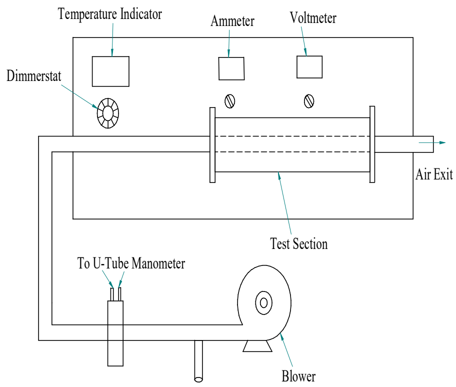
For 10^9 < Gr *x* Pr < 10^{12}, Nu = 0.13 (Gr × Pr)$^{0.33}$

Hence,

		Nu = $\frac{h_{theo}.d}{k}$. or h_{the} = $\frac{Nu.k}{l}$. Where, h_{the} = Theoretical heat transfer co-efficient, ($\frac{W}{m^2-K}$) The heat transfer co-efficient for the vertical tube was found to be _______ $\frac{W}{m^2-K}$
10	Graphs, Outputs	
11	Results & Analysis	**Result :** The co-efficient of heat transfer by experiment is h_{exp} = The co-efficient of heat transfer by theoretical is h_{theo} = **Points for Discussion :** 1. List of various precautions observed during experimentation. 2. Comment upon the values of heat transfer coefficient obtained experimentally and the one by using correlations.
12	Application Areas	Metallurgy, heat treating process applications.
13	Remarks	
14	Faculty Signature with Date	

Experiment 05 :Determination of Heat Transfer Coefficient in a Forced Convention Flow through a Pipe

-	**Experiment No.:**	5	**Marks**		**Date Planned**		**Date Conducted**	
1	Title	Determination of Heat Transfer Coefficient in a Forced Convention Flow through a Pipe						
2	Course Outcomes	Conduct experiments to determine convective heat transfer coefficient for forced convection.						
3	Aim	To determine the Forced Convection heat transfer coefficient for flow through the given Horizontal tube cylinder						
4	Material / Equipment Required	The experimental set up consists of a blower unit fitted with the test pipe. The test section is surrounded by band heater. Seven thermocouples are embedded on the test section and two thermo couples are placed in the air stream at the entrance and exit of the test section to measure the air inlet and outlet temperatures. Test pipe is connected to the delivery side of the blower along with the orifice to						

		measure flow of air through the pipe. Input to heater is given through dimmerstat and measured by voltmeter and ammeter. Air flow is controlled by the gate valve and is measured with the help of orifice meter and the manometer fitted on the board.
5	Theory, Formula, Principle, Concept	
	Procedure, Program, Activity, Algorithm, Pseudo Code	
7	Block, Circuit, Model Diagram, Reaction Equation, Expected Graph	 
8	Observation Table, Look-up Table, Output	
9	Sample Calculations	I. Experimental Method Experimental heat transfer co-efficient, $h_{exp} = Q / A_s (Ts - Ta)$ Where Q = Rate of heating, = V x I, watts. $A_s = \pi dl$, Where, d = Diameter of cylinder rod l = length of cylinder II. Analytical (Theoretical) Method

		(1) Bulk mean temperature, $T_f = T_1+T_7 / 2$. (°C) Where, T_1 = Air inlet temperature. (°C) T_7 = Air outlet temperature. (°C) Properties of air at the film temperature (T_f) is obtained from data book, hence determine Density, ρ = Specific heat, C_p = Kinematic viscosity, v = Thermal conductivity, k = Prandtl number, Pr (2) Discharge q = $C_d A_0 \sqrt{2.G.H_a}$ Where, C_d = Co-efficient of discharge = 0.65 $A_0 = \frac{\pi . d_o{}^2}{4}$ d_o = Diameter of orifice H_a = Head of air = $\rho_w H_w / \rho_a$ ρ_w = 1000 kg/m^3 ρ_a = 1.2 kg/m^3 (3) Velocity v = $\frac{q}{A}$. (m/s) (4) Reynold's No. Re = vd / ν Where, d = Diameter of the cylinder, (m) v = Velocity of the air. (m/s) From heat transfer Data hand book corresponding to this value of Reynolds number, the nusselt number(Nu) is given by Nu = 0.618 (Re)$^{0.466}$, if 40 < Re < 4000 Nu = 0.174 (Re)$^{0.618}$, if 4000 < Re < 40,000. Hence, Nu = $\frac{h_{theo} . d}{k}$. Or $h_{theo} = \frac{Nu.k}{d}$. Where, h_{theo} = Theoretical heat transfer co-efficient, $\left(\frac{W}{m^2 - K}\right)$
10	Graphs, Outputs	
11	Results & Analysis	**Result :** The co-efficient of heat transfer by experiment is h_{exp} = The co-efficient of heat transfer by theoretical is h_{theo} = **Points for Discussion :** (1) List of various precautions observed during experimentation. (2)Comment upon the values of heat transfer coefficient obtained experimentally and the one by using correlations.

12	Application Areas	2-D study state heat conduction equation is applied in CFD analysis(Finite difference and finite element method)
13	Remarks	
14s	Faculty Signature with Date	

Experiment 06 : Determination of Emissivity of a Surface.

-	**Experiment No.:**	6	**Marks**		**Date Planned**		**Date Conducted**	
1	Title	Determination of Emissivity of a Surface.						
2	Course Outcomes	Determine surface emissivity of a test plate						
3	Aim	To determine the emissivity of grey body at temperature.						
4	Material / Equipment Required	black body, test body, heater, digital voltmeter Ammeter, control body.						
5	Theory, Formula, Principle, Concept	Thermal Radiation is the energy emitted by a body as a result of its finite temperature. In contrast to heat transfer through convection and conduction, radiation heat transfer does not require a medium and can occur in vacuum. The amount of energy (E) emitted by the surface of a body via radiations is given by " Stefan Boltzmann law" as $E = \varepsilon\sigma T^4$ .... (1) Where, E = Energy emitted per unit surface of the body(Emissive power) σ = Stefan boltzsman constant = 5.669×10^{-8} . ($\frac{W}{m^2 - K^4}$) T = Absolute temperature of the surface. (K). ε = Emissivity of a body. Emissivity(ε) of a body is a dimensionless number and can vary between 0 and 1.A surface with ε =1 is called a perfect radiator and is called as a"**black body**".For real surfaces ε<1. Hence Equation (1) for a black body can be written as $E_b = \sigma T^4$ .... (2) From equations (1) and (2), it follows that $\varepsilon = \frac{E}{E_b}$ .... (3)						
6	Procedure, Program, Activity, Algorithm, Pseudo Code	(1) Switch on the heater to the black-body & adjust the power input to the heater to suitable value using regulator. (2) Switch on the heater to the test body & keep the power input to a value less than that of input to the black body. (3) Observe the temperature of black body & test surface in closed time interval &						

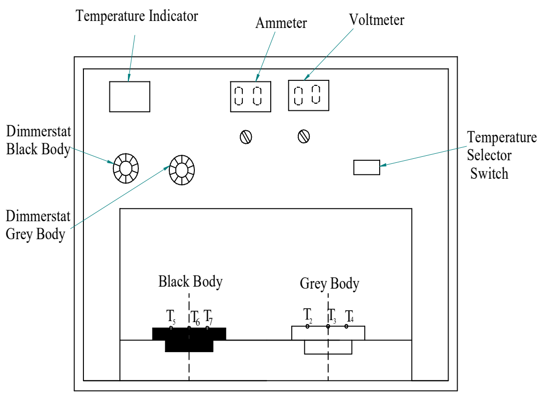
adjust power input to the test body heater such that both black body & test surface temperatures are almost same.

(4) Wait till the steady state is reached, record the input power to heaters & temperature of grey body, black body & enclosure now calculate the Emissivity.

7 Observation Table, Look-up Table, Output

Sl. No	Grey body readings					Black body readings					Room Temp T_1 (°C)	Enclosure Temp. T_8 (°C)	Emissi-vity ε
	Voltage V_2	Current I_2	Surface temp.(°C)			Voltage V_1	Current I_1	Surface temp.(°C)					
			T_2	T_3	T_4			T_5	T_6	T_7			

8 Block, Circuit, Model Diagram, Reaction Equation, Expected Graph



9 Sample Calculations

Heat supplied to grey body - $Q_g = V_g \times I_g$

Also, $Q_g = \varepsilon_g \times \sigma \times A \times (T_g^4 - T_8^4)$.................................. (4)

Where, A_g = area of the grey body

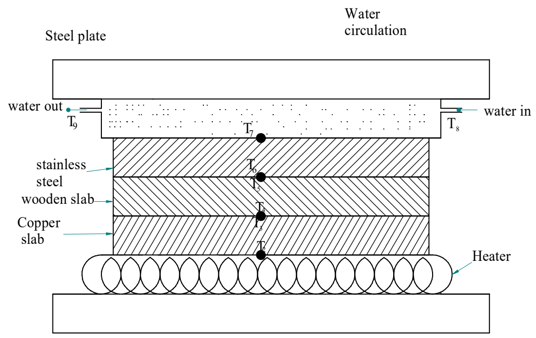
ε_b = Emissivity of Grey body

σ = Stefan boltzsman constant = 5.669×10^{-8}.

T_g = Avg. grey body temperature = $\dfrac{T_2 + T_3 + T_4}{3}$

		T_8 = Enclosure Temperature. Heat supplied to black body- $Q_b = V_b \times I_b$ Also, $Q_g = \varepsilon_b \times \sigma \times A \times (T_b^4 - T_8^4)$ .... (5) Where, A_b= area of the black body ε_b = Emissivity of black body σ = Stefan boltzsman constant = 5.669×10^{-8}. T_b = Avg. black body temperature = $\frac{T_5 + T_6 + T_7}{3}$ T_8 = Enclosure Temperature.
10	Graphs, Outputs	
11	Results & Analysis	Result: - The experiment is successfully completed, the results tabulated in tabular column. The Emissivity of given apparatus is ε_g = __________ Points for Discussion : **1** The value of Emissivity obtained is total is total Emissivity or monochromatic Emissivity. What is the difference between the two. **2** How and under what conditions Emissivity of a surface equals its absorptivity.
12	Application Areas	Solar flat plate collector, water heating process (solar pond), photo voltaic cell.
13	Remarks	
14	Faculty Signature with Date	

Experiment 07 : Analysis of steady and transient heat conduction, temperature distribution of plane wall and cylinder using Numerical approach (ANSYS/CFD package).

-	**Experiment No.:**	7	**Marks**		**Date Planned**		**Date Conducted**	
1	Title	Determination of Overall Heat Transfer Coefficient of a Composite wall						
2	Course Outcomes	Understand Overall Heat Transfer Coefficient of a Composite wall						
3	Aim	Analysis of steady and transient heat conduction, temperature distribution of plane wall and cylinder using Numerical approach (ANSYS/CFD package).						
4	Material / Equipment Required	Given Composite wall, Heater, Set of Thermocouples, Power Supply panel, Channel Temperature Indicator and necessary connections.						
5	Theory, Formula, Principle, Concept	The composition of two or more materials of different thermal conductivity arranged in series or parallel is called composite material (wall). Many engineering applications of practical utility involve heat transfer through composite materials. Consider for example, the wall of a refrigerator, hot cases; cold storage plants hot water tanks, etc., which always have some kind of insulating material between the inner and outer walls. The procedure for solving one-dimensional, steady state heat conduction problems for composite systems comprising parallel plates, coaxial cylinders or concentric spheres. It will be assumed that the parallel layers in the composite system are in perfect thermal contact or the resistance due to interface contact is negligible, i.e, the temperature continuous at the interface of two layers in contact.						
6	Procedure, Program, Activity, Algorithm, Pseudo Code	• Switch on the mains and console. • Set the water flow rate to 1-2 lpm (Fixed). • The heat input to the heater is fixed for any desired value. • After steady state is reached, average temperature of the slabs at the inter faces are noted. • By varying the heat input to the system through variac, different sets of readings can be obtained. Repeat the above operations for given Heat inputs.						
7	Block, Circuit, Model Diagram, Reaction Equation, Expected Graph							

8 Observation Table, Look-up Table, Output

Sl No	Voltage ' V ' Volts	Current ' I ' Amps	Temperatures (^{0}C)							Water inlet temperature T_8(^{0}C)	Water outlet temperature T_9(^{0}C)
			T_1	T_2	T_3	T_4	T_5	T_6	T_7		

9 Sample Calculations

(a) Heat flow through composite wall Q = V x I. (W)

$$Q = \frac{k_1 A_1 (T_2 - T_3)}{L_1} = \frac{k_2 A_2 (T_4 - T_5)}{L_2} = \frac{k_3 A_3 (T_6 - T_7)}{L_3} \quad ....(1)$$

k_1= Thermal conductivity of Mild steel. L_1 = thickness of Mild Steel.
k_2 = Thermal conductivity of Wood. L_2 = thickness of wood.
k_3 = Thermal conductivity of copper. L_3 = thickness of copper.
From equation ..(1)

$$k_1 = \frac{QL_1}{A_1 (T_2 - T_3)}, \quad \text{Where } A = \frac{\pi . d^2}{4}, \text{ d = Diameter of the slab}$$

$$k_2 = \frac{QL_2}{A_2 (T_4 - T_5)}, \quad A_1 = A_2 = A_3 = A.$$

$$k_3 = \frac{QL_3}{A_3 (T_6 - T_7)},$$

(b) Overall heat transfer coefficient (U_o)

$$1/ U_o = \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3} \quad , (\frac{W}{m^2 - K})$$

10 Graphs, Outputs

Result: The Overall heat transfer co-efficient of given composite slab was found to be

U_0 = _____W/ m-K.

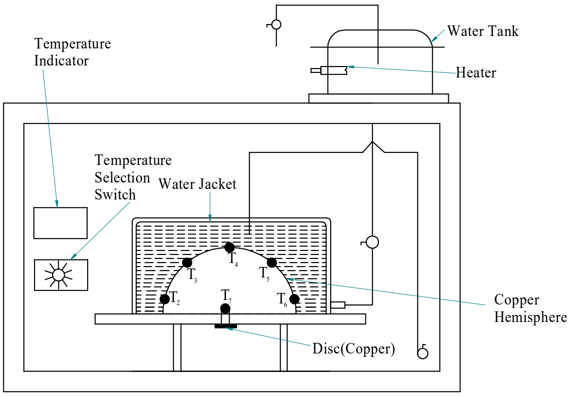
Points for discussion:-

3) Comment on the experimental set up, its validity and accuracy.

		4) Overall heat transfer co-efficient can also be calculated without the requirement of intermediate temperatures. comment on it.
11	Results & Analysis	
12	Application Areas	To compute the heat flux at any location, compute the thermal stress, design of insulation thickness, chip temperature calculation, heat treatment of metals.
13	Remarks	
14	Faculty Signature with Date	

Experiment 08 : Determination of Steffan Boltzmann Constant.

-	Experiment No.:	8	Marks		Date Planned		Date Conducted	
1	Title	Determination of Steffan Boltzmann Constant.						
2	Course Outcomes	Able to determine the Stefan Boltzmann Constant.						
3	Aim	To determine the value of Stefan Boltzmann constant.						
4	Material / Equipment Require	Copper hemispherical enclosure, Thermocouples jacket to hold hot water.						
5	Theory, Formula, Principle, Concept Power	The most commonly used law in radiation heat transfer between two bodies A and B is Stefan boltzman law which is given as $Q = \sigma \times A \times (T_A^4 - T_B^4)$ Where, Q = Heat transfer rate, W σ = Stefan boltzsman constant = 5.669×10^{-8}. T_A and T_B = Temperatures of bodies A and B respectively. The above equation is applicable to black bodies & valid only for thermal radiation. Other type of bodies (like a glossy painted surface or a polished metal plate) do not radiate as much energy as the black body but still the total radiation emitted flow this law.						
6	Procedure, Program, Activity, Algorithm, Pseudo Code	1. Switch on the main and console. 2. Switch on heater. 3. After water attains the maximum temperature open the valve and dump the water to the enclosure jackets. 4. Wait for few minutes to attain hemispherical atmosphere. 5. Measure the enclosure temperature using channel selector. 6. Insert the disc with sleeve in to the slot and record the temperature.						
7	Block, Circuit, Model Diagram, Reaction Equation, Expected Graph							



8 Observation Table, Look-up Table, Output

SL. NO	Temperatures (ºC)						Time in sec for which T_7 is noted as (ºC)					σ in $\frac{W}{m^2-K^4}$
	T_1	T_2	T_3	T_4	T_5	T_6	0	20	40	60	80	

9 Sample Calculations

1) Stefan boltzsman constant (σ):-

$$\sigma = \frac{m_{cu} . C_{Pcu} . \frac{dT}{dt}}{A_{cu}\left(T_S^{\ 4} - T_7^{\ 4}\right)}$$

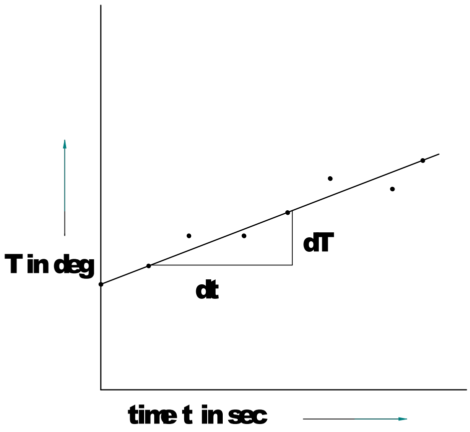
Where, m_{cu} = mass of copper. (kg)

C_{Pcu} = Specific heat of copper. ($\frac{J}{Kg-K}$)

$$T_S = \frac{T_2 + T_3 + T_4 + T_5 + T_6}{5}$$

T_1 = Ambient temperature.

$\frac{dT}{dt}$ = slope from graph Temperature (T) Vs time (t) .

10	Graphs, Outputs	
11	Results & Analysis	Result: The experiment was conducted successfully .The Stefan boltzman constant was found to be σ = ________ Points for Discussion : (1) What errors will creep in if the temperature recordings of the disc are not taken quickly.. (2) Comment why the shell is chosen as Hemisphere.
12	Application Areas	Solar flat plate collector, water heating process (solar pond), photo voltaic cell.
13	Remarks	
14	Faculty Signature with Date	

Experiment 09 :Determination of LMDT and Effectiveness in a Parallel Flow and Counter Flow Heat Ex-changers.

-	**Experiment No.:**	9	**Marks**		**Date Planned**		**Date Conducted**	

1	Title	Determination of LMDT and Effectiveness in a Parallel Flow and Counter Flow Heat Ex-changers.
2	Course Outcomes	Able to determination of rate of heat transfer by LMTD and effectiveness for different flow arrangement.
3	Aim	To determine rate of heat transfer and overall heat transfer co-efficient in parallel and counter flow heat ex-changer.
4	Material / Equipment Required	Heat ex-changer hearing inner copper tube through which water flows, heaters, rota meter, blower, channel selector and digital temperature, display.
5	Theory, Formula, Principle, Concept	Heat exchanger is a device by which heat is transferred from one medium to another, whether the media are separated by a solid wall so that they never mix, or the media are in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants,

<table>
<tr><td></td><td></td><td>petroleum refineries, and natural gas processing.The types of heat exchangers to be tested in the experiment are single-pass, parallel-flow and counter flow concentric tube heat exchangers. In a parallel-flow heat exchanger, the working fluids flow in the same direction.In the counter-flow exchanger, the fluids flow in parallel but in opposite direction.The variables that affect the performance of a heat exchanger are the fluid mass flow properties, the fluid inlet temperatures, the configuration, and Area and scale deposits of heat transfer surfaces.</td></tr>
<tr><td>6</td><td>Procedure, Program, Activity, Algorithm, Pseudo Code</td><td>1. Allow water to circulate in inner copper tube by opening flow control valve of the rota meter, monitor the flow rate.
2. Operate the valve system to make water flow either in parallel or counter flow direction.
3. Switch on the temperature indicator and allow about 10 min. for the temperature to become steady state is reached. Note down the temperature.
4. Measure the water flow rate from the rotameters for both the hot and cold fluid.
5. calculate the overall heat transfer co-efficient and effectiveness for both parallel and counter flow arrangements.</td></tr>
<tr><td>7</td><td>Observation Table, Look-up Table, Output</td><td>
<table>
<tr><td rowspan="2">Sl. No</td><td colspan="3">Hot Water Side</td><td colspan="3">Cold Water side</td></tr>
<tr><td>Flow rate (LPM)</td><td>T_2 in ^{0}C inlet</td><td>T_3 in ^{0}C outlet</td><td>Flow rate (LPM)</td><td>T_4 in ^{0}C inlet</td><td>T_5 in ^{0}C outlet</td></tr>
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<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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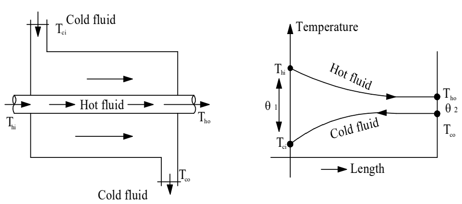
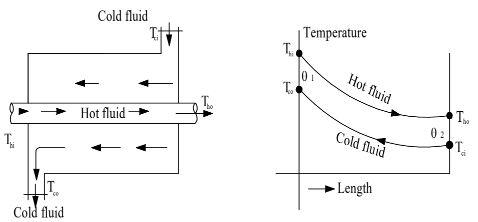
</td></tr>
<tr><td>8</td><td>Block, Circuit, Model Diagram, Reaction Equation, Expected Graph</td><td>
Parallel Flow HE



Counter Flow HE



</td></tr>
</table>

9	Sample Calculations	

(1) Heat transfer rate from hot water, $Q_h = Cp\ (m_h)\ .\Delta T_{wh}$

Where,

Mass flow rate (m_h) = (m_h in LPM) / 60, kg/sec

$C_P = C_{Pc} = C_{Ph} = 4184\ \left(\frac{J}{Kg - K}\right)$

$\Delta T_{wh} = T_2 - T_3$

(2) Heat transfer rate from cold water, $Q_c = Cp\ (m_c).\Delta T_{wc}$

Where,

Mass flow rate (m_c) = (m_c in LPM) / 60, kg/sec

$C_P = C_{Pc} = C_{Ph} = 4184\ \left(\frac{J}{Kg - K}\right)$

$\Delta T_{wc} = T_5 - T_4$

(3) $Q = \dfrac{Q_h + Q_c}{2}$

a) Log mean temperature difference (LMTD)

$$LMTD = \frac{\theta_1 - \theta_2}{\ln \frac{\theta_1}{\theta_2}}$$

Where,

$\theta_1 = T_{hi} - T_{ci} = T_2 - T_4$

$\theta_2 = T_{ho} - T_{co} = T_3 - T_5$

b) Overall Heat Transfer co-efficient (U)

U = $\frac{Q}{A_S \times LMTD}$, $(\frac{W}{m^2 - K})$

Where, A_S = ✍✉ d_o.L

(6) Effectiveness (⌜) = $\frac{T_2 - T_3}{T_2 - T_4}$

(b) Counter Flow

(1) Heat transfer rate from hot water, Q_h = Cp (m_h) .ΔT_{wh}

Where,

Mass flow rate (m_h) = (m_h in LPM) / 60, kg/sec

$C_P = C_{Pc} = C_{Ph}$ = 4184 $(\frac{J}{Kg - K})$

$\Delta T_{wh} = T_2 - T_3$

(2) Heat transfer rate from cold water, Q_c = Cp (m_c).ΔT_{wc}

Where,

Mass flow rate (m_c) = (m_c in LPM) / 60, kg/sec

$C_P = C_{Pc} = C_{Ph}$ = 4184 $(\frac{J}{Kg - K})$

$\Delta T_{wc} = T_4 - T_5$

, (3) Q = $\frac{Q_h + Q_c}{2}$

(4) Log mean temperature difference (LMTD)

LMTD = $\frac{\theta_1 - \theta_2}{\ln \frac{\theta_1}{\theta_2}}$

Where,

$\theta_1 = T_{hi} - T_{ci} = T_2 - T_4$

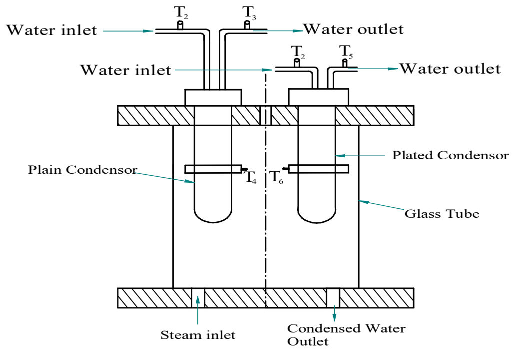
$\theta_2 = T_{ho} - T_{co} = T_3 - T_5$

(5) Overall Heat Transfer co-efficient (U)

		U = $\frac{Q}{A_S \times LMTD}$ (6) Effectiveness (Γ) **=** $\frac{T_2 - T_3}{T_2 - T_5}$
10	Graphs, Outputs	
11	Results & Analysis	<u>For Parallel Flow</u> i) The Heat transfer obtained is ______ watts ii) Overall Heat Transfer is _______ iii) Effectiveness is ______ <u>For Counter Flow</u> 1.The Heat transfer obtained is ______ watts ii) Overall Heat Transfer is ______ iii) Effectiveness is _____
12	Application Areas	LMTD and NTU methods for analysis of heat exchangers.
13	Remarks	
14	Faculty Signature with Date	

Experiment 10: Experiments on Boiling of Liquid and Condensation of Vapour.

-	**Experiment No.:**	10	**Marks**		**Date Planned**		**Date Conducted**	
1	Title	Experiments on Boiling of Liquid and Condensation of Vapour.						
2	Course Outcomes	Able to determination of heat transfer coefficient for Phase change analysis.						
3	Aim	To determine the average heat transfer co-efficient for film wise and dropwise condensation and comparison of both.						
4	Material / Equipment Required	Gas tube, steam generator copper coated internal tube, stop watch.						
5	Theory, Formula, Principle, Concept	Boilers and condenser which are used as heat ex-changer posses unique characteristics of heat transfer mechanism on the condensing and boiling side. When a Vapour strikes a surface temp below the corresponding saturation temperature the Vapour will immediately condense into the liquid phase. The porous of condensation may take place into two different type namely: a. Film wise condensation b. Drop wise condensation When the condensate tends to wet the surface it is called film wise condensation. When condensate does not wet the surface and when it forms droplets on the surface, it is known as drop wise condensation.						
6	Procedure, Program, Activity, Algorithm, Pseudo Code	(1) First fill the water in stainless steel tank and then switch on the main and console. (2) Switch on the supply pump starter. (3) Change the ball valve position of conducting film wise condensation experiment. (4) Switch on the heater and maintain a steady water flow, say 4LPM, through the rota meter. (5) Wait for sometime till steady steam is generated. Then the stem is passed through a separator to supply only dry stream to the cylinder. (6) The stem starts condensing on outer surface of the condenser tube and gets collected as a condensate at the bottom of the cylinder. (7) Note down the different temperatures of inlet and outlet water supply, stem pressure, flow rate of water. (8) Now change the ball valve position to drop wise condensation and conduct the experiment for same flow rate. (9) Repeat the above procedure for different flow rates and different steam pressures.						
7	Observation Table, Look-up Table, Output							

8	Block, Circuit, Model Diagram, Reaction Equation, Expected Graph	 
9	Sample Calculations	**Specimen calculations for film-wise condensation:** Outer diameter of condensing surface = d = _______, Length of the condensing surface = L = _______, Surface temperature = T_S = ________ Pressure of steam condensing = _________ Saturation temperature at condensing pressure = Tsat = _______ (From tables) Inlet temperature of cooling water = T_{wi} = ______ Exit temperature of cooling water = T_{wo} = ______ Volume flow rate of cooling water = V_w =______ Volume flow rate of condensate = V_s = Volume of steam admitted per time. = ________ Mass flow rate of water = m_w = ✕$_w$ V_w = ______ Specific volume of condensate = v_s = v_f at condensing pressure. Condensate flow rate = $m_{steam} = \frac{V_s}{v_s}$ Heat carried away by cooling water = $Q_w = m_w.C_{pw}[T_{wo} - T_{wi}]$ = __________ Heat given out by steam due to condensation = $Q_{steam} = m_{steam}.h_{fg}$ Mean film temperature = $T_m = \frac{T_{sat} + T_s}{2}$ Properties of condensate at T_m are: k =______ , ✕ = _______ , h_{fg} = _____ , Hence, Q_{steam} = _________.

Condensation heat transfer co-efficient = h_{av} = $\frac{Q_{steam}}{\pi dl(T_{sat} - T_s)}$

= _________

To find h_{av} using standard correlation:

Reynolds number for the condensate = Re = $\frac{4 \times m_{steam}}{\pi d \mu}$ = ________

If Re < 1800, Condensate flow is laminar.

Hence h_{av} = $\frac{1.47 \times \left[\frac{k^3 \times \rho^2 \times g}{\mu^2}\right]^{0.33}}{\mathrm{Re}^{0.33}}$

= _____________ $(\frac{W}{m^2 - K})$.

Specimen calculations for drop-wise condensation:

Surface temperature = T_S = _______

Pressure of steam condensing = ________

Saturation temperature at condensing pressure = T_{sat} = _______ (From tables)

Inlet temperature of cooling water = T_{wi} = ______

Exit temperature of cooling water = T_{wo} = ______

Volume flow rate of cooling water = V_w =______

Volume flow rate of condensate = V_s = Volume of steam admitted per time.

= ________

Mass flow rate of water = m_w = ✕$_w$ V_w = ______

Specific volume of condensate = v_s = v_f at condensing pressure.

Condensate mass flow rate = m_{steam} = $\frac{V_s}{v_s}$

Heat carried away by cooling water = Q_w = $m_w.C_{pw}[T_{wo} - T_{wi}]$

= _________

Heat given out by steam due to condensation = Q_{steam} = $m_{steam}.h_{fg}$

Mean film temperature = T_m = $\frac{T_{sat} + T_s}{2}$

Properties of condensate at T_m are: ◡ ▪ ♉♉♉♉♉♉♉ ✉ k =______ , ✕ = _______ , h_{fg} = _____ ,

Hence, Q_{steam} = _________.

Condensation heat transfer co-efficient = h_{av} = $\frac{Q_{steam}}{\pi dl(T_{sat} - T_s)}$

= _________

		To find h_{av} using standard correlation for drop wise condensation: Reynolds number for the condensate = Re = $\frac{4 \times m_{steam}}{\pi d \mu}$ = ________ If Re < 1800, Condensate flow is laminar. Hence $h_{av} = \frac{1.47 \times \left[\frac{k^3 \times \rho^2 \times g}{\mu^2}\right]^{0.33}}{\mathrm{Re}^{0.33}}$ = ____________ $(\frac{W}{m^2 - K})$.
10	Graphs, Outputs	
11	Results & Analysis	Result: Average heat transfer co-efficient for film wise condensation is ______ Average heat transfer co-efficient for film wise condensation is ______ Points for Discussion : (1) List of various precautions especially that of steam generator observed during experimentation. (2) Which is more effective among film wise and drop wise condensation and why.
12	Application Areas	Boiling and condensation knowledge is applicable to calculate critical heat flux, and condensation rate in heat transfer problems.
13	Remarks	
14	Faculty Signature with Date	

Experiment 11 :Performance Test on a Vapour Compression Refrigeration

-	**Experiment No.:**	11	**Marks**		**Date Planned**		**Date Conducted**	
1	Title	Performance Test on a Vapour Compression Refrigeration						
2	Course Outcomes	Able to understand effect of heating and humidification on a Vapour Compression Air – Conditioner						
3	Aim	To conduct a test on Vapour Compression Refrigerator and find its coefficient of performance.						
4	Material / Equipment Required	Refrigerant, Compressor, Condenser, Cooling fan, Throttle valve, Capillary tube, Evaporator.						
5	Theory, Formula, Principle, Concept	Refrigeration is a process by which the temperature of a given space is reduced below that of the atmosphere or surroundings. Refrigeration can be realized by several methods, for example, Ice refrigeration, Dry ice refrigeration, Evaporative refrigeration, Air refrigeration, Vapour compression refrigeration etc. The modem refrigeration uses the vapour compression method. In this method, a closed system (the refrigerant) experiences a thermodynamic cycle ; by virtue of doing network on the system in such a cycle, it is possible to extract heat from a low temperature source (the refrigerated space) and to reject heat to a higher temperature sink (the atmosphere or cooling water). The performance of refrigerators and heat pumps is expressed in terms of the **coefficient of performance** (COP), defined as COP = $\frac{Desired.output}{required.input}$						
6	Procedure, Program, Activity, Algorithm, Pseudo Code	(a). Switch-on the Mains and the Console. (b) Keep either the Throttle Valve or the capillary Tube open-when the capillary tube is open, the throttle valve should be closed and vice versa. Both devices have the same expansion (or throttling) effect. (c) Switch-on the motor which drives the compressor and the fan (which cools the condenser). (d) The refrigerant passes through the vapour compression cycle as mentioned earlier resulting in cooling in the evaporator chamber or freezer. (e) Wait for about 5 minutes and note the Temperatures T_1 to T_5 and Pressures P_1 and P_2.						
7	Observation Table, Look-up Table, Output							

Sl.No.	Pressure upstream of compressor (P_1) kg/cm^2	Pressure downstream of compressor (P_2) lb/in^2	Température (°C)	From p-h curve Enthalpy (kJ/kg)

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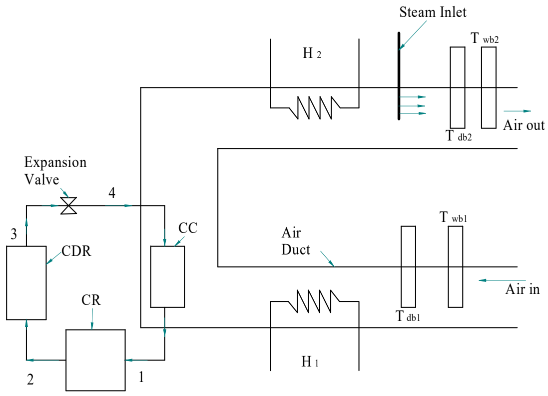
					Compressor Inlet	T_1 =	h_1 =
					Compressor Outlet	T_2 =	h_2 =
					Condenser Outlet	T_3 =	h_3 =
					Evaporator Inlet	T_4 =	h_4 =

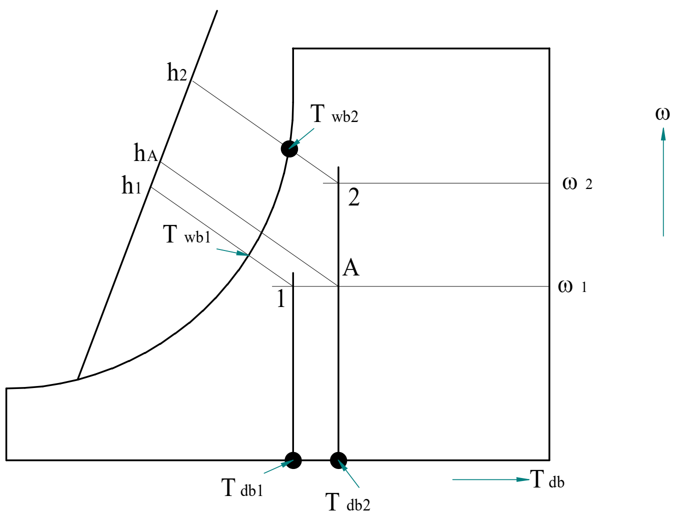
8	Block, Circuit, Model Diagram, Reaction Equation, Expected Graph	
9	Sample Calculations	In a steady state, the heat balance is given by, $Q_L + W_{in} = Q_H$ …………………. Eq (1) Q_L = Heat removed by the evaporator from the refrigerated system, = Heat gained by the refrigerant in the evaporator. = $h_1 - h_4$ per Kg of refrigerant. Q_H = Heat transferred from the refrigerant in the condenser. = $h_2 - h_3$ per Kg of refrigerant. W_{in} = Work done by the compressor on the refrigerant. = $h_2 – h_1$ per Kg of refrigerant. h_1= Enthalpy of the refrigerant at exit of the evaporator. h_2 = Enthalpy of the refrigerant at exit of the compressor. h_3 = Enthalpy of the refrigerant at exit of condenser. h_4 = Enthalpy of the refrigerant at exit of the throttle valve. The values of enthalpies of the refrigerant at different states can be obtained from tables/ charts using the measured values of pressures and temperatures. The work done in the compressor can be directly obtained from the energy meter in the panel. The co-efficient of performance (COP) of the refrigerant system is given by,

		COP = $\frac{Q_H}{W_{in}} = \frac{h_1 - h_4}{h_2 - h1}$ .... Eq. (2) Where, Q_H = Amount of heat extracted in the refrigerator W_{in}= Net work done.
10	Graphs, Outputs	
11	Results & Analysis	Result: The COP of the refrigerator came out to be _______ . Point for discussion (1) Discuss the suitability of different Compressor speeds for typical duties and others. (2) Can refrigerator equipment can be used as heater.If yes how it is done.
12	Application Areas	Establishing temperature distribution within building, determining heat loss calculations, ventilating and air-conditioning system.
13	Remarks	
14	Faculty Signature with Date	

Experiment 12 : Air Conditioning Test Rig

-	**Experiment No.:**	12	**Marks**		**Date Planned**		**Date Conducted**	
1	Title	Performance Test on a Vapour Compression Air – Conditioner						
2	Course Outcomes	Able to understand effect of heating and humidification on a Vapour Compression Air – Conditioner						
3	Aim	To study the effect of Heating and humidification of air conditioning process						
4	Material / Equipment Required	Cooling Coil, Air Heaters-2 Sets, Steam Generator, Duct						
5	Theory, Formula, Principle, Concept	The science of Air Conditioning deals with maintaining a desirable internal air conditions irrespective of external atmospheric conditions. The factors involved in any air conditioning installation are: (a) Temperature (b) Humidity (c) Air movement and circulation (d) Air filtering, cleaning and purification. The simultaneous control of these factors within the required limits is essential for human comfort or for any industrial application of the air conditioning system. In any air conditioning system, temperature and humidity are controlled by thermodynamic processes. Depending on the season, the air conditioning processes involve cooling, heating, humidification and dehumidification of air. Other aspects such as air movements, circulation, purification, etc. are obtained by installing suitable fans, blowers, ducting and						

		filters. This equipment is designed to demonstrate different air conditioning processes such as cooling, heating, humidification, etc. required for different seasons of the year.
6	Procedure, Program, Activity, Algorithm, Pseudo Code	The purpose of the experiment is to increase the humidity and dry bulb temperature of the incoming air.Hence for this experiment the refrigeration system should be switched off and the steam boilers and heaters H1 and H2 should be on.After steady state is reached the following measurements are made and noted.
7	Observation Table, Look-up Table, Output	
8	Block, Circuit, Model Diagram, Reaction Equation, Expected Graph	 
9	Sample Calculations	T_{db1} = _____ T_{wb1} = _____ T_{db2} = _____ T_{wb2} = _____ The velocity of air at the exit section of the duct = v_2 =

		Cross sectional area of the duct = A_2 = ____ The inlet and exit conditions of the air are represented by the psychrometric charts as shown in the figure 11.1 (a) From Psychrometric chart, we have ω_1 = ________ , ω_2 = ________ h_1 = ________ , h_2 = ________ h_A = ________ , v_2 = ________ Volume flow rate of air in ($\frac{m^3}{s}$) = V_{air} = $A_2.v_2$ Heater energy meter constant = ________ Time taken for one revolution of energy meter = ______ s Temperature of steam supply = T_{steam} = _____ ^{0}C Mass flow rate of dry air in ($\frac{Kg}{s}$)= m_a = $\frac{V_{air}}{v_2}$ =______ Amount of moisture added to air = m_w = $\omega_2 - \omega_1$ = = __________. Heat supplied by the heating coil = $\frac{Number.of.revolutions.of.energy.meter \times 3600}{Energy.meter.cons\tan t \times time.takenfor.1.rev.}$ Hence Q_{coil} = Energy balance equation for the process gives $Q_{coil} + m_a(\omega_2 - \omega_1)h_{steam} = Q_{Air} + Q_{Loss}$ ……………….(1) From steam tables h_{steam} = h_g at T_{steam} = ________ $\therefore Q_{Loss}$ = _________ Sensible heat added to air = Q_S = $m_a[h_A-h_1]$ = ______ Sensible heat factor = SHF = $\frac{Q_S}{Q_{air}}$ = __________
10	Graphs, Outputs	

11	Results & Analysis	Result: Sensible heat factor for heating and humidification process is ___________ , Points for Discussion : (1) List of various precautions observed during experimentation. (2) What is dew factor.
12	Application Areas	Establishing temperature distribution within building, determining heat loss calculations, ventilating and air-conditioning system.
13	Remarks	
14	Faculty Signature with Date	

Experiment 13: Experiment on Transient Conduction Heat Transfer.

-	**Experiment No.:**	13	**Marks**		**Date Planned**		**Date Conducted**	
1	Title	Experiment on Transient Conduction Heat Transfer.						
2	Course Outcomes	Able to determine temperature distribution and unsteady state heat conduction						
3	Aim	To obtain temperature profile for conduction through a cylindrical rod heated by a constant source and to compare theoretically predicted temperature distribution under transient conditions.						
4	Material / Equipment Required	Transient heat conduction set-up, thermocouples, stop watch/clock.						
5	Theory, Formula, Principle, Concept	A Heat transfer process which is time dependent is designated as an unsteady state or transient heat transfer. There are large number of situations where changes in condition result in transient temperature distribution.Unsteady state heat transfer generally occurs before steady state operating conditions. Transient temperature distribution results in manufacture of bricks, Cooking and freezing of food and in heat and cold treatment of metals.						
6	Procedure, Program, Activity, Algorithm, Pseudo Code	➔ Heat the metal rod(Stainless steel) by electrical heating at constant rate by adjusting the current and voltage. ➔ Adjust the flow of water to one litres/min using rota meter. Note the readings of the Ammeter and the Voltmeter. ➔ Note down the initial temperature at seven different positions, say at distances 65mm, 130mm, 195mm etc. from the heat source. ➔ Start the stopwatch and note the temperature indicated by the Thermocouples at a various points recorded at 5 minutes interval. ➔ Continue to note the temperatures till constant temperature is attained. The calculations are performed to obtain temperature profile and compared with theoretical values obtained. ➔ Temperature profile: Theoretical temperature and experimentally observed temperature versus distance from the hot source is drawn on a graph sheet for 15 & 30 minutes time intervals.						

<table>
<tr><td>7</td><td>Observation Table, Look-up Table, Output</td><td>
<table>
<tr><th>Time in sec.</th><th>At distance near Heater. X_1=0 m</th><th>At X_1=.06m</th><th>At X_1=.12m</th><th>At X_1=.18 m</th><th>At X_1= 0.24 m</th><th>At X_1=.30m</th><th>At X_1=.36m</th><th>T_8</th><th>T_9</th></tr>
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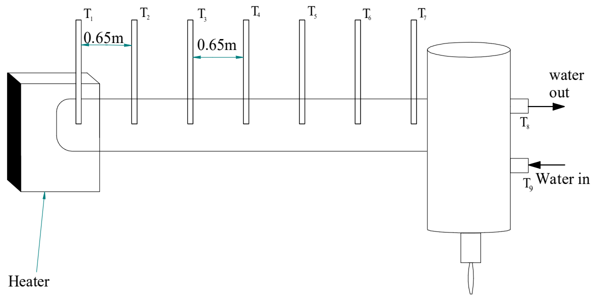
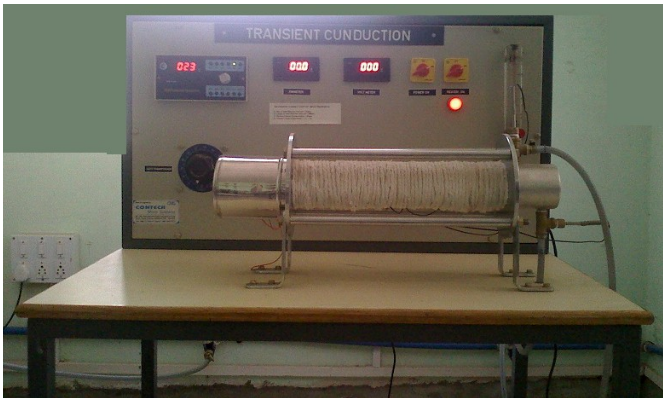
<tr><td>8</td><td>Block, Circuit, Model Diagram, Reaction Equation, Expected Graph</td><td>





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<tr><td>9</td><td>Sample Calculations</td><td>
Voltmeter reading V: (volts)
Ammeter reading I : (amps)
Total heat supplied Q = V x I = (watts)
Thermal diffusivity of the material is calculated by

$$\alpha = \frac{k}{\rho \times C_P}, \quad (\frac{m^2}{s})$$

ρ = Density of material (Copper) = 8954 $\frac{Kg}{m^3}$

C_P = Specific heat of material (Copper) = 381 $\frac{J}{Kg-K}$

k = Thermal conductivity (Copper = 386 $\frac{W}{m-K}$)

A= Area of cross section of metal rod = $\frac{\pi . d^2}{4}$ = ________ m^2

Where, d = Diameter of the rod in. m.
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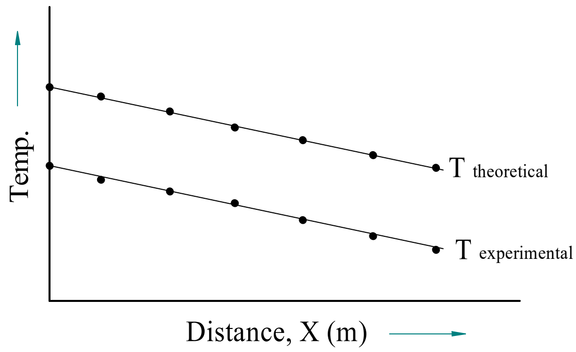
		Calculate the Value of Z using the formula: Z = $\frac{X}{2\sqrt{\alpha \times t}}$ From this, Calculate the error function value of Z from the Data Hand book i.e., erf (z). Now,the Temperature distribution for a body subjected to constant heat flux condition is given by T(X) – Ti = $\frac{2q \times \sqrt{\frac{\alpha \times t}{\pi}} \times \exp\left[\frac{-X^2}{4 \times \alpha \times t}\right]}{k}$ - $\frac{q \times X \times [1 - erf(Z)]}{k}$. taking particular time (say, t = 900 seconds) and substitute in the above Theoretical equation. T_i = Initial temperature before starting the experiment. t = At any particular times (say, t = 900 seconds) X = Different distances at which thermocouples are placed. Temperature (^{O}C) T $_{experimental}$ = Values are obtained directly from the experiment at different times.
10	Graphs, Outputs	
11	Results & Analysis	Result: The heat conduction experiment is conducted under transient conditions and the temperature conduction through the rod heated by a constant heat flux is obtained and compared with theoretical values. Points for Discussion : 1)Whether the rod can modelled as a lumped system one.Comment on it.
12	Application Areas	Forced convection systems applicable for extremely high temperatures for functions
13	Remarks	
14	Faculty Signature with Date	

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Experiment 14 : Determination of temperature distribution along a rectangular and circular fin subjected to heat loss through convection using Numerical approach (ANSYS/CFD package)

-	**Experiment No.:**	14	**Marks**		**Date Planned**		**Date Conducted**	
1	Title	Determination of Effectiveness on a Metallic fin.						
2	Course Outcomes	Estimate the effective thermal resistance and efficiency in pin-fin						
3	Aim	Determination of temperature distribution along a rectangular and circular fin subjected to heat loss through convection using Numerical approach (ANSYS/CFD package)						
4	Material / Equipment Required	The experimental set up consists of a blower unit having a rectangular duct inside which the pin fin is fitted. One end of the pin fin is connected to heater. Five Thermocouples are embedded on the fin surface. Blower along with the orifice is used to measure flow of air through the duct. Input to heater is given through dimmer stat and measured by voltmeter and ammeter. Air flow is controlled by the gate valve and is measured with the help of orifice meter and the manometer fitted on the board.						
5	Theory, Formula, Principle, Concept	(i) Fins are extended surfaces which are used to increase the rate of heat transfer between a surface and the adjacent fluid. Fins are classified into three viz. angular fins, straight fins and pin-fins. Angular fins are fixed to cylindrical surfaces, straight fins and pin fins are fixed to plane surfaces. Fins are used in I.C. Engines, Compresses, Radiation, Heat exchanges etc. (ii) Natural convection is the heat transfer between a surface and adjacent fluid particles due to the macroscopic motion of fluid particles, set up by buoyancy effect resulting from the density difference caused by their temperature difference, (iii) Fin effectiveness is the ratio of heat transfer with the fin to the heat transfer without fin, It is denoted by, $\varepsilon = \dfrac{\tanh(ml)}{\sqrt{\dfrac{h.A}{k_f.P}}}$. (iv) Fin efficiency is the ratio of heat lost from the fin to the heat that would be lost when the entire surface of the fin is under base temperature, it is given by $\eta = \dfrac{\tanh ml}{ml}$.						
6	Procedure, Program, Activity, Algorithm, Pseudo Code	*(a) Natural Convection:* 1. Switch on the supply and adjust the variac to obtain the required heat input. 2. Note down the following readings after reaching the steady state: (i) Voltmeter reading 'V' volts (ii) Ammeter reading 'A' amps (iii) Thermocouples readings (T_1 to T_6)^{0}C. 3. Repeat the procedure for different heat inputs and tabulate the readings. *(b) Forced Convection:* 1. Switch on the supply and adjust the variac to obtain the required heat input. 2. Start the blower, set the manometer head as required. 3. Note down the following readings after reaching the steady state: (i) Voltmeter reading 'V' volts						

(ii) Ammeter reading 'A' amps
(iii) Thermocouples readings (T 1 to T 6)^{0}C.
(iv) Manometer reading ‘h’ cm.
Repeat the procedure for different heat inputs and tabulate the readings

7 Block, Circuit, Model Diagram, Reaction Equation, Expected Graph

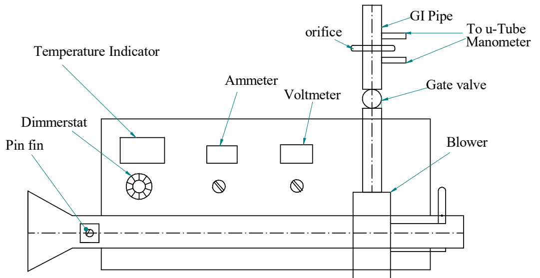

Fig 3.1(a) Pin fin apparatus

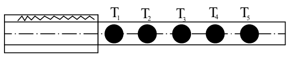

Fig 3.2(b) Pin fin enlarged

8 Observation Table, Look-up Table, Output

Sl. No.	Voltage (V) Volts	Current amps	Power Q=VI Watts	Temperature at different point in the outer surface of cylinder (ºC)						h_{the} W/m^2-K	η_{the} (%)	η_{exp} (%)	ε
					T_2	T_3	T_4	T_5	T_6				

9 Sample Calculations

(1) Experimental Efficiency of pin fin(η_{exp})
The efficiency of the pin fin experimentally is given by

$$\eta_{exp} = \frac{Q_{fin}}{(Q_{fin})_{max}}$$

Where, Q_{fin} = V x I, W

$(Q_{fin})_{max} = h_{exp}.A_S.(T_s – T_a) + \sigma.A_S.(T_s^4 – T_a^4)$, W

But, $h_{exp} = Q_{fin} / \{As (Ts – Ta)$

$A_S = \pi$.d.l. (m^2)

(2) Theoretical Efficiency of pin fin(η_{the})

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$\eta_{the} = \frac{\tanh ml}{ml}$

Where, m = $\sqrt{\frac{h.P}{k_f.A}}$

h = heat transfer coefficient of fin

P = Perimeter of fin (πD)

k_f = thermal conductivity of pin fin = 110 ($\frac{W}{m-K}$)

A= Area of fin = $\frac{\pi.d^2}{4}$, (d = Diameter of the pin fin, m), m^2

l = Length of pin fin, m

To find heat transfer coefficient of fin(h)

2) Film temperature, $T_f = \frac{Ts + Ta}{2}$ (°C)

Where, T_s = Surface temperature of the cylinder = $\frac{T_2 + T_3 + T_4 + T_5 + T_6}{5}$ (K)

$T_a = T_1$, ambient temperature (K)

Properties of air at the film temperature (T_f) is obtained from data book, hence determine

Kinematic viscosity, v = Thermal conductivity, k =

Prandtl number, Pr =

(ii) Grassoff number Gr = $\frac{g.\beta.\Delta T.d^3}{\nu^2}$

Where,

β = Co-efficient of thermal expansion = $\frac{1}{(T_f + 273)}$. (K^{-1})

$\Delta T = T_f - T_1$. (K)

d = Diameter of the pin fin. (m)

v = Kinematic viscosity. (m^2/s) ×

∴ Ra. No= Gr *x* Pr =

From heat transfer Data hand book corresponding to this value of Rayleigh number Ra, the nusselt number(Nu) is given by

For 10^{-1} < Gr × Pr < 10^4, Nu = 0.68 + $\frac{0.67 \times (Gr \times Pr)^{0.25}}{\left\{1 + \left[\frac{0.492}{Pr}\right]^{0.5625}\right\}^{0.444}}$

For 10^4 < Gr × Pr < 10^9, Nu = 0.59 (Gr × *x* Pr)$^{0.25}$

		For $10^9 < Gr \times Pr < 10^{12}$, $Nu = 0.13 (Gr\, x\, Pr)^{0.33}$ Hence, $Nu = \frac{h.l}{k}$. Or $h = \frac{Nu.k}{l}$. Where, h= h_{the} = natural heat transfer co-efficient, $(\frac{W}{m^2 - K})$ (3) Effectiveness of Fin, $\varepsilon = \frac{\tanh(ml)}{\sqrt{\frac{h.A}{k_f.P}}}$
10	Graphs, Outputs	
11	Results & Analysis	**Result:-** *free convection* h_{the} = ______ , η_{exp} = _______ , ε = ______ *forced convection* h_{the} = ______ , η_{exp} = _______, ε = ______ **Points for discussion:-** (1) If the readings are taken when the steady state is yet to be reached,how will the accuracy of the results will be affected. (2) From the observations taken in this experiment, explain how would you determine the thermal conductivity of the material of the fin.
12	Application Areas	Buildings, Mechanical systems, Refrigeration, Spacecraft, Automotive
13	Remarks	
14	Faculty Signature with Date	