HEAT AND MASS TRANSFER

LABORATORY MANUAL

MECHANICAL ENGINEERING DEPARTMENT

(ISO 9001:2008 Certified)

MES COLLEGE OF ENGINEERING, KUTTIPPURAM

Heat and Mass Transfer Laboratory Manual

MECHANICAL ENGINEERING DEPARTMENT

Revision	Date	Prepared by			Approved by		
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VISION

To develop the Department into a premier destination of international level for advanced learning in Mechanical Engineering and to mould quality engineers to serve the society through creative solutions.

MISSION

- To mould engineers who would be able to apply the basic science and mathematics with confidence in professional activities for the benefit of all.
- To make our graduates experts in practical problem solving with abstract thinking skills.
- To make our students life-long learners capable of building their careers upon a solid foundation of knowledge and competent in communicating technical materials and concepts in individual group situations

PROGRAM EDUCATIONAL OBJECTIVES (PEOs)

After 3-4 years of graduation, our students will be able to

- Demonstrate their skills in technical profession and/or higher education by using the acquired knowledge in Mathematics, Science and Engineering fundamentals.
- Analyze the real life problems and propose sustainable design solutions for specific needs through applications of Engineering principles.
- Recognize the ethical responsibility as engineers and judiciously serve their peers, employers & society for the benefit of all.
- Practice life-long learning by continuing up gradation of possessed skills.

PROGRAM SPECIFIC OUTCOMES (PSOs)

At the end of four year programme the students (graduates) will be able to:

- Demonstrate basic knowledge in mathematics, science and engineering.
- Design, manufacture and analyze a Mechanical system using modern engineering software tools and measurement systems.
- Cognize concepts involved in thermal and fluid energy systems.
- Utilize self education to develop lifelong learning to appraise and adapt global and societal contexts to propose Engineering solutions.

PROGRAM OUTCOMES (POs)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analy**sis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

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Date:
Exp No: **01**

DETERMINATION OF LMTD AND EFFECTIVENESS OF SHELL & TUBE HEAT EXCHANGER

Aim: To find overall heat transfer coefficient and effectiveness of a heat exchange under parallel and counter flow conditions. Also plot the temperature distribution both the cases along the length of . heat of heat exchanger.

INTRODUCTION

Heat exchanger is the device used to transfer the heat from one fluid to another Transfer of heat is needed for many applications. Commonly used types of heat exchanger are transfer type, storage type and direct contact type, both, hot and cold fluids are passing simultaneously through the heat exchanger and heat is being transferred through the separating wall between them. Transfer type heat exchangers are simple for connection are installations and hence are used in many applications.

In transfer type heat exchanger, different type of flow arrangements are used, viz, parallel, counter or cross flow. The shell and tube heat exchanger is two pass heat exchanger. The hot fluid is hot water obtained from water heater. The cold fluid is tap water. The schematic flow arrangement is shown in fig. Hot water enters the lower side of end box, flows through the tubes in lower half of shell and comes to the other end of the shell, where it reverses its direction, flows through tubes in upper half of the shell and leaves out. Cold water enters lower part of the shell passes over the tubes between the baffles and leaves out the shell through outlet at upper surface of shell.

SPECIFICATION .

1) Shell -150 NB, 750 m. m long provided with end boxes.
2) One end box with divider plate.
3) 25% cut baffles — 4 Nos. in the shell.
4) Tubes — 4.5 I.D., 6.35O.D., 750 m. m. copper with triangular pitch.- 32 Nos.
5) Instantaneous water heater, 3 kW capacity, to supply hot water.
6) Thermometer for measuring the water temperature.
7) Valves to control hot and cold water flow

SERVICES REQUIRED FROM CUSTOMER

1) Water supply about 10 lit/mm at constant head.
2) 230V, 16A AC Supply
3) Floor space of about 1.5mtr **x** 1mtr.
4) Suitable drain arrangement for water.

EXPERIMENTAL PROCEDURE-

1) Connect the water supply and start water flow, for heat water (tube side) keep flow rate above 2.5 Lit/mm (maximum flow rate is 7 Lit/mm), keep cold water (shell side) flow rate between 3 to 8 Lit/mm.
2) Connect the main electric supply (250V, I 5 A) and switch 'ON' the water heater.

NEVER SWITCH ON THE HEATER BEFORE STARTING WATER SUPPLY.-

3) Observe water inlet and outlet temperatures.
4) Wait till steady state is reached and note down the observation
5) Repeat the procedure by changing the water flow rate.

OBSERVATION

Sr. No .	HOT WATER			COLD WATER		
	Inlet temp' T_{hi} ^{O}C	Outlet temp. T_{h0} ^{o}C	Discharge Time for 10 ltrs of water I	Inlet temp. $\mathbf{T_{ci}}$ $\mathbf{^{o}C}$ "	Outlet temp. $\mathbf{T_{co}}$ $\mathbf{^{o}C}$	Discharge time for 10 Itrs of water. .

DATA

1) Sp. Heat of water = C_{PW}=4.2 KJ/Kg K

2) Inside area of tube = $A_1 = 4.5 \times 10^{-3} \times \pi \times 0.75 \times 32 = O.34m^2$

3) Outside area of tubes = A_0== $6.35 \times 10^{-3} \times \pi \times 0.75 \times 32$ O.48m^2

4) Density of water, P_w =1000 Kg/rn^3

CACULATIONS

1. Hot water inlet ternp. T_{hi}= °C

Hot water outlet temp. T_{ho} = °C

Cold water inlet temp. T_{ci} = °C

Cold water outlet temp. T_{co} = °C

2. Mass flow rate —

Let time required for 10 ltrs. Flow of water in measuring tank for cold water be t and hot water be t_h,

Volume flow rate, $v_c = 0.01\ 1/t_c\ m^3/s$

Mass flow rate, $m_c = v_h \times \rho_w$ Kg / s

Similarly, for hot water , $m_h = v_h \times \rho_w$ Kg / s.

3. Heat collected by cold water

$$Q_c = mc \times c_{pw} (T_{hi} - T_{ho})\ KJ/s$$

Heat lost by hot water

$$Q_h == rn_h \times C_{Pm} (T_{h1} _ T_{ho})\ KJ/s$$

4. Logarithmic mean temperature difference (LMTD)

For shell and tube heat exchanger,

$\Delta T = F \times LMTD_{ef}$ °C

Where, $LMTD_{ef}$ = LMTD if the arrangement was counterflow,

(for l — shell pass and 2 — tube pass, $LMTD_{ef}$ should be taken)

$$LMTD_{cf} = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{In \frac{(T_{hi} - T_{co})}{(T_{ho} - T_{ci})}}$$

PRECAUTIONS:

All valves are to be opened and free flow of water through heater, shell and tubes is to be ensured. The ammeter and voltmeter readings are to be noted for any abnormalities. In case of any abnormalities the mains is to be switched off and trouble shot out. The maxirnurn flow rate in either circuit should not exceed 9 litres/min. Air flow rate should be kept constant for a particular set of reading.

PROCEDURE:

All valves were opened fully to ensure free flow of water through the heater, tubes and shell. After observing the precautions the heater was switched on. The ratio of mass flow rates of hot and cold water was made approximately to 1 :2.

Inlet and outlet temperatures of both cold and hot water were monitored in every 10 minutes from the temperature indicator using the selector knob until steady state temperatures were reached. The steady state values are used for calculations. Once the temperature become steady, the time for collecting I litre of hot water and that for collecting 1 litre of cold water was also noted down. The observations were tabulated.

RESULT:

Experimental heat transfer coefficient h_{expt} = (W /m^2 K)

Theoretical heat transfer coefficient $h_{theoretical}$ = (W /m^2 K)

Date:
Exp No:**02**

DETERMINATION OF TRANSIENT HEAT TRANSFER CHARACTERISTICS OF A LUMPED SYSTEM COPPER SPHERE

AIM:

To determine the temperature decay with time when a solid cools in air.

EXPERIMENTAL APPARATUS:

A 50mm copper sphere is heated by gas. The temperature at the center of the sphere is measured by thermometer and the time is measured by a stopwatch.

PRINCIPLE:

instantaneous energy balance of a solid of volume V and surface area A with large (technically infinite) thermal conductivity cooling by losing heat to atmosphere at temperature T_f is $\rho c\ VdT/dt = hA(T - T_t)$, where ρ = the density, c = the specific heat and h = the convective heat transfer co-efficient.

In terms of the dimensionless temperature, $\theta\ (= (T - T_t)/(T_o - T_t))$, where, T_o is the initial temperature of the body, this equation may be rewritten as $d\theta/dt = (hA/\rho cV)\theta$. Here, the term $\rho cV/hA$, which has the dimension of time, is called the time constant and denoted as $_T$. Then, the governing equation becomes $d\theta//d(t/_T) = (hA/\rho cV)\theta$.. The solution of this first order equation (obtained by the variables separable method) is $(T - T_T)/(T_0 - T_f) = e^{-T/t}$

By measuring the temperature at different time the experimental cooling curve (rate) may be determined. From the dimensions and properties of the body the theoretical cooling rate may be obtained from the above equation.

For bodies with finite thermal conductivity internal temperature distribution becomes significant, so that the Heisler's charts are used.

PROCEDURE:

1 . Note down the initial temperature of the copper sphere

2. Heat it with the gas burner up to a temperature of 150°C

3. Stop heating and note down the temperature at every 1 MIN till the room temperature is reached

RESULT:

1. The experimental cooling curve is plotted
2. Time Constant =ρcV/hA =
3. The theoretical cooling curve is plotted

OBSERVATION:

Sl. No.	Time (s)	Temperature (^oC)	Q_{th}	Q_{exp}

Date:

Exp No:**03**

DETERMINATION OF TRANSIENT HEAT TRANSFER CHARACTERISTICS OF A LUMPED SYSTEM BRASS CYLINDER

AIM:

To determine the temperature decay with time when a solid cools in air.

EXPERIMENTAL APPARATUS:

A 146mm long brass cylinder of diameter 87.4 mm is used for the experiment it is heated by gas. The temperature of the middle part of the cylinder is measured by thermometer, a stopwatch measures time.

PRINCIPLE:

When a solid of volume V and surface area A with large (technically infinite) thermal conductivity initially at temperature T_0 cools by losing heat to atmosphere at temperature T_f

Newton's law of cooling curve gives

$\rho CVdT/dt = hA(T-T_f)$

Where ρ is the density, C is the specific heat and h is the convective heat transfer coefficient. The solution of this first order equation is $T-T_f/ T_0 -T_f= e^{(-hA/\rho CV)t}$

By measuring the temperature at different time the experimental cooling curve rate may be determined. From the dimensions and properties of the body the theoretical cooling rate may be obtained from the above equation. For bodies with finite thermal conductivity Heistler's charts are used.

PROCEEDURE:

- Note down the initial temperature of the brass cylinder
- Heat it with the gas burner up to a temperature of 150°C
- Stop heating and not down the temperature at every 60 sec till the room temperature is reached.

RESULT:

- The experimental cooling curve is plotted
- The theoretical cooling curve is plotted
- hA /pCV=
- Time constant = pCV/hA =

INFERENCE:

OBSERVATIONS:

Sl.No.	Time (Sec)	Temperature (oC)	Qth	Qexp

Date:

Exp No:**04**

DETERMINATION OF SOLAR DIRECT NORMAL IRRADIANCE (DNI) USING PYRHELIOMETER

AIM:

To measure the intensity of direct solar radiation falling on a surface.

APPARATUS:

The experimental set up of pyrheliometer consists of a thermopile with the heat sink mounted at the bottom of a nickel-plated tube and provided with several circular diaphragms. The receiving surface of the pyrheliometer is perpendicular to the axis of the tube The leads from the thermopile are taken out through a cap at the bottom of the tube

The pyrheliometer tube is rigidly mounted on a tripod stand provided with two knobs so that the instrument can be rotated both in azimuth and elevation. The pyrheliometer can be accurately set to face the sun, by adjusting the elevation and azimuth, till the image of the sun fails on the screen. In front of the tube there is a circular opening, which allows radiation to fall on the thermopile when the tube is pointed at the sun. A cap is provided for covering the top end of the tube to protect the sensitive surface when the instrument is not in use.

PRINCIPLE:

The sensing element of pyrheliometer consists of a thermopile, the active junctions of which are in thermal contact with a massive heat sink at constant temperature. When the blackened front surface is exposed to radiation, its temperature rises until the heat losses from the receiver become equal to the radiant: power input. The voltage developed by the thermopile also reaches a steady value, when the thermal equilibrium is established. Since the temperature rise is small. The thermoelectric voltage generated by the thermopile is proportional to this temperature rise and hence to the input energy rate The emf generated is measured with a milli voltmeter. The intensity of direct solar radiation incident on the thermopile is obtained from the calibration factor of the instrument, which is given as

$K = 5$ mV/cal/cm^2 mm.

PRECAUTIONS:

Readings of the pyrheliometer output should be taken only after the instrument has reached a steady state and after ensuring that it is correctly pointed towards the sun.

PROCEDURE:

The instrument is placed on a level platform or table in the direct sun. The tube of the instrument is pointed towards the sun with the help of the azimuth and elevation of the knobs. The two leads of the thermopile are connected to the milli voltmeter, which was kept in the shade. The zero reading of the instrument is taken with the cap covering the top end of the tube. The cap is removed and the instrument is allowed to attain an equilibrium state by keeping the surface perpendicular to the radiation. Three readings of the output of the pyrheliometer on the millivoltmeter along with the time are noted down. .

CALCULATIONS:

The intensity of direct solar radiation is calculated:

$I = V/K$ [cal/cm^2 mm] where,

V is the difference between the mean ofthe three-voltmeter readings and its initial zero reading.

K is the constant of the pyrheliometer= 5 mv/cal/cm^2 mm

RESULT:

Intensity of direct solar radiation is.....

INFERENCE:

OBSERVATION:

Serial No..	Time	Volt meter reading in mv	Mean

Date:

Exp No:**05**

DETERMINATION OF EMISSIVITY OF SPECIMEN(EMISSIVITY APPARATUS)

AIM:

To measure the emissivity of a surface.

EXPERIMENTAL APPARATUS:

Two vertical aluminum plates (25 [cm] square), one blackened and the other polished (the sample plate) are electrically heated to identical temperatures (measured by thermocouples). Since they are identically oriented their surface temperatures (film tem: and hence properties) are same, heat transferred by natural convection will be identical for them. Then, the difference in heat input is due to the difference in the h at lost by radiation.

PRINCIPLE & CALCULATIONS:

Heated bodies exposed to cold air lose heat by radiation and by natural convection. It is difficult to estimate the heat transferred by natural convection accurately. Hence a comparison method should be used for this purpose. The calculations involved are:

If Q_s and Q_b are the heat input into the black and sample

(polished) plates respectively. Then, $Q_b = \sigma A_b(TW_b^4 — Ta^4)$

and, $Q_S = \sigma A_s€ (_{Tws}^4 — Ta^4)$ Since, the plate areas as well as temperatures are same Q_b-Q_s $=\sigma As (1 -€) (TW_b^4 — Ta^4)$ From this, the emissivity of the sample plate. can be calculated.

EXPERIMENTAL PROCEDURE:

(1) Check that all thennocouples indicate room temperature. (2) Switch the heaters of both plates on. (3) Smce the black plate loses more heat adjust the heat input accordingly. (4) Not down all the readings every 10 [min] till steady state is reached. (5) Wait for 90 [min]. (6) Make final adjustments 1 0 bring the plate temperature at steady state.

RESULT:

The emissivity of the surface ==

MEASUREMNTOF EMISSIVITYOF SURFACE

OBSERVATIONS:

Area of the plates, A_b= .....M^2

A_s= ..... M^2

Ambient temperature, T_a= .....^oC

Sl. No.	Time	Voltage across the thermocouples of black surface				Avenge Temp.	Voltage across the thermocouples of polished surface				Avenge Temp.	Power I/P to black body	Power I/P to polished body	Heat radiated by black body	Heat radiated by polished body	Emissivity of polished body
		B_1	B_2	B_3	B_4		S_1	S_2	S_3	S_4						
Unit	Sec	mv	mv	Mv	mv		mv	mv	Mv	mv	$_oC$	w	w	w	W	

Date:

Exp No:**06**

DETERMINATION OF LMTD AND EFFECTIVENESS OF PARALLEL AND COUNTER FLOW HEAT EXCHANGER (CONCENTRIC TUBE HEAT EXCHANGER).

:

AIM:

This experiment aims at determi4flng the overall heat transfer coefficient and the effectiveness of the concentric tube heat exchanger.

EXPERIMINTAL SEF UP:

As the name indicates, in this, two tubes are placed concentric tubes one inside the other. Hot water from the geyser flows inside the inner tube and co1d water from overhead tank flows inside the annulus formed by the two tubes. The outer tube is insulated so that all the heat lost by the hot fluid is absorbed by the cold one. Thermometers are provided for measuring the inlet and outlet temperatures of the hot and cold water. Mass flow rate of water is determined by noting the time needed (by stopwatch) to collect a known quantity of water (in measuring jar).

PRINCIPLE & CALCULATIONS

An electric heater heats water flowing from an overhead tank to the desired temperature. This hot water, circulating through tubes, exchanges heat with cold water circulating through shell. The coefficient of heat transfer is obtained by equating the heat lost by the hot water to the heat gained by the cold water. The calculations involved are:

a) Logarithmic Mean Temperature Difference (LMTD)

It can be shown (see the instruction sheet for forced convection) that when temperatures of both fluids or temperatures of fluid and wall changes, the proper temperature difference is LMID (also denoted θm), defined as

$\theta m = (\Delta T)_1 - (\Delta T)_o / In ((\Delta T)_1 / (\Delta T)_o)$

Where, $(\Delta T)_1 = (T_h — T_c)_x = o$

$(\Delta T)_o = (_{Th}-T_c) \; x = L$

In these expressions, .T_h denotes the temperature of hot fluid in [°C], T_c denotes the temperature of cold fluid in [°C], x 0 denotes the heat exchanger entrance and x = L denotes the exit of the heat exchanger.

b) Heat Transfer Rates

The heat absorbed by the cold water is computed as

$Q_c = M_c * C_c * (T_{ce} _ T_{ci})$

Where, T_{ci} is the inlet temperature of the cold water and T_{ce} is the exit temperature. Similarly, the heat lost by the hot water is obtained from the formula,

$Q_h = M_h * Ch * (T_{hi} - T_{he})$

Where, T_h denotes the inlet temperature of hot water and T_{he} is the exit temperature. M_h & M_c are mass flow rate for hot and cold water respectively. C_h & C_c are specific heat for hot and cold fluid respectively.

c) Heat Balance

The energy conservation principle (energy balance) principle demands that $Q_c = Q_h$, i.e., heat absorbed by cold water equals heat lost by hot water. If this condition is not satisfied, then $Q_h - Q_c$ is the heat lost and should be accounted for.

d) Overall Heat Transfer Coefficient (Q)

This is defined by the equation,

. $Q = F * U * A * \theta m$

Where, θm is the LMTD defined above. When the flow arrangement is neither pure parallel flow nor counter flow as in our case, the correction factor, denoted as U, is obtained from experimental curves.

This equation shows that the value of overall heat transfer coefficient depends on the choice of the surface area. Choosing the area of outside surface of tubes, we get the shell side overall heat transfer coefficient as

$Us = Q/(A_o * \theta m)$

Where, the outside surface area of tubes is computed as

$Ao = (\mu * Do^2)/4$

e) Effectiveness (€

This is defined as

$E=(Q_1)/Q_{rnax}$

Where, Q_1 is the actual heat transferred (Q_h or Q_c). The maximum heat transferred is computed as

$Q_{max}=(M*C)_{min} *(T_{hi}-Tci)$

PRECAUTIONS:

Ensure free flow of water through heater, shell and tubes by opening all valves. If the ammeter and voltmeter readings are abnormal switch the mains off and rectify the fault. Ensure that the maximum flow rate in either circuit does not exceed 9 [1 itres/min).

EXPERIMENTAL PROCEDURE:

- Start the flow of both water streams.
- Check that the inlet and outlet temperatures of these two streams are same and at atmospheric value.
- Switch the geyser on.
- Take readings of the inlet and outlet temperatures as well as the mass flow rates of each stream every 10 [minute] till steady state is reached.

RESULTS:

The overall heat transfer coefficient =

The effectiveness of the heat exchanger =

OBSERVATIONS:

Sl.No.	Time for collecting 1 liter of water		Temperature of water				Mass flow rate of water	
	Hot water	Cold water	Hot water		Cold water		Hot water	Cold water
			Inlet	Outlet	Inlet	Outlet		
	T_h	T_c	T_{hi}	T_{ho}	T_{ci}	T_{co}		
Units	S	S	$_oC$	$_oC$	$_oC$	$_oC$	Kg/s	Kg/s
1								
2								
3								
4								
5								
6								

Date:

Exp No:**07**

DETERMINATION OF SOLAR RADIATION FLUX DENSITY USING PYRANOMETER

AIM:

To find the intensity of diffused solar radiation.

APPARATUS:

Pyranometer consists of a thin blackened surface which is supported inside a relatively massive well-polished case. A multi junction thermopile is connected to the sensitive surface, which is blackened by Parson' s black lacquer.. Two concentric glass domes; made of special flint glass 30 & 50 mm in diameters, Protect it. The thermopile is fitted in a cylindrical chamber of a solid brass case. Two electrical leads of the thermopile are taken out through two tubes. The instrument can be accurately leveled by means of three leveling screws and the circular spirit level.

PRINCIPLE AND CALCULATIONS:

The solar radiation falling on a black surface will cause a temperature rise . This temperature rise can be measured by using a thermopile and is a measure of the intensity solar radiation

The calculation involved is:

Intensity of the direct solar radiate I == V/K (cal/cm2/min), where

V is mean of the three milli voltmeter readings (mV)

K is the Pyranometer constant 5 mV/cal/cm2/min

PRECAUTIONS:

The Pyranometer is an instrument which must be handled with utmost care. The instrument should be mounted in such a position that the sun's rays falling on it are not obstructed. The readings should be taken at steady state conditions.

PROCEEDURE:

The instrument was placed on a leveled platform or table directly. Under the sun. The voltmeter was kept in the shade and the two leads of the thermopile were connected to it. Three readings of the output of the pyranometer on the voltmeter, along. along with the time

taken were noted down. The experiment was repeated by changing the location of the Pyranometer.

RESULT:

Intensity of diffused solar radiation =

OBSERVATION:

Serial No..	Time	Volt meter reading in mv	Mean

Date:

Exp No:**08**

DETERMINATION OF HEAT TRANSFER COEFFICIENT IN FREE CONVECTION (NATURAL CONVECTION APPARATUS).

AIM:

(a) To determine the local heat transfer coefficient.

(b) To compare the experimental and theoretical values.

APPARATUS:

The test section is an electrically heated vertical brass tube (d = 22mm & L = 265mm) enclosed by a rectangular duct three sides of which are made of metal. The front side made of glass. The surface temperature of the brass tube is measured by thermocouples at a number of places.

PRINCIPLE AND CALCULATIONS:

The relation $Q = hA(T_w - T_f)$ defines convective heat transfer coefficient, h between a fluid at temperature T_f and a surface (wall) at temperature T_w, where, the surface area of the tube is computed as $A = \pi dL$

The heat input to the electric heater is calculated by the formula, Q(X/t)*(3600/K), where, X is the number of revolutions of the energy meter disc in t seconds and K is the meter constant in [rev/kWh). Then, the heat input will be in [kWsj. From this. the heat transferred by radiation should be subtracted. But considering the magnitude, the effect of radiation is neglected.

Heat transfer coefficient can be theoretically determined from the relation h=Nuk/L, where k is the fluid thermal conductivity For a vertical cylinders and plates, the following equations are recommended for Nusselt number:

for $10^4 < GrPr < 10^9$, $Nu = O.59(GrPr)^{¼}$

and for $10^9 < GrPr < 10^{12}$, $Nu = 0\ 1\ 3(GrPr)^{1/3}$

Here the Grashofs number is defined as $Gr = g\beta L^3 (T_w - T\alpha)/v^2$, and

The Prandtl number is defined as $Pr = C\rho\mu/k$,

where, g is the acceleration due to gravity in (m/s^2),

L is the length of test section in (m),

μ is the dynamic viscosity in (Ns/m^2),

v is the kinematics viscosity in (m^2/s),

c_p is the specific heat in (J/kgK),

k is the thermal conductivity offluid in (W/mK).

For gases, the coefficient of volume expansion is $\beta = 1/T_r$

where T_f, = (Tw+Tα/)2 is the absolute film temperature.
All the fluid properties are taken from data book at film temperature
To calculate local heat transfer coefficient 'h' substitute T_f and T_w respectively in expression together with appropriate heat flux, Q

PRECAUTIONS:

Vary position should be kept at minimum position while system was switched on and selector switch should be kept in off position initially.

PROCEDURE:

- Switch the selector switch to natural convection to facilitate current flow through heating element.
- Note down the temperature indicated by all thermocouples and ensure that they are near atmospheric temperature.
- Switch on the heater.
- Adjust the variac to get required input.
- Every 10mm, note down the temperatures T_1 , T_2, T_3, T_4 and T_5 till steady state (i.e., values remain constant for two successive periods).
- Note down the time needed for 5 revolution of energy meter disc.

RESULT:

Calculated experimental and theoretical values of heat transfer coefficient.
Experimental value of heat transfer coefficient =
Theoretical value of heat transfer coefficient =

INFERENCE

Observations:

(1) Tube diameter = 22 mm

(2) Length = 265 mm

Sl . No.	Serial Clock time, t	Temperature Readings										Current through the Coil A (amp)	Time for 'n' rev. Of the Engergy meter, t(sec)
		T_1		T_2		T_3		T_4		T_5			
		mV	$_oC$	mV	$_oC$	mV	$_oC$	mV	$_oC$	mV	$_oC$		

Date:

Exp No:**09**

DETERMINATION OF HEAT TRANSFER COEFFICIENT IN FORCED CONVECTION (FORCED CONVECTION APPARATUS).

AIM:

To conduct a test on forced convection equipment to determine.

1 . The heat transfer coefficient.

2. To compare the experimental value with theoretical value.

APPARATUS:

The set up consists of a U-shaped hollow GI pipe enclosing a heating element (test section) fixed horizontally on a table. One end of the pipe is connected to the blower outlet which forces air into the pipe. Other end is kept opened to atmosphere. Thermocouple sensors are provided on the surface of the pipe and are connected to the temperature indicators to measure the following temperatures.

- Inlet air temperature
- Outlet air temperature
- Surface temperature of pipe

A U-tube manometer and orifice meter is provided to measure the airflow through the pipe. Panel board also features ammeter, voltmeter, selector switches etc.

SPECIFICATIONS:

Length of test section confining heating element, L — 267 mm

Inner diameter of pipe, D_1 —34 mm

Diameter of heating element, D_2 . — 22 mm

Orifice plate diameter, d — 27.4 mm

Coefficient of discharge, C_d — 0.62

Energy meter constant — 2400 rev I KW Hr

PRINCIPLE:

Air flow rate. Q

Manometric head, h (h_1 -h_2) (m), where

(h_1- h_2) is the height difference between two limbs of the manometer.

Density of air at NTP, (ρ_{air}) NTP = 1 .293 (kg/m^3)

Density of water, ρw = 1000 (Kg/ m^3)

Density of air at RTP, $(\rho air)_{RTP}$ $= \dfrac{(\rho air)\ NTP \times 273}{(273 + t_{amb})}$ (Kg I m3)

Where t_{amb} is the ambient temperature.

Equivalent air head, $H_m = (h_w \times \rho_w) / (\rho_{air})$ RTP (m)

Area of orifice, $A_0 = \mu d_2 / 4$ (m), where d is the diameter of orifice plate.

Volumetric flow rate of air, $Q = C_d \times A_0 \times \sqrt{(2gH_m)}$ (m3/s)

Flow velocity, V

Flow area of pipe, $A = (\pi/ 4) \times (D_1^2 - D_2^2)$ (m^2),

Where D_1 is the inner diameter of pipe and D_2 is the diameter of heating element.

Flow velocity, V = Q /A (m/s)

Heat transfer, q

Heat transfer area, A_s $= \pi \times D_2 \times L$ (m^2)

Mass flow rate of air, m $= Q \times (\rho_{air})_{RTP}$ (Kg/s)

Heat transferred in to air, $q = m \times c_\rho \times (T_9 - T_6)$ (W), where

T_9 is the outlet air temperature in °c and

T_6 is the inlet air temperature in °c

For internal flow through pipe, heat transfer is also given by

$q = h_{expt} \times A \times T_s - T_b)$, where h_{expt} is the experimental value of heat transfer coefficient $(W / m^2 K)$, where

T_b is the bulk mean temperature, $T_b = (T_6 + T_9) / 2$ and

Ts is the surface temperature, $Ts = (T_7 + T_8)/ 2$, where

T_7 and T_8 are the surface temperatures of heating section-at steady state.

$$h_{expt} = \frac{m \times c_\rho \times (T_9 - T_6)}{A \times (T_s - T_b)} \quad (W/m2°K) - -$$

Theoretical Heat Transfer Coefficient $h_{theoretical}$

Fluid properties are evaluated at $T_b = (T_6 + T_9) /2$

Prandtl number, Pr

Another non-dimensional number, which takes into, accounts three physical properties of the fluid at a time. It signifies the relative speed with which momentum and energy are propagated through a fluid. It is given by the equation.

Pr =(π x C_p) / k, where
π is the coefficient of dynamic viscosity (N s / m^2),
c_p is the specific heat of fluid (J / kg°K) and
k is the thermal conductivity of fluid
All properties are evaluated at T_r

Nusselt Number. Nu

A non-dimensional number which gives the measure of heat transfer rate. It is found from the equation.

N_u = 0,59 (G_t P_t) ^{025} for $10^4 < G_r P_r < 10^9$ and
N_u = 0.13 (G_r P_r) ^{033} for $10^9 < G_r P_r < 10^{12}$ where,
Grashoff no Gr = (g x L^3 x β x(T_5—T_α))/ v^2 and
prandtl no P_r = (π x c_ρ) / K_f where

g = acceleration due to gravity (m/s^2), .
L= length of test section (m),
π= dynamic- viscosity (Ns/m^2),
v = kinematic viscosity (m^2/s),
c_ρ =specific heat(J/kg K),
K_f= thermal conductivity of fluid (w/m k) and
β is the coefficient of thermal expansion , $\beta=1/T_f$ where .
T_f is the absolute film temperature, K
T_f= (T_s +T_α)/2
(All the fluid properties are taken at film temp. from data book)
Nusselt Number is also given by
Nu(hxLc)/k

Reynold's number. Re

Reynold's number is a non dimensional number which decides the type of flow and is the ratio of inertia force to viscous force. It is given by the equation

Re = V x Lc /υ, where

Lc is the characteristic length, Lc= D_1 - D_2 (m)
Nu (h x Lc) I k = 0.023 x (Re)°8 x(Pr)°4 for 2300 < Re < iO for laminar flow (for Re < 2300)
Nu= (h x Lc)/k =0.023 x (Re)$0_{.8}$ x $(Pr)^{0.4}$ for $2300<Re<10^7$
For laminar flow(for Re < 2300)
Nu=3.65 + {[0.0688 x(d/Lc) x (Re x Pr)] / [1+0.04 x [(d/Lc) x (Re xPr)] $^{(2/3)]\}}$
N_u = (h xLc)//K

Date:

Exp No:**10**

DEMONSTRATION OF FINDING CRITICAL THICKNESS OF INSULATION OF A MATERIAL

AIM:

To conduct an experimental to determine the critical thickness of asbestos rope

APPARATUS:

Multimeter, Auto transformer

SPECIFICATIONS:

GI Pipe (4 Nos), Length=l5cm

Inner Radius2.85cm

Insulation	Pipe1	Pipe 2	Pipe 3	Pipe4
Outer Radius in cm	6.41	5.46	4.77	3.85

PRINCIPLE:

Heat transfer through insulation $Q= T_i-.T_o/ (R_{ins}+R_o)$

Where $R_o=1/2\pi\ r_oLh$

R_{ins}=in $(r_o/r_1)/ 2\ \pi$ KL

T_o = Outer temperature of the insulation

T_1= Inner temperature of the insulation

r_o = Outer radius of the insulation

r_1 = Inner radius of the insulation

K= Thermal conductivity

h= Co-efficient of heat transfer

L= Length of the pipe

CRITICAL RADIUS OF INSULATION:

It is possible that R0 may decrease faster than increase causing an increase in Q. In fact that Q would approach zero if infinite amount of insulation were added. This means that there must be a value of r0 for which Q is maximum. This value of r_o is known as critical radius of insulation.

PROCEDURE:

- Connect the experimental set up to the autotransformer.
- Switch on the supply.
- Take the readings of the thermocouple using multimeter
- Note down the readings till steady state is reached.

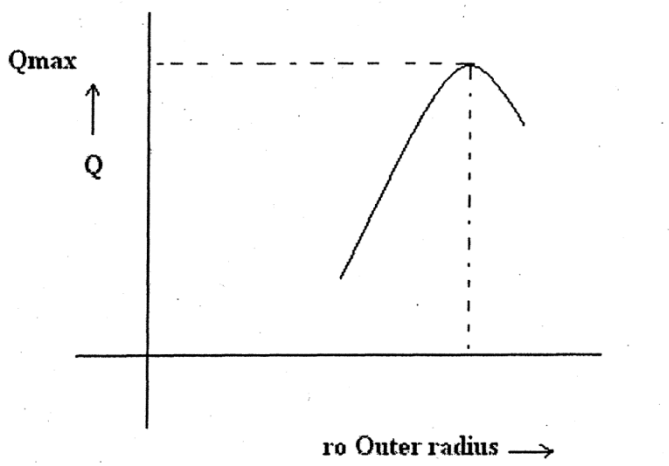
RESULT:

The values of heat flux obtained in each case are plotted against the corresponding insulation.
From graph, critical radius of insulation =
Critical thickness of insulation =

OBSERVATION

Sl. No.	Length of Tube L	Inner Dia of insulation d_1	Outer dia of insulation d_0	Inner Temperature					Outer Temperature					Heat Transfer Q
				T_1	T_2	T_3	T_M	$_oC$	T_1	T_2	T_3	T_M	oC	
Unit	cm	cm	cm	mv	mv	mv	mv	$_oc$	mv	mv	mv	mv	$_oc$	w
1														
2														
3														

GRAPH:



Date:

Exp No:**11**

DETERMINATION OF THERMAL CONDUCTIVITY OF METAL ROD

AIM:

To determine the thermal conductivity of metal rod

EXPERIMENT AL APPARATUS:

A 48 mm diameter, 500 mm long circular steel rod is gas heated at one end The rod is insulated along its periphery so that heat is conducted axially. Thermocouples placed at a distance of 100 mm measures of axial temperatures. The rate of heat conduction is measured by a calorimeter fixed at the other end of the rod. Stoap watch and measuring jar are used to measure water flow rate thermometer measure the temperature rise of water .

PRINCIPLE:

A cylindrical metal rod is heated by at one end and cooled at the other .Its cylindrical surface is insulated so that the rod conducts heat axially. Its temperature is measured at some points along the axis. By Fourier's equation, the heat conducted at steady state is $Q=KA(\Delta T/\Delta x)$

By measuring Q, the rate of heat conducted and the temperature drop 'ΔT 'with in the distance 'Δx 'thermal conductivity can be calculated since $A= \pi d^2/4$

(l) The energy equation gives the rate of heat conduction as

$Q=mc\ (T_1-T_2)$

Where m is the mass flow rate of water, c is the specific heat(c=4.1868kj/kgk), T_1 and T_2 are its inlet and exit temperatures

(2) Heat conduction equation

$Q=KA\ (\Delta T/\Delta x)$

$K= (Q/A)\ (\Delta T/\Delta x)$ where $A= \pi rd^2/4$

PROCEEDURE:

- Verify that all thermocouples read from temperature
- Check that the thermometers read properly
- Start heating the rod by gas

- Take the readings of all thermocouples and the thermometers every 10 minutes till steady state is reached .
- Measure the water flow rate

RESULT:

The thermal conductivity of metal rod is.....

OBSERVATION:

Sl. No.	Voltmeter Readings				Temperature Reading				Node			
	T_1	T_2	T_3	T_4	V_1	V_2	V_3	V_4				
Unit	mv	mv	mv	mv								

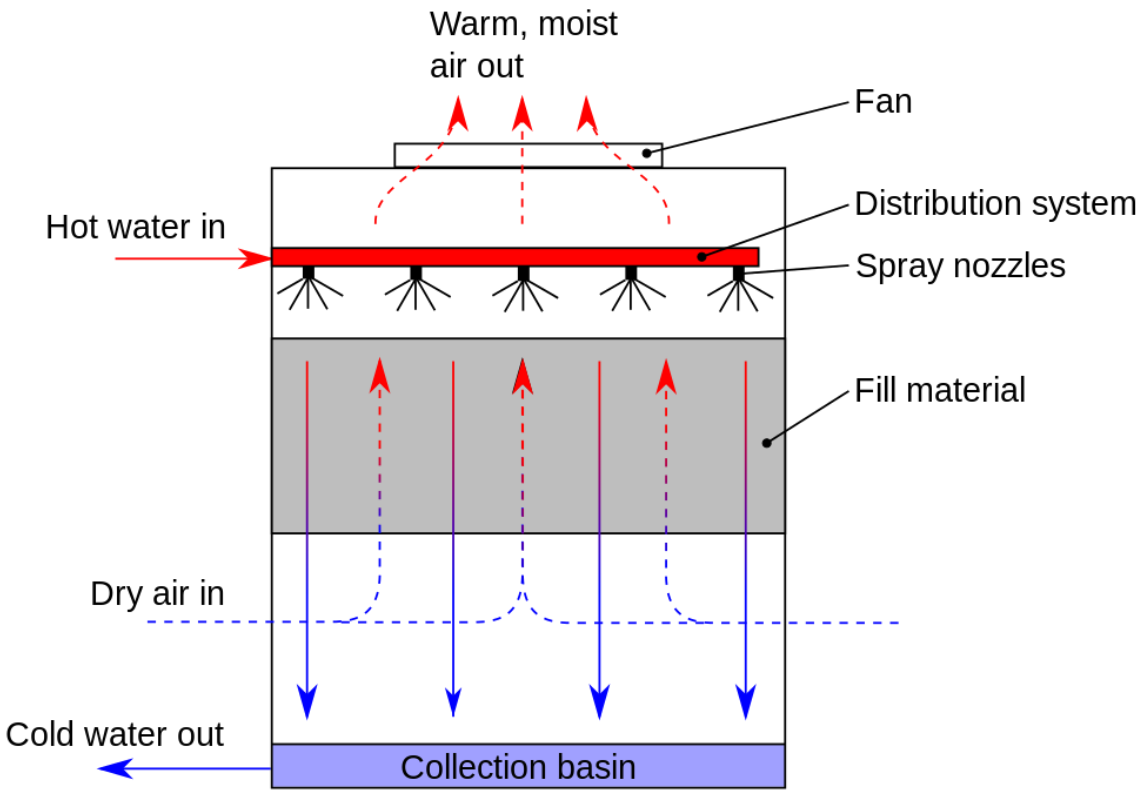
Date:

Exp No:**12**

DEMONSTRATION OF HEAT TRANSFER MECHANISM IN A MIXED FLOW, INDUCED DRAFT COOLING TOWER

AIM: To demonstrate the working of an induce Draft Cooling Tower

PRINCIPLE: A cooling tower is a heat rejection device that rejects waste heat to the atmosphere through the cooling of a water stream to a lower temperature. Cooling towers may either use the evaporation of water to remove process heat and cool the working fluid to near the wet-bulb air temperature or, in the case of *closed circuit dry cooling towers*, rely solely on air to cool the working fluid to near the dry-bulb air temperature.



In a counterflow design, the air flow is directly opposite to the water flow (see diagram at left). Air flow first enters an open area beneath the fill media, and is then drawn up vertically. The water is sprayed through pressurized nozzles near the top of the tower, and then flows downward through the fill, opposite to the air flow.

Advantages of the crossflow design:

- Gravity water distribution allows smaller pumps and maintenance while in use.
- Non-pressurized spray simplifies variable flow

Disadvantages of the crossflow design:

- More prone to freezing than counterflow designs.
- Variable flow is useless in some conditions.
- More prone to dirt buildup in the fill than counterflow designs, especially in dusty or sandy areas.

RESULT

The basic working of an induced Draft Cooling Tower is done

Date:

Exp No:**13**

DEMONSTRATION OF THE USE OF *EXTENDED* SURFACES TO IMPROVE THE *HEAT TRANSFER* FROM THE SURFACE.

AIM:

To conduct an experiment to determine the temperature distribution and heat transfer rate through extended surface of different quantities geometncs and to compare the experimental result with those obtained from theoretical calculation m a given fin apparatus .

PRINCIPLE:

Heat transfer through metal tod takes place by the process of conduction and dissipation of heat to the environment takes place by the process of forced convection The fin increases the effective area of cross section thereby increasing the rate of heat transfer.

CALCULATION:

Calculation of heat transfer coefficient

ΔP = Pressure difference = $\rho g (h_2 - h_1)$

ρ = Density of air at room temperature A= Area of orifice

A = Area of orifice

D = Diameter of fin

π = Dynamic viscosity

$Re=(m/A)*D/\pi$

$N_{UD} = 0.683(Re)^{0.466} (Pr)^{0.33}$

Re= Reynolds number

Pr = Prandtl's number

$h= (N_{uD}*k)/D$

h = Heat transfer coefficient

Short Rectangular Aluminium Rod

(a) Theoretical value of temperature at particular distance 'x' from root is

$T_x = T\alpha + (To - T\alpha) e^{-mx}$

T_o = Root temperature

$T\alpha$ = Ambient temperature

$m= \sqrt{IhP/kA}$

P = Perimeter of rod =2 (l+b)

k = Thermal conductivity

A = Area of cross section

m = Mass flow rate

(b) Heat dissipation, $Q= \sqrt{hP/kA} (T_o - T_\alpha)$

(c) Fin effectiveness, $tanhml/ \sqrt{hP/kA}$

PRECAUTION:

Ensure that no materials enter the plenum duct that would cause failing of bower blades The readings should only be taken when the temperature readings are steady Also take notice to close the gas valve after doing the experiment.

PROCEDURE:

After attaining steady state the voltage readings of all the thermocouples using the milli voltmeter convert it to temperature using conversion charts Measure the pressure drop from the manometer and also the ambient temperature.

RESULT: :

The experiment of heat conduction through extended surface was conducted and the following values are obtained

Heat transfer coefficient, h=

Theoretical temperature at x=L/4, $T_{L/4}$ =

Theoretical temperature at x=L/2, $T_{L/2}$ =

Theoretical temperature at x=3L/4, $T_{31/4}$ =

Fin Effectiveness, t=

OBSERVATION

Sl.No.	Root temp	Temp at x=1/4	Temp at x = ½	Temp at x = 3¼	Theoretical temp at x = ¼	Theoretical temp at x = ¼	Theoretical temp at x = ½	Theoretical temp at x = 3¼	Heat dissipated	F
Unit	^oC	^oC	^oC	^oC	^oC	^oC	^oC	^oC	^oC	

PRACTICAL EVALUATION SHEET
HEAT AND MASS TRANSFER LAB

STUDENT NAME: **ROLL NO:**

Exp.No.	Name of Experiment	Date of Exp.	Lab Practicals and Record					TOTAL (70)	Remarks
			Procedure (10)	Observations (10)	Result (10)	Record (30)	Viva (10)		
1	Determination of LMTD and effectiveness of shell & tube heat exchanger								
2	Determination of transient heat transfer characteristics of a lumped system copper sphere								
3	Determination of transient heat transfer characteristics of a lumped system brass cylinder								
4	Determination of solar direct normal irradiance (DNI) using pyrheliometer								
5	Determination of emissivity of specimen (emissivity apparatus)								
6	Determination of LMTD and effectiveness of parallel and counter flow heat exchanger (concentric tube heat exchanger).								
7	Determination of solar radiation flux density using pyranometer								
8	Determination of heat transfer coefficient in free convection (natural convection apparatus).								
9	Determination of heat transfer coefficient in forced convection (forced convection apparatus).								
10	Demonstration of finding critical thickness of insulation of a material								
11	Determination of thermal conductivity of metal rod								
12	Demonstration of heat transfer mechanism in a mixed flow, induced draft cooling tower								
13	Demonstration of the use of *extended* surfaces to improve the *heat transfer* from the surface								