LAB MANUAL

HEAT TRANSFER

(MED 373)

G.S. Mandal's

MAHARASHTRA INSTITUTE OF TECHNOLOGY,

AURANGABAD

DEPARTMENT OF MECHANICAL ENGINEERING

	G.S. Mandal's **MAHARASHTRA INSTITUTE OF TECHNOLOGY, AURANGABAD** **DEPARTMENT OF MECHANICAL ENGINEERING**

NAME OF LABORATORY: HEAT TRANSFER

LABORATORY MANUAL

CLASS: THIRD YEAR	**PART:** II	**COURSE CODE: MED** 373

NAME OF COURSE: HEAT TRANSFER

INDEX

Vision: To be a center of excellence in the field of Mechanical Engineering where the best of teaching, learning, and research synergize and serve the society through innovation and excellence in teaching.

Mission: To provide world-class undergraduate and graduate education in Mechanical Engineering by imparting quality techno-managerial education and training to meet the current and emerging needs of the industry and society at large.

Program Educational Objectives [PEOs]

PEO-I Graduates will apply the tools and skills acquired during their undergraduate studies either in advanced studies or as employees in engineering industries

PEO-2 Graduates of the program will have a successful technical and professional careers.

PEO-3 Graduates of the program will continue to learn to adapt constantly evolving technology.

PEO-4 Graduates will demonstrate sensitivity toward societal issues.

Program Outcomes [POs]

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems
2. **Problem analysis:** Identity, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using the 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 search 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 modelling 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.

Program Specific Outcomes [PSOs]

PSO-I: Ability to design & analyse components & systems for mechanical performance

PSO-II: Ability to apply and solve the problems of heat power and thermal systems.

PSO-III: Ability to solve real life problems with the exposure to manufacturing industries

Course Objective of Heat Transfer [MED322]

- The laboratory course is aimed to provide the practical exposure to the students about the determination of amount of heat transferred/exchanged in various modes of heat transfer including thermal conductivity of different materials and determination of different constants in heat transfer.

Course Outcomes of Heat Transfer [MED303]

On successful completion of this Course, students should be able to:

CO1	Explain the basic concepts, laws of heat transfer, various modes of heat transfer and fundamentals of heat Exchangers.
CO2	Develop solution for one dimensional steady state heat conduction and unsteady state heat conduction problem.
CO3	Analyze fundamental relationship between thermo-physical properties and modes of heat transfer.

CO4	Choose empirical correlations for forced, free convection and phase change process to determine values for the convection heat transfer coefficient
CO5	Formulate numerical solutions for radiation heat transfer problems
CO6	Evaluate the temperature profiles and performance of fins and heat exchangers.

University Syllabus

Dr. Babasaheb Ambedkar Marathwada University, Aurangabad
(Faculty of Science & Technology)
Syllabus of Third Year B. Tech (Mechanical Engineering) Semester VI

Course Code: MED373 Course: Lab-Heat Transfer **Teaching Scheme:** Practical: 2 Hrs/week	Credits: 0-0-1 Practical: 25 Marks

Course Content (Any 10 of the following)
The lab work consists of the assignments/experiments related to
1. Determination of Thermal conductivity of metal rod
2. Determination of Thermal conductivity of Composite Wall
3. Determination of Thermal conductivity of Insulating Powder
4. Determination of the local heat transfer coefficient of air for a vertical tube losing heat by natural convection.
5. Determination of average heat transfer coefficient in forced convection of air in a tube.
6. Determination of heat transfer, fin efficiency and temperature distribution along the length of pin-fin in natural and forced convection.
7. Experimental verification of Steffen Boltzmann's constant.
8. Determination of emissivity of the test plate surface.
9. Determination of LMTD, the heat transfer rate, overall heat transfer coefficient and effectiveness for parallel flow and counter flow arrangement of a heat exchanger.
10. Determination of heat transfer coefficient in dropwise and film wise condensation.
11. Experimental study of pool boiling phenomenon up to critical heat flux point.
12. Assignments on Unit I, II, III,IV,V,VI (Any Three)

The assessment of term work shall be done on the basis of the following.

- Continuous assessment
- Performing the experiments in the laboratory
- Oral examination conducted on the syllabus and term work mentioned above.

Laboratory Instructions

Please Do: -

- Switch off all electrical appliances before leaving the lab.
- Sign on the lab utilization register before leaving the lab.
- Inform to the lab-in-charge/instructor about any abnormal incidence immediately.

Please Do Not: -

- Touch any equipment/s without permission.
- Start or stop any equipment/s without permission.
- Start or stop any equipment/s in the absence of course coordinator.

EXPERIMENT NO. 1
DETERMINATION OF THERMAL CONDUCTIVITY OF METAL ROD

OBJECTIVE

To determine thermal conductivity of given metal bar.

INTRODUCTION

Thermal conductivity is the physical property of the material denoting the ease with which a substance can accomplish the transmission of thermal energy by molecular motion. Thermal conductivity of a material is found to depend on the chemical composition of the substance or substances of which it is composed, the phase (i.e. gas, liquid and solid) 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 a homogeneous material.

DESCRIPTION

The experimental consists of metal bar in three pieces stacked together as shown in fig in vertical position. The top piece consists of a brass bar into which cold water is circulated by using an inlet and outlet tubes for water connections. The heater section and cooling section are both covered by a Nylon Insulating cylinder.

In the middle or below the cooling part is a specimen material to be tested for thermal conductivity is inserted in a Nylon Insulating cylinder. Then follows a lower portion of Nylon cylinder into which a portion of the brass bar is inserted in Nylon with heater. Three thermocouples are provided to the bar in bottom Heating portion, three thermocouples are provided in middle portion of the Test specimen (Aluminum, MS and Stainless Steel) is provided.

The entire portion of the three pieces of metal bar is linearly aligned to form one continuous portion with the help two clamps fitted on the outside of top & bottom pieces of Nylon portions.

SPECIFICATION

Diameter of metal bar	25 mm
Test length of the bar	28 mm
Diameter of nylon bar	80 mm
Voltmeter	0-1000V
Ammeter	0-2 amp
Dimmer stat	0-2 amp /open type, 0-230V
Heater	200W cartridge type,50mm Length,12.5mm Φ
Temperature indicator	0 – 200°C
Thermocouple	3mm Φ x 40 mm Length ,9 Qty. (Cromel-Aluminum type)
Big glass fuse	10A,250VAC (02 No)

THEORY

In good electrical conductors a rather large number of free electrons move about in the lattice structure of the material. Just as these electrons may transport electric charge, they may also carry thermal energy from a high temperature region to a low temp region. In fact, these electrons are frequently referred as the electron gas. Energy may also be transmitted as vibrational energy in lattice structure of the material. In general, however, this latter mode of energy transfer is not as large as the electron transport and it is for this reason that good electrical conductors are almost always good heat conductors viz. Copper, Aluminum and Silver.

Thermal energy may be conducted in solids by two modes: -Lattice Vibrations and Transport by free electrons.

With increase in the temperature however the increased lattice vibrations come in the way of transport by free electrons and for most of pure metals the thermal conductivity decreases with increase in temperature**.**

PROCEDURE

- tart the electric supply.
- Give input to the heater by slowing rotating the dimmer stat and adjust it to voltage equal 60 to 80, 100 volts etc. for different sets.
- Start the cooling water supply through the jacket and adjust it so that there is no temperature difference at the inlet and outlet of the water.
- Take readings when steady state condition is reached.
- Note the temperature readings 0 to 9.
- Observe the Thermal Conductivity.

OBSERVATION

- Radius of metal bar (r_i) : 12.5 mm
- Outer Radius of nylon bar (r_o): 100 mm
- Length of metal bar: 30 mm
- Length of nylon bar : 112 mm
- Distance between test plate 'dl 'or 'Δl' : 15 mm
- Thermal Conductivity of nylon bar: 0.232 W/m K

OBSERVATION TABLE

Observation Time	Voltage in Volts (V)	Current in amp (I)	Cooling side temp °C			Test piece temp °C			Heater side temp. °C			Atm. Temp °C
			T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_a

SAMPLE CALCULATION

1 Heat in put (supplied) heater q = V x I ; q = ……. Watts

2 Average temperature of heater side section $T_{avg} = (T_7+T_8+T_9)/3$; T_{avg} =________________

3 Temperature drop in specimen T_4 to T_6, $\Delta T_s = (T_4 - T_6)$; ΔT_s=____________

4 Heat loss through heating section (q)

$$q = \frac{2\Pi k l (T_{avg} - T_{out})}{\ln\left(\frac{r_o}{r_i}\right)}$$ =__________Watts

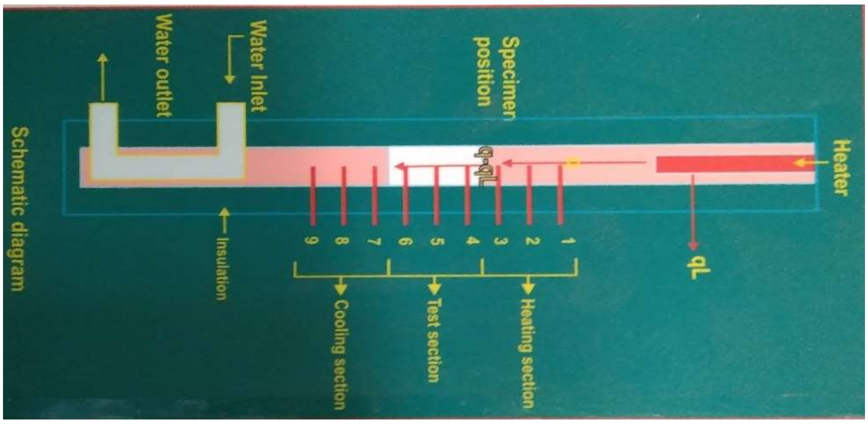
5 Thermal conductivity of specimen K,

$$K = \frac{(q - q_L) \times \Delta L}{A \times \Delta Ts} = \_\_\_\_\_\_\_\_\_\_ \text{W/mK}$$

RESULT & CONCLUSION

- The temperature of the bar decreases along the length of the bar and can be plotted.
- Thermal conductivity of test section is _________________ W/mK

DIAGRAM OF EXPERIMENTAL SET UP



QUESTIONS

1.Define 'Thermal Conductivity'.

2.Derive SI unit of thermal conductivity from its definition.

3.How thermal conductivity varies with temperature?

4.What is steady and unsteady state heat transfer?

5.State Fourier's Law of heat conduction

EXPERIMENT NO. 2
DETERMINATION OF THERMAL CONDUCTIVITY OF COMPOSITE WALL

OBJECTIVE

To determine total Thermal Resistance and Thermal Conductivity of Composite Walls.

DESCRIPTION

Many practical situations in engineering practice involve heat transfer through a medium comprising two or more material of different thermal conductivity, e.g. the walls of building, refrigerator, cold storage plants, hot water tanks etc.

The apparatus consists of a central heater sandwiched between two sheets. Three types of slabs are provided on both sides of heater, which forms a composite structure. A small hand press frame is provided to ensure the perfect contact between the slabs. A dimmer stat is provided for varying the input to the heater and measurement of input to the heater and measurement of input is carried out by a voltmeter, ammeter. Thermocouples are embedded between interaces of the slabs, to read the temperature at the surface.The experiments can be conducted at various values of input and calculation can be more accordingly.

SPECIFICATION

Heater	: 300 W nichrome heater wound on micaform Insulator
Heater control unit	: 0-230 V
Voltmeter	: 0-100-200V
Ammeter	: 0-2 A
Dimmer stat	: 0-2 A, 0-230V single phase
Temperature Indicator	: 0 – 200°C,digital type
Thermocouples	: Chromel–Alumel(8 No)

PRECAUTION

- Keep dimmer stat to zero before start.
- Increase the voltage slowly.
- Keep all the assembly undisturbed.
- Remove air gap between plates by moving handpress gently.
- While removing the plates do not disturb the thermocouples.
- Operate selector switch of temperature indicator gently.

OBSERVATION

- Diameter of all slab : 300 mm
- Thickness of all slab : 12 mm

OBSERVATION TABLE

Observation Time	Voltage in Volts(V)	Current in amp(I)	Temperature readings in ^{o}C							
			T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8

CALCULATION

For calculating the thermal conductivity of composite walls, it is assumed that due to large diameter of the plates, heat flowing through central portion is uni-directional i.e. axial flow. Thus for calculations, central half dia. area, where uni directional flow is assumed, is considered. Accordingly thermo-couples are fixed at close to center of the plates.

*Heat in put(supplied) by heater : Q = V x I   Q =_______Watts

1 Heat flux $q = \frac{Q/2}{A} = \frac{(V.I)/2}{\pi r^2} =$ _________ W/m^2

2 Total thickness of composite slab $L = L_a + L_b + L_c =$________

3 Mean reading temperatures in °C

- $T_a = [T_1+T_2]/2$ T_a = ________ ^0C
- $T_b = [T_3+T_4]/2$ T_b = ________ ^0C
- $T_c = [T_5+T_6]/2$ T_c =_________ ^0C
- $T_d = [T_7+T_8]/2$ T_d =_________ ^0C

4 Thermal resistances

- $R_a = (T_a - T_b)/Q$ R_a=_______ $^0C/W$
- $R_b = (T_b - T_c)/Q$ R_b =_______ $^0C/W$
- $R_c = (T_c - T_d)/Q$ R_c =_______ $^0C/W$

***Total Thermal resistance of composite slab** $R_{comp} = (T_a - T_d) / q$, R_{comp} = _______

5 Thermal Conductivities

- $K_a = q \times L_a/(T_a - T_b)$ = _______W/mK
- $K_b = q \times L_b/(T_b - T_c)$ = _______W/mK
- $K_c = q \times L_c/(T_c - T_d)$ =_______W/mK

***Thermal conductivity of composite slab** K = Ka + Kb +Kc, K_{comp}=_____W/mK

DIAGRAM OF EXPERIMENTAL SET UP

RESULT & CONCLUSION

1 Total Thermal resistance of composite slab R_{comp}= ________ K/W

2 Thermal conductivity of composite slab K_{comp}= _______ W/mK

QUESTIONS

1. For which material thermal conductivity is highest?
2. Why negative sign in Fourier's Law?
3. What are the units of thermal conductivity?
4. What is the physical significance of thermal diffusivity?
5. Is heat transfer a scalar or vector quantity?

EXPERIMENT No.3
DETERMINATION OF THERMAL CONDUCTIVITY OF INSULATING POWDER

OBJECTIVE

To determine thermal conductivity of an insulating powder.

INTRODUCTION

It is desirable to reduce the heat loss to the surroundings in many heat exchange equipment's. Insulating materials have a very low value of thermal conductivity and are used in different shapes, sizes and forms. Insulating powder such as asbestos because of their ease of taking any complex shape between the confining surfaces and their having large air space in between particles are in great demand these days. The thermal conductivity of an insulating powder will depend upon the geometry of the surface, particle thermal conductivity, size and number of contained air spaces and the modes of the heat transfer in different situations of the application.

DESCRIPTION

The apparatus consists of two thin walled concentric copper spheres. The inner sphere houses the heating coil. The insulating powder (Asbestos powder – lagging material) is packed between the two shells. The power supply to the heating coil is by using a dimmer stat and is measured by Voltmeter and Ammeter. Chromel Alumel thermocouples are used to measure the temperatures. Thermocouples 1 to 4 are embedded on inner sphere and 5 to 10 are embedded on the outer shell. Positions 1 to 10 are as shown in the figure. Temperature readings in turn enable to find out the thermal conductivity of the insulating powder packed between the two shells.

We assume the insulating powder as an isotropic material and the value of thermal conductivity to be constant. The apparatus assumes one-dimensional radial heat conduction across the powder and thermal conductivity can be determined.

SPECIFICATIONS

Radius of inner copper sphere r_i	: 50 mm
Radius of outer copper sphere r_o	: 100 mm
Voltmeter	: 0-200V
Ammeter	: 0-2 A
Dimmer stat	: 0-2 A, 0-230V
Heater	: 200W mica type
Temperature indicator	: 0 – 300ºC
Thermocouple	: Chromel-Alumel(8 No)
Insulating powder	: Asbestos Magnesia

Chromel Alumel Thermocouples 1 to 4 embedded on inner sphere to measure Ti. Chromel Alumel Thermocouples 5 to 10 on outer sphere to measure to. Insulating Powder – Asbestos Magnesia Commercially available powder and packed between two spheres.

PROCEDURE

- Switch on Main supply and then switch on heater switch.
- Increase slowly the input to heater by dimmer stat and adjust input 40 W by voltmeter and ammeter and this input should not change throughout experiment.
- Wait till satisfactory steady state condition is reach, this is by noting the temperature readings T_1 to T_{10} after time interval of 10 minutes
- Take the readings till steady state is reached.(i.e dT/dt =0)
- Note down the temperature readings T_1 to T_8 at steady state.

OBSERVATION

- Radius of inner sphere : 50 mm
- Radius of outer sphere : 100 mm

OBSERVATION TABLE

Sr. No	Inner sphere temperatures in ^{0}C				Outer sphere temperatures in ^{0}C					
	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**	**T_{10}**

CALCULATIONS

1 Heat in put(supplied) heater Q = V x I Q= ____________Watts

2 Average temperature of inner sphere surface $T_i = \frac{(T1+T2+T3+T4)}{4} =$ T_i =________ ^{0}C

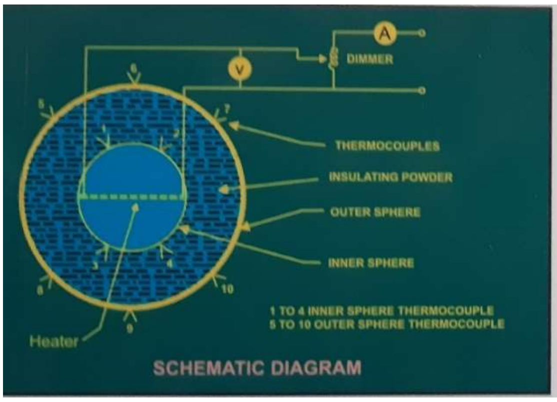
3 Average temperature of outer sphere surface $T_o = \frac{(T5+T6+T7+T8+T9+T10)}{4}$

T_0=________ ^{0}C

4 Thermal conductivity of insulating powder $K = \frac{Q(ro-ri)}{4\pi\, ri.ro(Ti-To)} =$

K=………W/mK

DIAGRAM OF EXPERIMENTAL SET UP



RESULT & CONCLUSION

Thermal conductivity of insulating powder is=___________W/mK

QUESTIONS

1. Explain concept of critical radius of insulation.
2. What is critical radius of insulation for cylinder and sphere?
3. Differentiate between heat insulator and heat conductor
4. Define thermal diffusion and thermal conductance.
5. Enlist different heat insulators used along with the values of their thermal conductivities.

EXPERIMENT NO 4

DETERMINATION OF THE LOCAL HEAT TRANSFER COEFFICIENT OF AIR FOR A VERTICAL TUBE LOOSING HEAT BY NATURAL CONVECTION

OBJECTIVE

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

INTRODUCTION

In contrast to the forced convection, Natural convection phenomenon is due to the temperature difference between the surface and the fluid and is not created by any external agency. The present experimental set up is designed and fabricated to study the natural convection phenomenon from a vertical cylinder in terms of the variation of local heat transfer coefficient and its comparison with the value obtained by using an appropriate correlation.

DESCRIPTION

The apparatus consists of a cartridge heater with 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. One side of the duct is made up of Perspex for visualization. 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 seven thermocouples.

The heat input to the heater is measured by an ammeter and a voltmeter and is varied by a dimmer stat. The vertical cylinder with the thermocouple positions is shown in the fig , while the possible flow pattern and also the expected variation of local heat transfer coefficient. The tube surface is polished to minimize the radiation losses.

SPECIFICATIONS

Diameter of the heater(d)	: 25 mm
Length of the heater (L)	: 750 mm
Duct size	: 250mmx250mmx900mm
Ammeter	: 0-2 A
Voltmeter	: 0-200V
Dimmer stat	: 0-2 A, 0-230V
Heater	: 400W Cartridge type
Temperature indicator	: 0 – 200°C
Thermocouple	: Chromel-Alumel(8 No)

THEORY

When a hot body is kept in a still atmosphere, heat is transferred to the surrounding fluid by natural convection. The fluid layer in contact with the hot body gets heated, rises due to the decrease in its density and the cold fluid rushes in from bottom side. The process is continuous and the heat transfer takes place due to the relative motion of the hot and cold fluid particles.

The surface heat transfer coefficient, of a system transferring heat by natural convection depends on the shape dimensions and orientation of the fluid and the temperature difference between the heat transferring surface and the fluid. The dependence of 'h' on all the above-mentioned parameters is generally expressed in terms of non-dimensional groups

PROCEDURE

- Switch on main supply and then switch on heater switch.
- Increase slowly the input to heater by dimmer stat and adjust input 40 W by voltmeter and ammeter and this input should not change throughout experiment.
- Wait till satisfactory steady state condition is reach, this is by noting the temperature
- readings T_1 to T_8 after time interval of 10 minutes
- Take the readings till steady state is reached.(i.e dT/dt =0)
- Note down the temperature readings T_1 to T_8 at steady state.

OBSERVATION

- Diameter of the heater(d) : 25 mm
- Length of the heater (L) : 750 mm
- Input to heater : V x I in watt

OBSERVATION TABLE

Observation Time	Voltage in Volts(V)	Current in amp(I)	Temperature readings in ^oC							
			T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8=Ta

CALCULATIONS

***Experimental heat transfer coefficient**

- Heat in put(supplied)heater Q = V x I, Q=…………..Watts
- Area of heat transfer surface As= π. d. L , As=…………m^2

- Average temperature of tube surface Ts $= \frac{(T1+T2+T3+T4+T5+T6+T\ \ )}{7}$

  Ts= ______ ^{0}C
- Heat transfer coefficient h $= \frac{Q}{As(Ts-T\ \ )}$

  h=_______W/m^{2}K

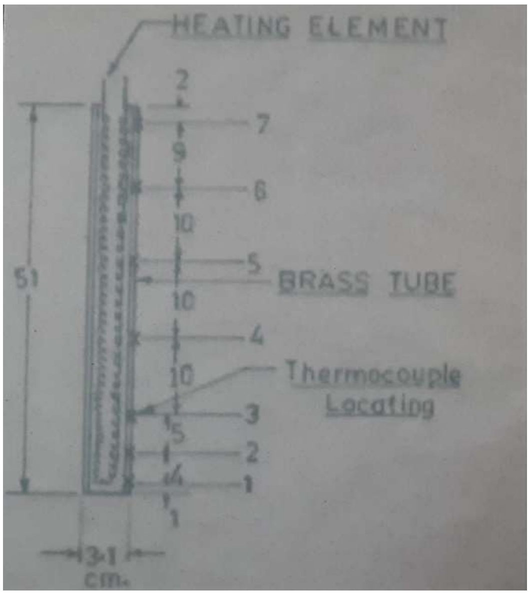
***Experimental heat transfer coefficient by using convection correlations.**

- Film temperature T_f= (Ts +Ta)/2 ; T_f=______ºC
- Coefficient of thermal expansion β=[1/(Tf+273)] ; β=______/K
- Prandtl Number (Pr) = μ. C_p /K ; Pr=___________
- Grashoff Number (Gr) = $\frac{\beta x\ g\ x\ L3(Ts-Ta)}{\nu 2}$; Gr =________
- Nu (Nusselt no) = 0.59(Gr x Pr)$^{1/4}$ (For Gr. Pr < 10^9)
- Nu = $\frac{h\ x\ Lh}{Kair}$ = $[\frac{Nu\ x\ K}{L}]$; h=________W/m^{2}K

PRECUATION

- Adjust the temperature indicator to ambient level by using compensation screw, before starting the experiment, if needed.
- Keep Dimmer stat to zero volt position and increase it slowly.
- Use the proper range of Ammeter and Voltmeter.
- Operate the changeover switch of temperature indicator gently from 1 to 8 positions.
- Never exceed 80 volts.

DIAGRAM OF EXPERIMENTAL SET UP



RESULTS & CONCLUSION

1.The experimental local heat transfer coefficient for a vertical tube losing heat by natural convection =_____________ W/m^2K

2. Experimental heat transfer coefficient by using convection correlations is =_____________ W/m^2K

QUESTIONS

1. What is convection?
2. Classify convection.
3. What is forced convection & natural convection?
4. Explain difference between forced convection and natural convection?
5. On which properties does convection heat transfer strongly depend?

EXPERIMENT NO 5

DETERMINATION OF AVERAGE HEAT TRANSFER COEFFICIENT IN FORCED CONVECTION OF AIR IN A TUBE

OBJECTIVE

To determine the heat transfer coefficient in forced convection of air in a tube.

INTRODUCTION

In many practical situations and equipment's, we invariably deal with flow of fluids in tubes e.g. boiler, super heaters and condensers of a power plant, automobile radiators, water and air heaters or coolers etc. the knowledge and evolution of forced convection heat transfer coefficient for fluid flow in tubes is essentially a prerequisite for an optional design of all thermal system

Convection is the transfer of heat within a fluid by mixing of one portion of fluid with the other. Convection is possible only in a fluid medium and is directly linked with the transport of medium itself.

In forced convection, fluid motion is principally produced by some superimposed velocity field like a fan, blower or a pump, the energy transport is said due to forced convection.

DESCRIPTION

The apparatus consists of a blower unit fitted with the test pipe. The test section is surrounded by a Nichrome band heater. Four thermocouples are embedded on the test section and two thermocouples are placed in the air stream at the entrance and exit of the test section to measure the air temperature. 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 the heater is given through a dimmer stat and measured by meters.

It is to be noted that only a part of the total heat supplied is utilized in heating the air. A temperature indicator with cold junction compensation is provided to measure temperatures of pipe wall at various points in the test section. Airflow is measured with the help of orifice meter and the water manometer fitted on the board.

SPECIFICATION

Pipe diameter(D)	: D_i=28 mm,D_o=33 mm
Length of test section (L)	: 570 mm
Orifice diameter(do)	: 14 mm
Blower motor	: single phase
Ammeter	: 0-10 A
Voltmeter	: 0-100V
Dimmer stat	: 0-2 A, 0-230V
Heater	: Nichrome band type
Temperature indicator	: 0 – 200°C
Thermocouple	: Chromel-Alumel(6 No)

PROCEDURE

- Switch ON the mains system
- Switch ON blower.
- Adjust the flow by means of gate valve to some desired difference in the manometer level.
- Switch ON heater
- Start the heating of the test section with the help of dimmer stat and adjust desired heat input with the help of Voltmeter and Ammeter.
- Take readings of all the six thermocouples when steady state is reached.
- Note down the heater input.

PRECAUTION

- Keep the dimmer stat at zero position before switching ON the power supply.
- Increase the voltmeter gradually.
- Do not stop the blower in between the testing period.
- Do not disturb thermocouples while testing. Operate selector switch of the thermocouple gently. Don't exceed 200 watts
- Operate selector switch of the temperature indicator gently.

OBSERVATION

- Diameter of the test pipe(d) : Di=28 mm, D_o=33 mm
- Length of the test section (L) : 570 mm
- Diameter of orifice d_o : 14 mm
- Input to heater : V x I in watt

OBSERVATION TABLE

Voltage in Volts(V)	Current in amp(I)	Temperature readings in °C						Manometer Reading		
		T_1	T_2	T_3	T_4	T_5	T_6	H_1	H_2	$H_w=H_1-H_2$

CALCULATION

For Experimental heat transfer coefficient

- Mean Film Temperature (T_f) ; $T_f=(T_1+T_6)/2$ =________ ^0C
- Density of air = $(\rho_a)_{Ta} = P/RT_f$ =___________ kg/m^3
- Discharge (volume flow) rate $V= \frac{\pi}{4} d^2_o \times C_d (2gH_w \times \rho_w/\rho_a)^{1/2}$; V=______m^3/sec
- Mass flow rate of air M_a = density (ρ_{air}) x Volume flow rate(V_{air})
- $M_a= \rho_{air} \times V_{air}$; Ma= ________Kg/s
- Average temperature of tube surface $Ts = \frac{(T2+T3+T4+T5)}{4}$ =________ ^0C
- Area of test section $As = \pi \times Di \times L$ =_______m^2
- Heat carried (gained) by air, $Qa = M_a \times C_p \times (T_6-T_1)$ watt ; Qa=_____Watt
- Convection heat transfer rate $Q = h_a . A_s.(T_s-T_f)$ hence

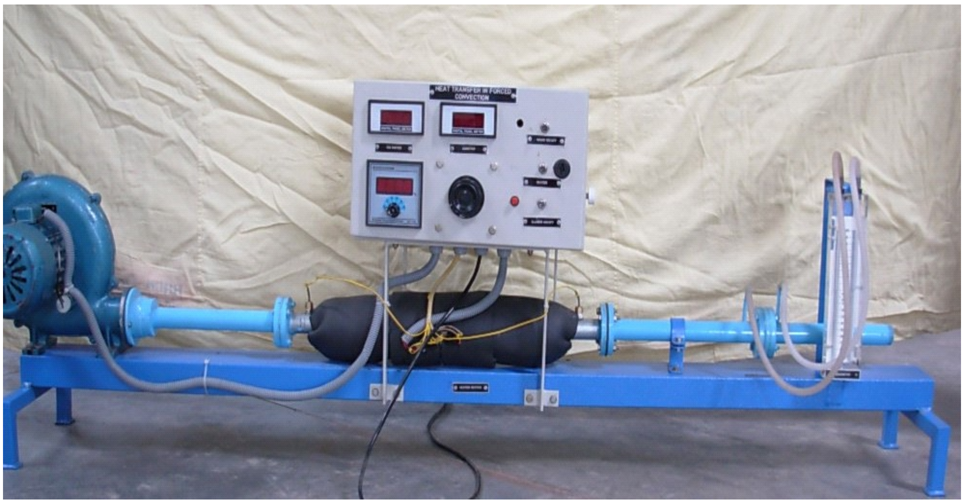
$$h_a = \frac{Qa}{As\,(Ts-Ta)} = \_\_\_\_\_\_\_\_\_\_ W/m^2K$$

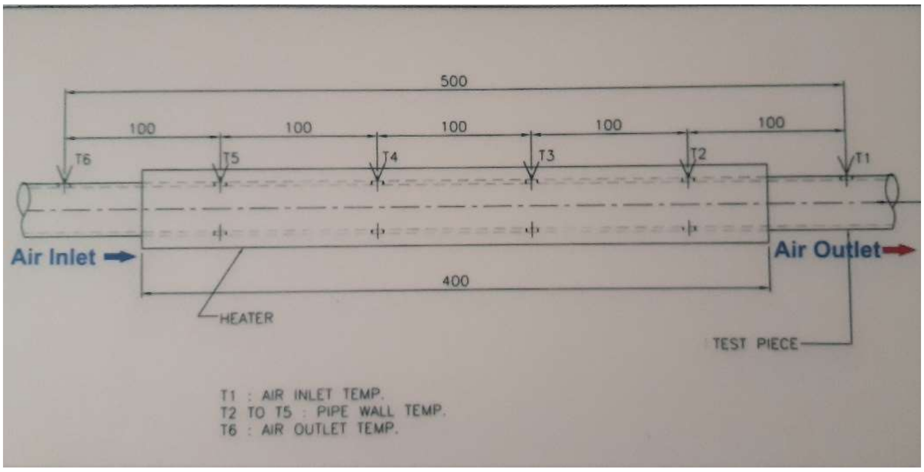
Experimental heat transfer coefficient by using convection empirical correlations.

- $V_m=V/(\pi/4D_i)^2$ = _________
- $Re= (\rho_a \times V_m \times D_i)/\mu = V_m \times D_i / \nu$ = ______
- $Pr = \mu.C_p / k$ =_______
- Nusselt Number (Nu) $= 0.023(Re)^{0.8}Pr)^{0.4}$ =_______

- Nu = $\frac{ha\,.Di}{Kair}$
- h_a = ___________ W/m^{2}K

DIAGRAM OF EXPERIMENTAL SET UP





RESULT & CONCLUSION

1.The heat transfer coefficient in forced convection by experiment is________
2.The heat transfer coefficient in forced convection by empirical relation_________

QUESTIONS

1. What is forced convection?
2. Define Grashoff number and discuss significance of Grashoff number?
3. The free convection heat transfer is significantly affected by----
4. The convective heat transfer coefficient from a hot cylindrical surface exposed to still air varies in accordance with------
5. The ratio of heat transfer by convection to that by conduction is called-----

EXPERIMENT NO 6
DETERMINATION OF HEAT TRANSFER, FIN EFFICIENCY AND TEMPERATURE DISTRIBUTION ALONG THE LENGTH OF PIN-FIN IN NATURAL AND FORCED CONVECTION

OBJECTIVE

To study the temperature distribution along the length of a pin fin in natural and forced convection.

INTRODUCTION

Extended surface or fins are used to increase the heat transfer rate from a surface to a fluid wherever it is not possible to increase the value of the surface heat transfer coefficient or the temperature difference between the surface and the fluid. The use of this is very common and they are fabricated in a variety of shapes. Circumferential fins around the cylinder of a motor cycle engine and fins attached to condenser tubes of a refrigerator are a few familiar examples.

It is obvious that a fin surface sticks out from the primary heat transfer surface. The temperature difference with surrounding fluid will steadily diminish as one move out along the fin. The design of the fins therefore requires knowledge of the temperature distribution in the fin. The main object of this experimental set up is to study the temperature distribution in a simple pin fin.

DESCRIPTION

Aluminum fin of circular cross section is fitted across a long rectangular duct. The other end of the duct is connected to the suction side of a blower and the air flows past the fin perpendicular to its axis. One end of the fin projects outside the duct and is heated by heater.

Temperatures at five points along the length of the fin are measured by Chromel Alumel thermocouples connected along the length of the fin. The airflow rate is measure by an orifice meter fitted on the delivery side of the blower.

SPECIFICATIONS

• Diameter of the fin(D)	: 12.5 mm (AL, Brass and M.S)
• Length of the fin (L)	: 144 mm
• Duct size	: 150mmx100 mm
• Diameter of orifice(d)	:166 mm
• Diameter of delivery pipe	: 52 mm
• Blower capacity	: 1 h.p single phase
• Ammeter	: 0-2 A
• Voltmeter	: 0-100-200V
• Dimmer stat	: 0-2 A, 0-230V
• Temperature indicator	: 0 – 200°C
• Thermocouple	: Chromel-Alumel(6 No)

EXPERIMENTAL PROCEDURE

FOR PIN FIN NATURAL CONVECTION

- Start heating the fin by switching ON the heater element and adjust the power on dimmer stat to say 60 watts (Increase slowly from 0 onwards.)
- Note down the thermocouple readings 1 to 5 at the interval of 10 minutes.
- When steady state is reached (i.e. dT/dt =0), record the final readings 1 to 5 and record the ambient temperature reading 6.

FOR PIN FIN FORCED CONVECTION

- Start heating the fin by switching ON the heater and adjust power equal to 60 watts.
- Start the blower and adjust the difference of level in the manometer with the help of blower control – disc value.
- Note down the thermocouple readings (1) to (5) at a time interval of 10 minutes.
- When the steady state is reached, record the final readings (1) to (5) and record the ambient temperature reading (6).

PRECAUTIONS

- Keep the dimmer stat to zero position before start and end of the experiment.
- See that throughout the experiment, the blower is OFF in natural convection heat transfer.
- Operate gently selector switch of temperature indicator.
- Never exceed the heater input to 80V

OBSERVATION

- Diameter of the fin(D) : 12.5 mm (AL, Brass and M.S)
- Length of the fin (L) : 144 mm
- Diameter of orifice(d) :166 mm
- Diameter of delivery pipe : 52 mm

OBSERVATION TABLE FOR PIN FIN NATURAL CONVECTION

Sr. No	Voltmeter reading in volt	Ammeter Reading in Amp		Temperature Readings °C					
				T_1	T_2	T_3	T_4	T_5	T_{duct}

OBSERVATION TABLE FOR PIN FIN FORCED CONVECTION

Sr. No	Voltmeter reading in volt	Ammeter Reading in Amp	Manometer Reading	Temperature Readings °C					
				T_1	T_2	T_3	T_4	T_5	T_{duct}

CALCULATION FOR PIN FIN NATURAL CONVECTION

- Average temperature of tube surface Ts $= \frac{(T1+T2+T3+T4+T5)}{5}$; Ts=_____ ^{0}C
- Film temperature T_f= (Ts +Td)/2 ; T_f=______C
- Coefficient of thermal expansion β=1/(Tf+273) = β=……………/K
- Prandtl No Pr = $\mu C_p/K$; Pr=_________
- Grashoff Number (Gr) = $\frac{\beta x\ g\ x\ L^3(Ts-Td)}{\nu^2}$; Gr =______
- Nusselt Number (Nu) = $0.59(Gr\ x Pr)^{1/4}$ (For Gr.Pr<10^9)
- Nu = $\frac{h\ x\ L}{Kair}$
- h = $[\frac{Nu\ x\ K}{L}]$; h=_________W/m^2K
- Perimeter P= π x D =_______m

- Cross section area of fin $A = \frac{\pi \times D^2}{4}$
- $m = (hP/K_f A)^{0.5}$
- Heat transfer rate by fin $Q = m x(Ts - T_f)\ Tanh(mL)$
- Effectiveness of fin $\mathcal{E} = \frac{Tan\ h(mL)}{mL}$

CALCULATION FOR PIN FIN FORCED CONVECTION

- Average temperature of tube surface $Ts = \frac{(T1+T2+T3+T4+T5)}{5}$; Ts=_____ °C
- Film temperature $T_f = (Ts + Td)/2$; T_f=______ °C
- Velocity from orifice in m / sec (V_O) = $Cd \times [2gh \times (\rho m - \rho a / \rho a)]^{0.5}$ m/sec
- Velocity of Air in duct in m / sec (Va) = $\{[V_O \times (\pi/4) \times d_O^2] / (W \times B)\}$
- Reynolds Number (Re) = $\rho_a \times V_a \times D / \mu_a$

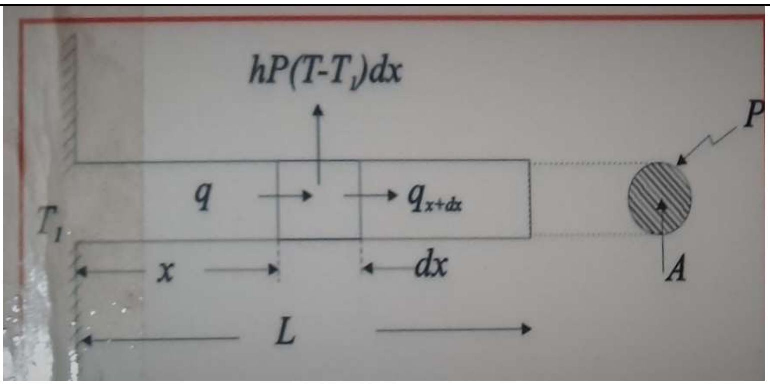
  Where, ρ_a = Density of Air at duct temp. = 1.165 Kg / m^3
  D = diameter of fin in meter
  μa = Dynamic viscosity of air at Tduct in Kg / m - s

- Prandtl Number at mean fin temp = Pr=_________
- Nusselt Number (Nu) = $C (Re)^n (Pr)^{0.33}$
  Where, c and n are taken from following table

Re	C	n
0.4 – 4	0.989	0.33
4 – 40	0.911	0.385
40 – 4000	0.683	0.466
4000 – 40000	0.193	0.618

- $Nu = \frac{h \times L}{K_{air}}$
- Heat transfer coefficient for Forced convection $h = [\frac{Nu \times K}{L}]$
- h=__________W/m^{2}K
- Perimeter P= π x D =________m
- Cross section area of fin $A = \frac{\pi \times D^2}{4}$
- Mass flow rate $m = (hP/K_f A)^{0.5}$
- Heat transfer rate by fin $Q = m x (Ts - T_f) \, Tanh(mL)$
- Effectiveness of fin $\mathcal{E} = \frac{Tan\,h(mL)}{mL}$

DIAGRAM OF EXPERIMENTAL SET UP



RESULT & CONCLUSION

____

____

____

QUESTIONS

1. What is the material used in pin fin experiment?
2. What are types of fins!
3. Why the fins are used?
4. Give the relation between 'Fluid velocity' and 'Heat transfer'?
5. Fluid properties are evaluated at what temperature?

EXPERIMENT NO. 7
EXPERIMENTAL VERIFICATION OF STEFFEN BOLTZMANN'S CONSTANT

OBJECTIVE

The objective of this experimental set up is to calculate the value of Boltzmann Constant (σ) by using certain parameters like emissive power & temp of a black body.

INTRODUCTION

Concept of black body: -It is defined as ideal body, which observes all incident radiant energy without reflecting or transmitting any energy. This applies for radiation of all wavelengths & for all angle of incidence.

DESCRIPTION OF SET UP

The apparatus is centered on a flanged copper hemisphere B fixed on non-conducting plate A. The outer surface of B is enclosed in a metal water jacket used to heat B to some suitable constant temperature. The hemispherical shape of B is chosen solely on the grounds that it simplifies the task of draining the water between Test Piece & hemisphere. Four chromel alumel thermocouples are attached to various points on surface of Hemisphere to measure its mean temperature.

The test piece, which is mounted in an insulating Bakelite sleeve S. is fitted in a hole, drilled in the center of base plate 'A'. A Chromel Alumel thermocouple is used to measure the temperature of Test Piece (T_5).

The thermocouple is mounted on the disc to study the rise of its temperature. When the disc is inserted at the temperature T_5 ($T_5 > T$) i.e. the temperature of the enclosure, the response of the temperature change of the disc with time is used to calculate the Stefan Boltzmann constant**.**

SPECIFICATION

Hemispherical enclosure diameter	: 205 mm
Base plate, Bakelite diameter	: 255 mm
Test disc diameter	: 20 mm
Mass of the test disc	: 0.006 Kg
Specific heat of the copper test disc	: 0.41868 KJ/kg °C
Thermocouple on hemisphere & test piece	: 4 and 1 (Chrome alumel)
Digital temperature Indicator	: 0-200 °C range
Water Heater	: 2 KW (instant with thermostat)
Hot water bath	: 5.75 liters

THEORY

Thermal Radiation is the important mode of heat transfer observed in several engineering and other applications. All bodies at temp above ° K emit energy in the form of radiation. Different theories are developed to study the Radiation Heat transfer like Maxwell theory explains the radiation phenomenon as propagation of energy in the form of electromagnetic wave, while Max Plank's hypothesis treats it as energy being carried through photons or quanta's Whichever of these theories are used, it is convenient to classify all electromagnetic radiant energy emission in terms of wavelength.

The most commonly used law of thermal radiation is the Stefan Boltzmann law which states that heat flux or emissive power of a black body is proportional to the forth power of absolute temperature of the surface and is given by:

$E_b = \sigma T^4$ W / m^2

Where,

Eb = Emissive power = ______ (W / m^2)

σ = Stefan Boltzmann constant

= 5.699x 10^{-8} W /m^2 K^4

T = Temperature of Black body (^{0} K)

The Stefan Boltzmann law can be derived by integrating the Plank's law over the entire spectrum of wavelengths from 0 to ∞, though historically it is worth noting that the Stefan Boltzmann law was independently developed before Plank's law.

The radiation energy falling on Test Piece from the enclosure is given by:

$$E = A_D T^4 \sigma \quad \text{-----------} (1)$$

Where,

A_D = Area of the disc D in m²

T = Average temperature of the enclosure

Recorded by the Thermocouple K

The emissivity of the disc D is assumed to be unity (Black disc) the radiant energy, emitted by disc D into enclosure will be

$$E_t = A_D T_5^4 \sigma \quad \text{-----------} (2)$$

The net heat input to disc D per unit time is given by (1) - (2)

$$E - E_t = \sigma AD (T^4 - T5^4) \quad \text{---------} (3)$$

If the test piece has mass m and specific heat S then in a short time after test piece is inserted in A,

$$m.s.\ (dT/dt) \quad = \sigma\ AD\ (T^4 - T_5^4)$$

In this equation, m.s. $(dT/dt)_{t=0}$ denotes the rate of rise of temperature of the test piece at the instant when its temperature is T5 and will vary with T5. it is clearly best measured at time t = 0 before heat conducted from A to test piece begins to have any significant effect.

This is obtained from plot of temperature rise of test piece with respect to time and obtaining its slope at t = 0 when temperature is T5. This will be the required value of dT/dt at t=0. The thermocouple mounted on disc is to be used for this purpose. Note that the test piece with its insulating sleeve S is placed quickly in position and start the timer and record the temperature at fixed time intervals. The whole process is completed in about 30 seconds of time. Longer test piece is left in position; the greater is the probability of errors due to heat conduction from A to test piece .the experiment is repeated for obtaining better results.

PROCEDURE

- Fill water in the tank completely and set thermostat to desired temperature @ 90°C for water heating
- Switch on the heater to heat the water and wait till the water is heated to set temperature.
- Remove the test piece before pouring the hot water into the jacket, then pour hot water in the water jacket.
- Record the temperature of thermocouple (T1 to T4) of hemispherical enclosure
- The hemisphere surface will come to some uniform temperature in a short time T.
- The test piece is now inserted at temperature T5 in the Bakelite plate

- Note down the temperature readings of test piece at the interval of **5** seconds @ ten readings.
- Plot the temperature time data for the test piece.

OBSERVATION

- Test disc diameter : 20mm
- Test disc thickness : 3 mm
- Mass of the test disc :0.006 kg
- Stefan Boltzmann Constant : 5.669 x10^{-8} W/m^2.k^4

OBSERVATION TABLE

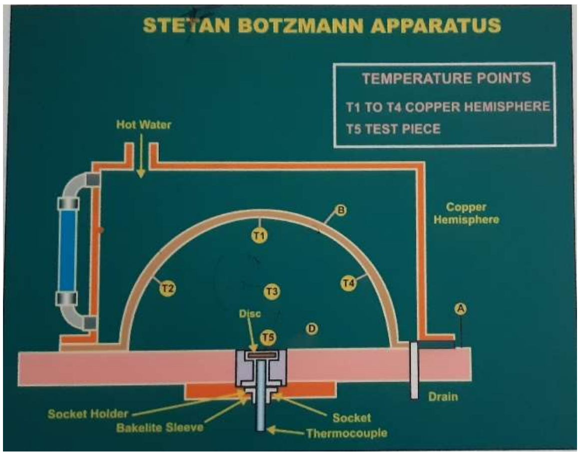
Thermocouples	T_1	T_2	T_3	T_4				
Temperature in ºC								
Time in sec	5	10	15	20	25	30	35	40
Test Disc Temp(T_5)								

CALCULATION

- Average temperature of hemispherical sphere Ts= $(T_1+T_2+T_3+T_4)/4$; Ts = ______ºC
- Temperature of disc at the instant when inserted T= T_5=______ºC

- Slope from graph dT-dt , $\left(\frac{dT}{dt}\right)t{=}0{=}\frac{Y2-Y1}{X2-X1}{=}$__________
- Area of disc A= $\frac{\pi}{4}$x d^2 =__________ m^2
- Stefan Boltzmann Constant $\sigma = \frac{m \times g \times c_p\,(dT/dt)}{A(\,T^4_s - T^4_5)}$; σ = -----------$W/m^2.k^4$

DIAGRAM OF EXPERIMENTAL SET UP



RESULT & CONCLUSION

The value of Stefan Boltzmann constant by experiment (σ)=___________W/m^2.k^4

QUESTIONS

1. Explain Stefan – Boltzmann's law?
2. What is value of the Stefan – Boltzmann constant?
3. Define Shape factor (or) view factor (or) configure factor (or) angle factor
4. Thermal radiation occurs in the portion of electromagnetic spectrum between the wavelengths _______
5. For infinite parallel plates with emissivity's ε1 and ε2 shape factor for radiation from surface 1 to surface 2 is ______

EXPERIMENT NO.8
DETERMINATION OF EMISSIVITY OF THE TEST PLATE SURFACE

OBJECTIVE

The objective of this experimental set up is to determine emissivity of the test plate surface

INTRODUCTION

All substances at all temperatures emit radiations. Thermal radiation is an electromagnetic wave and dose not require any material medium for propagation. All bodies can emit radiation and have also the capacity to absorb all or a part of the radiation coming from the surrounding towards it.

An idealized black surface is one, which absorbs all the incident radiation with reflectivity and transmissivity equal to zero. The radiant energy per unit time per unit area from the surface of the body is called as the emissive power and is denoted by 'e'. The emissivity of the surface is the ratio of the emissive power of the surface to the emissive power of the black surface at the same temperature. It is denoted by '$\in$' .

$$\in = (E/E_b)$$

Absorptivity of a black body is 1 and by the knowledge of Kirchoff's law, emissivity of the black body becomes unity.

DESCRIPTION

The experimental set up consists of two circular Aluminum plates identical in size and is provided with heating coils sandwiched. The plates are mounted on brackets and are kept in an enclosure so as to provide undisturbed natural convection surroundings. The heat input to the heater is varied by separate dimmer stat and is measured by using an ammeter and a voltmeter with the help of double pole double through switch.

The temperatures of the plates are measured by thermocouples separate wires are connected to diametrically opposite points to get the average surface temperatures of the plates. Another thermocouple is kept in the enclosure to read the ambient temperature of enclosure.

Plate 1 is blackened by a thick layer of the lamp black to form the idealized black surface whereas plate 2 is the test plate whose emissivity is to be determined. The heater inputs to the two plates are dissipated from the plates by conduction, convection and radiation.

The experimental set up is designed in such a way that under steady state conditions the heat dissipation by conduction and convection is same for both the plates when the surface temperatures are same and the difference in the heater input readings is because of the difference in the radiation characteristics due to their different emissivity's. The schematic arrangement of the setup is shown in the figure.

SPECIFICATION

Test Plate(aluminum) diameter	: 155 mm
Black Plate(aluminum) diameter	: 155 mm
Voltmeter	: 0-100-200V
Ammeter	: 0-2 A
Dimmer stat	: 0-2 A, 0-260V
Heater	: 400W Nichrome sandwich between two mica sheet
Temperature indicator	: 0 – 300ºC
Thermocouple	: Chromel-Alumel

THEORY

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

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

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

PROCEDURE

- Switch on Main supply and then switch on heater switch.
- Increase slowly the input to the heater to black plate by dimmer stat and adjust input 30/50/75 W .Adjust heater input to test plate slightly less than the black plate 27/35/55W.Heat Input of black plate should not change throughout the experiment.
- Wait till satisfactory steady state condition is reach, this is by noting the temperature readings T_b after time interval of 5 minutes
- Take the readings till steady state is reached.(i.e $dT_b/dt = 0$),
- Note down the temperature readings T_b at steady state.
- Adjust heat input to test plate to maintain temperature of test plate same as temperature of black plate, it will require some trial and error and has to wait to obtain the steady state condition
- After attaining steady state, record the temperature, voltmeter and ammeter readings of both the plates.

- Repeat the procedure for various temperatures at higher value.

PRECAUTION

- Keep the dimmer stat to zero position before start and end of the experiment.
- Operate gently selector switch of temperature indicator.
- Never exceed the heater input to 100V
- See that the black plate is having the layer of lump black uniformly.

OBSERVATIONS

- Diameters of plates d : 155 mm
- Emissivity of black plate $\mathcal{E}_b$: 1
- Stefan Boltzmann constant σ: 5.667 x10^{-8} w/m^2k^4

OBSERVATION TABLE

Observe. Time	Black Plate			Test Plat			Ambient Temp.K
	Voltage V_b	Current I_b	Temp.K T_b	Voltage V_s	Current I_s	Temp.K T_s	
1							
2							

CALCULATION

1 Heat in put to black plate Wb = Vb x Ib Wb=_______Watts

2 Heat in put to test plate Ws = Vs x Is Wss =_______Watts

3 Area of plate A=(π)/4 d2 = 0.018859 m2

4 Emissivity ($\mathcal{E}$) of Test Plate can be calculated from Stefan Boltzmann law i.e

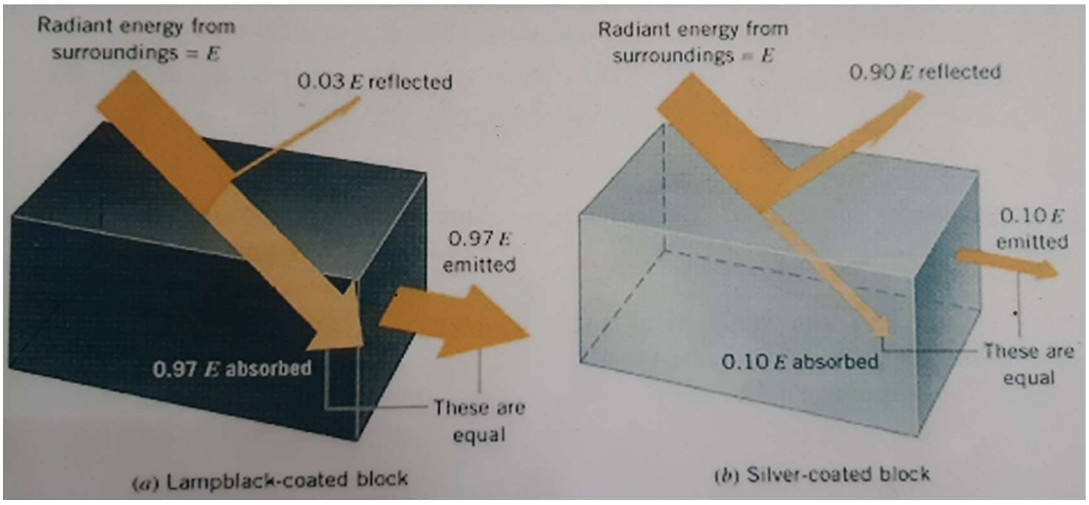
$Qb=Eb=\mathcal{E}b\sigma AT4$

$Qs=Es=\mathcal{E}s\ .\sigma A\ T4$

$Qb-Qs=(\mathcal{E}b-\mathcal{E})\ \sigma A[\ Ts4-Ta4]$

$\mathcal{E}=1-(Eb-Es)/\sigma A(T4-\ T4)$; Hence $\mathcal{E}$ = ________W/mK

DIAGRAM OF EXPERIMENTAL SET UP



RESULT & CONCLUSION

Emissivity of test plate is   Ɛ= ____________

QUESTIONS

1. Explain Kirchhoff's law.
2. Radiation between two surfaces mainly depends on________
3. Explain Radiosity?
4. Explain Radiation Heat transfer between two surfaces?
5. What is network representation and what is its algebra?

EXPERIMENT 9

A] DETERMINATION OF LMTD, THE HEAT TRANSFER RATE, OVERALL HEAT TRANSFER COEFFICIENT AND EFFECTIVENESS OF A PARALLEL FLOW AND COUNTER FLOW HEAT EXCHANGER

OBJECTIVE

To determine heat transfer rate and overall heat transfer coefficient of Parallel flow and counter flow heat exchanger.

INTRODUCTION

Heat exchanger is a device used for affecting the process of heat exchange between two fluids that are at different temperatures. It is useful in many engineering processes like those in Refrigeration and Air conditioning system, power system, food processing systems, chemical reactor and space or aeronautical applications. The necessity for doing this arises in multitude of industrial applications. Common examples of best exchangers are the radiator of a car, the condenser at the back of the domestic refrigerator, and the steam boiler of a thermal power plant.

DESCRIPTION & CONSTRUCTION

The simple example of transfer type of heat exchanger can be in the form of a tube in tube type arrangement as shown in the figure. One fluid flowing through the inner tube and the other through the annulus surroundings it. The heat transfer takes place across the walls of the inner tube. The experiments are conducted by keeping the approximately identical flow rates while running the unit as a parallel flow heat exchanger.

The temperatures are measured with the help of the temperature sensor. The readings are recorded when steady state is reached. The outer tube is provided with adequate insulation to minimize the heat losses.

The PF heat exchanger consist of following components

- Main Frame
- Heat Exchanger
- Temperature Indicator
- Hot water Generator
- Hot & cold-water flow rate measurement
- Temperature Sensors

The total assembly is supported on a main frame. The apparatus consists of a 'tube in tube' type concentric tube heat exchanger. The hot fluid is water, which is obtained from the hot water generator it is attached at the bottom of assembly to supply the hot fluid i.e., water with the help of pump through the inner tube while the cold fluid is flowing through annulus. Pump set is connected to the hot water generator to suck the water from it & deliver as per requirement. Different valves are provided in the system to regulate the flow of fluid to the system. The hot water & cold water admitted at the same end named parallel flow heat exchanger accordingly, is done by valve operation.

The concentric type heat exchanger is connected in system, which transfers thermal energy between two fluids at different temperature.

SPECIFICATION

Inner Pipe	: di=10.5mm, do=12.5 mm (Copper)
Outer pipe	: Di =28 mm, Do= 33 mm (G.I)
Length of heat exchanger	: 1.5 m

Heater	: 3 KW (thermostat range 10-110ºC)
Temperature indicator	: 0 – 200ºC
Thermocouple	: Chromel-Alumel (6 No)

TYPE OF HEAT EXCHANGERS

Heat exchangers are classified in three categories.

- **Transfer Type**
  - **According to flow arrangement**
    - ✓ Parallel flow
    - ✓ Counter flow
    - ✓ Cross flow
- **Storage Type**
- **Direct Transfer Type**
    - ✓ Shell and tube heat Exchanger
    - ✓ Concentric tube Heat Exchanger

A Transfer type heat exchanger is the one in which both fluids pass simultaneously flow through the device and heat is transferred through separating walls. In practice most of the heat exchangers used are transfer type ones. The transfer type heat exchangers are further classified according to flow arrangements as

- Parallel Flow, in which fluids flow in the same direction.
- Counter flow, in which they flow in opposite direction.

PROCEDURE

- Set the temperature of the geyser to some fix temperature say 60 ºC to heat the water.
- Once set temperature of water is reached, start the flow of water through hot and cold-water side for Parallel (same direction)/counter flow (opposite direction) with the help of valve.
- Wait to stabilize the temperature on the indicator, as it gets stabilized take temperature readings.
- Measure the flow rate of both hot and cold fluids by measuring flask and stopwatch. $m_h < m_c$
- Take the readings for different flow rates.

PRECAUTIONS

- Do not put ON heater unless water flow is continuous.
- Once the flow is fixed, do not change the flow rate before taking the readings.
- Check oil in oil well of thermo pocket and thermocouples are placed in.
- Equipment should be properly earthed.
- Drain out the water of both tube after the experiment is over
- Do not put on heater unless water flow is continuous.
- Once the flow is fixed, do not change it until note down the readings for that flow.

OBSERVATIONS

- Inner Pipe : di=10.5mm, do=12.5mm (Copper)
- Outer pipe : Di =28 mm, Do= 33 mm (G.I)
- Length of heat exchanger : 1.5 m
- Specific heat of both fluid Cpc & Cph : 4.174 KJ/kg K

OBSERVATION TABLE

Sr. No	Hot Water side			Cold Water side		
	Flow rate m_h in Kg/h	Inlet temp T_{hi}	Outlet temp T_{ho}	Flow rate m_c in Kg/h	Inlet temp T_{ci}	Outlet temp T_{co}
1						
2						

CALCULATION FOR PARALLEL FLOW

1Heat transfer rate from hot water

$Q_h = m_h.C_{ph}.(Thi\text{-}Tho) =$ ________

2Heat transfer rate from cold water

$Q_c = m_c.C_{pc}.(Tco\text{-}Tci) =$ ________

3 Total heat transfer rate

$Q = (Q_h + Q_c)/2 =$_________

4 Logarithmic mean temperature difference

$$LMTD = \Delta Tm = \frac{\Delta Ti \quad \Delta To}{\ln \Delta Ti / \Delta To}$$

Where, $\Delta Ti = Thi - Tci$ and $\Delta To = Tho - Tco$

5 Overall heat transfer coefficients

Overall heat transfer coefficient based on outer area

$Uo = \frac{Qc}{Ao \; x \Delta Tm} =$ __________W/m^2K

Overall heat transfer coefficient based on inner area

$Ui = \frac{Qh}{Ai \times \Delta Tm}$ = ________ W/m^2K

Where $Ai = \pi \times di \times L$ ______m^2 and $Ao = \pi \times do \times L$ ________m^2

6 Effectiveness of Heat Exchanger

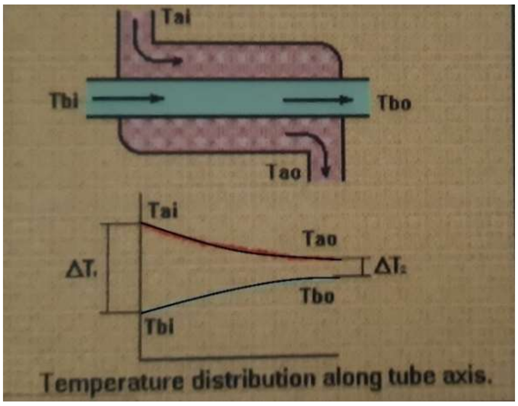
Effectiveness =(Actual heat transfer) / (Maximum heat transfer)

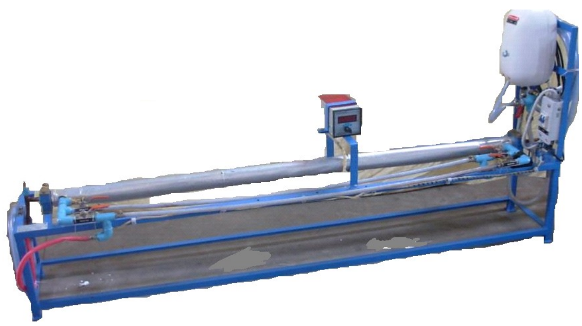
$= Q_{act} / Q_{max} = Q_{act} / mCp_{min}(Thi-Tci)$

- $Q_{act} = m_h x C_{ph} x(Thi-Tho) = m_c \times C_{pc} x(Tco-Tci)$ =_______KJ/s
- $C_{min} = m_h x C_{ph}$ =_________
- $C_{max} = m_c x C_{pc}$ =__________
- NTU= $Ui \times Ai / C_{min} = Uo \times Ao / C_{min}$ =_______
- Effectiveness of Heat Exchanger (Ɛ)= $\frac{m_c \times C_{pc} (T_{co}-T_{ci})}{m_h \times C_{ph} \times (T_{hi}-T_{ci})}$ =_____________

With $m_h < m_c$

DIAGRAM OF EXPERIMENTAL SET UP





RESULT & CONCLUSION

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QUESTIONS

1.Explain about a heat exchanger.

2.Classify heat exchangers.

3. What is the relation between fouling and overall heat transfer coefficient?

4. The effectiveness of heat exchanger is given by ________

5. Explain LMTD for parallel flow.

B] DETERMINATION OF LMTD, THE HEAT TRANSFER RATE, OVERALL HEAT TRANSFER COEFFICIENT AND EFFECTIVENESS OF A COUNTER FLOW HEAT EXCHANGER

OBJECTIVE

To determine heat transfer rate and overall heat transfer coefficient of counter flow heat exchanger.

INTRODUCTION

Heat exchanger is a device used for affecting the process of heat exchange between two fluids that are at different temperatures. It is useful in many engineering processes like those in Refrigeration and Air conditioning system, power system, food processing systems, chemical reactor and space or aeronautical applications. The necessity for doing this arises in multitude of industrial applications. Common examples of best exchangers are the radiator of a car, the condenser at the back of the domestic refrigerator, and the steam boiler of a thermal power plant.

DESCRIPTION & CONSTRUCTION

The simple example of transfer type of heat exchanger can be in the form of a tube in tube type arrangement as shown in the figure. One fluid flowing through the inner tube and the other through the annulus surroundings it. The heat transfer takes place across the walls of the inner tube. The experiments are conducted by keeping the approximately identical flow rates while running the unit as a counter flow heat exchanger.

The temperatures are measured with the help of the temperature sensor. The readings are recorded when steady state is reached. The outer tube is provided with adequate insulation to minimize the heat losses.

The CF heat exchanger consist of following components

- Main Frame
- Heat Exchanger
- Temperature Indicator
- Hot water Generator
- Hot & cold-water flow rate measurement
- Temperature Sensors

The total assembly is supported on a main frame. The apparatus consists of a 'tube in tube' type concentric tube heat exchanger. The hot fluid is water, which is obtained from the hot water generator it is attached at the bottom of assembly to supply the hot fluid i.e., water with the help of pump through the inner tube while the cold fluid is flowing through annulus. Pump set is connected to the hot water generator to suck the water from it & deliver as per requirement. Different valves are provided in the system to regulate the flow of fluid to the system. The hot water & cold water admitted at the different end named counter flow heat exchanger accordingly, is done by valve operation. The concentric type heat exchanger is connected in system, which transfers thermal energy between two fluids at different temperature.

SPECIFICATION

Inner Pipe	: di=10.5mm, do=12.5 mm (Copper)
Outer pipe	: Di =28 mm, Do= 33 mm (G.I)
Length of heat exchanger	: 1.5 m

Heater	: 3 KW (thermostat range 10-110ºC)
Temperature indicator	: 0 – 200ºC
Thermocouple	: Chromel-Alumel (6 No)

TYPE OF HEAT EXCHANGERS

Heat exchangers are classified in three categories.

- **Transfer Type**
  - **According to flow arrangement**
    - ✓ Parallel flow
    - ✓ Counter flow
    - ✓ Cross flow
- **Storage Type**
- **Direct Transfer Type**
    - ✓ Shell and tube heat Exchanger
    - ✓ Concentric tube Heat Exchanger

A Transfer type heat exchanger is the one in which both fluids pass simultaneously flow through the device and heat is transferred through separating walls. In practice most of the heat exchangers used are transfer type ones. The transfer type heat exchangers are further classified according to flow arrangements as

- Parallel Flow, in which fluids flow in the same direction.
- Counter flow, in which they flow in opposite direction.

PROCEDURE

- Set the temperature of the geyser to some fix temperature say 60 ºC to heat the water.
- Once set temperature of water is reached, start the flow of water through hot and cold-water side for Parallel (same direction)/counter flow (opposite direction) with the help of valve.
- Wait to stabilize the temperature on the indicator, as it gets stabilized take temperature readings.
- Measure the flow rate of both hot and cold fluids by measuring flask and stopwatch. $m_h < m_c$
- Take the readings for different flow rates.

PRECAUTIONS

- Do not put ON heater unless water flow is continuous.
- Once the flow is fixed, do not change the flow rate before taking the readings.
- Check oil in oil well of thermo pocket and thermocouples are placed in.
- Equipment should be properly earthed.
- Drain out the water of both tube after the experiment is over
- Do not put on heater unless water flow is continuous.
- Once the flow is fixed, do not change it until note down the readings for that flow.

OBSERVATIONS

- Inner Pipe : di=10.5mm, do=12.5mm (Copper)
- Outer pipe : Di =28 mm, Do= 33 mm (G.I)
- Length of heat exchanger : 1.5 m
- Specific heat of both fluid Cpc & Cph : 4.174 KJ/kg K

OBSERVATION TABLE

Sr. No	Hot Water side			Cold Water side		
	Flow rate m_h in Kg/h	Inlet temp T_{hi}	Outlet temp T_{ho}	Flow rate m_c in Kg/h	Inlet temp T_{ci}	Outlet temp T_{co}
1						
2						

CALCULATION FOR COUNTER FLOW

1Heat transfer rate from hot water

$Q_h = m_h.C_{ph}.(Thi\text{-}Tho) =$ ________

2Heat transfer rate from cold water

$Q_c= m_c.C_{pc}.(Tco\text{-}Tci)=$ __________

3 Total heat transfer rate

$Q = (Q_h + Q_c)/2 =$ ___________

4 Logarithmic mean temperature difference

$$\text{LMTD} = \Delta\text{Tm} = \frac{\Delta\text{Ti} - \Delta\text{To}}{\ln \Delta\text{Ti} / \Delta\text{To}}$$

Where, ΔTi =Thi-Tco and ΔTo=Tho-Tci (counter flow)

5 Overall heat transfer coefficients

*Overall heat transfer coefficient based on outer area

$Uo = \frac{Qc}{Ao \ x\Delta Tm}$ = _______W/m^{2}K

*Overall heat transfer coefficient based on inner area

$Ui = \frac{Qh}{Ai \ x\Delta Tm}$ = _________W/m^{2}K

Where Ai=π x di x L= _________m^2 and Ao = π x do x L = ________m^2

6 Effectiveness of Heat Exchanger

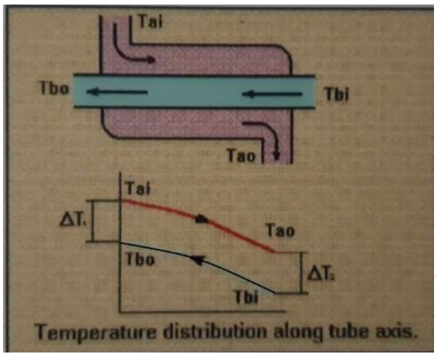
Effectiveness =(Actual heat transfer) / (Maximum heat transfer)

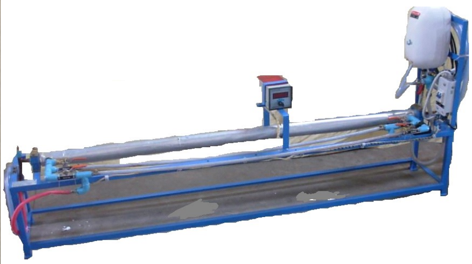
= Q_{act} / Q_{max} = Q_{act} / mCp_{min}(Thi-Tci)

- Q_{act}= m_hxC_{ph} x(Thi-Tho) = m_c x C_{pc} x(Tco-Tci) =_______KJ/s
- C_{min} = m_hxC_{ph} =_________
- C_{max}= m_cxC_{pc} =__________
- NTU= Ui x Ai / C_{min} = Uo x Ao / C_{min} =_______
- Effectiveness of Heat Exchanger (Ɛ)= $\frac{m_c \times C_{pc} (T_{co}-T_{ci})}{m_h \times C_{ph} \times (T_{hi}-T_{ci})}$ =_____________

With m_h<m_c

DIAGRAM OF EXPERIMENTAL SET UP





RESULT & CONCLUSION

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QUESTIONS

1. Classify heat exchangers.
2. Which type of heat transfer takes place in heat exchangers?
3. What is fouling?
4. What is the relation between fouling and overall heat transfer coefficient?
5. The normal automobile radiator is a heat exchanger of which type?

DETERMINATION OF HEAT TRANSFER COEFFICIENT IN DROPWISE AND FILM-WISE CONDENSATION

OBJECTIVE

To determine the heat transfer coefficient in dropwise and film-wise condensation.

INTRODUCTION

Condensation of vapor is needed in many of the processes, like steam condensers, refrigeration etc. When vapor comes in contact with surface having temperature lower than saturation temperature, condensation occurs. When the condensate formed wets the surface, a film is formed over surface and the condensation is film wise condensation. When condensate does not wet the surface, drops are formed over the surface and condensation is dropwise condensation.

DESCRIPTION

The apparatus consists of two condensers, which are fitted inside a glass cylinder, which is clamped between two flanges. Steam from steam generator enters the cylinder through a separator. Water is circulated through the condensers. One of the condenser is with natural surface finish to promote filmwise condensation and the other is chrome plated to create dropwise condensation. Water flow is measured by a rotameter. Various temperatures are measured by a digital temperature indicator. Steam pressure is measured by a pressure gauge. Thus heat transfer coefficients in dropwise and filmwise condensation can be calculated.

SPECIFICATION

Condensers - made of copper	: 19 mm O.D., 150 mm long, one with natural surface and one with chrome plated surface
Rotameter	: 25 -250 LPH for water flow measurement.
Steam generator	: with 1.5 Kw electrical heater

Multichannel digital temperature indicator	: 0 - 200 0C using chromel - Alumel thermocouples.
Pressure gauge	: To measure steam pressure
Necessary valves for water and steam control	

PROCEDURE

Fill up the water in the steam generator and close the water filling valve. Start water supply through one of the condensers. Close the steam control valve, Switch on the supply and start the heater. After some time, steam will be generated. Open steam control valve and allow steam to enter the cylinder and pressure gauge will show some reading. Open drain valve and ensure that air in the cylinder is expelled out. Close the drain valve and observe the condensers. Depending upon the condenser in operation, dropwise or filmwise condensation will be observed. Wait for some time for steady state and note down all the readings. Repeat the procedure for the other condenser.

PRECAUTION

- Operate all the switches and controls gently.
- Never allow steam to enter the cylinder unless the water is flowing through condenser.
- Always ensure that the equipment is earthed properly before switching on the supply.
- Keep the dimmer stat at zero position before switching ON the power supply.
- Increase the voltmeter gradually.
- Do not disturb thermocouples while testing.
- Operate selector switch of the temperature indicator gently.

OBSERVATION TABLE

Sr. No.	1	2
Steam Pressure Kg/cm^2		
Water Flow Rate LPH		
Steam Temperature - T_1 °C		
Dropwise Condensation Surface Temperature - T_2 °C		

Film wise Condensation Surface Temperature - T_3 ^{0}C		
Water Inlet Temperature - T_4 ºC		
Water Outlet Temperature From Dropwise Condenser - T_5 ºC		
Water Outlet Temperature From Film wise Condenser - T_6 ºC		

CALCULATION

Filmwise Condensation : -

Water flow = LPH = W Kg /sec.

Water inlet temp. T_4 = ºC

Water outlet temp. = ºC

(T_5 for dropwise condensation and T_6 for filmwise condensation.)

Heat transfer rate at the condenser wall,

$$q = W .C_P. (T_5 - T_4) \text{ watts.}$$

where, CP = Specific heat of water = 4. 2 x 10^3 J / Kg K

Surface area of the condenser A = 9.24 x 10^{3} m^3

Heat transfer coefficient,

$$h_L = \frac{q}{A (T_S - T_W)} \text{ W / m}^2 \text{ ºC}$$

Where T_S = Temperature of steam = (T_1)

and T_w = condenser wall temperature (T_2 or T_3)

Theoretically, for film wise condensation,

$$h_L = 0.943 \left[\frac{\lambda \rho^2 g k^3}{(T_S - T_W) \mu L}\right]^{0.25}$$

Where,

λ = Total heat of steam at T_S, J / kg. ------- (from steam pr. table)

ρ = Density of water, kg / m^3. ----------------- (from chart)

g = Gravitational acceleration, = 9.81 m / sec^2

k = Thermal conductivity of water , W / m °C ------ (from chart)

μ = Viscosity of water, N. s / m^2 ------------------ (from chart)

and , L = Length of condenser = 0.15 m .

Above values at mean temperature ,tm $= \left[\frac{T_S + T_w}{2} \right]$ °C

Dropwise condensation : -

Water flow = LPH = W Kg / sec.

Water inlet temp. T_4 = °C

Water outlet temp. = °C

(T_5 for dropwise condensation and T_6 for film wise condensation.)

Heat transfer rate at the condenser wall,

$$q = W .C_P. (T_5 - T_4) \quad \text{watts.}$$

where, C_P = Specific heat of water = 4. 2 x 10^3 J / Kg K

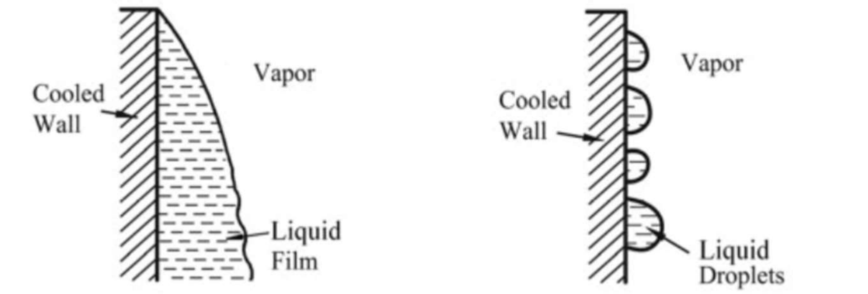
Surface area of the condenser A = 9.24 x 10^3 m^3

Heat transfer coefficient,

$$h_L = \left[\frac{q}{A (T_S - T_W)} \right] \quad W / m^2 \ ^\circ C$$

In filmwise condensation, film of water acts as barrier to heat transfer where as, in case of drop formation, there is no barrier to heat transfer. Hence heat transfer coefficient in dropwise condensation is much greater than filmwise condensation, and is preferred for condensation. But practically, it is difficult to prolong the dropwise condensation and after a period of condensation the surface becomes wetted by the liquid. Hence slowly filmwise condensation starts.

DIAGRAM OF EXPERIMENTAL SET UP



(a) Filmwise condensation (b) Dropwise condensation

RESULT & CONCLUSION

1.The heat transfer coefficient in drop wise condensation by experiment is________
2.The heat transfer coefficient in film wise condensation is _________

QUESTIONS

1. When the condensate formed wets the surface, a film is formed over surface and the condensation is _______ condensation.
2. When condensate does not wet the surface, drops are formed over the surface and condensation is ________ condensation.
3. Dropwise condensation usually occurs on which types of surfaces?
4. For film wise condensation on a vertical plane, the film thickness δ and heat transfer coefficient h vary with distance x from the leading edge as______.
5. In condensation over a vertical surface, the value of convection coefficient varies as______________.

EXPERIMENT NO 11

EXPERIMENTAL STUDY OF POOL BOILING PHENOMENON UP TO CRITICAL HEAT FLUX POINT.

OBJECTIVE

To determine the heat transfer coefficient in forced convection of air in a tube.

INTRODUCTION

When heat is added to a liquid from a submerged solid surface which is at a temperature higher than the saturation temperature of the liquid, it is usual for a part of the liquid to change phase. This change of phase is called boiling.

Boiling is of various types, the type depending upon the temperature difference between the surface and the liquid. The different types are indicated in Fig. 1, in which a typical experimental boiling curve obtained in a saturated pool of liquid is drawn.

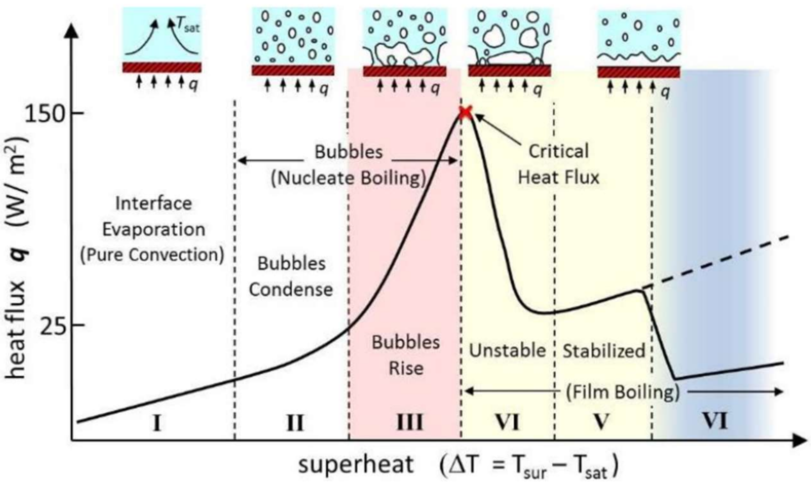


Fig1: Boiling curve

The heat flux supplied to the surface is plotted against (Tw - Ts) the difference between the temperature of the surface and the saturation temperature of the liquid.

It is seen that the boiling curve can be divided into three regions:

I) Natural Convection Region,

II) Nucleate Boiling Region and

III) Film Boiling Region.

The region of natural convection occur at low temperature differences (of the order of 100C or less). Heat transfer from the heated surface to the liquid in its vicinity causes the liquid to be superheated.

This superheated liquid rises to the free liquid surface by natural convection, where vapour is produced by evaporation.

As the temperature difference (Tw - Ts) is increased, nucleate boiling starts. In this region, it is observed that bubbles start to form at certain locations on the heated surface. Region (II) consists of two parts. In the first part (II - a) the bubbles formed are very few in number. They condense in the liquid and do not reach the free surface. In the second part (II - b) the rate of bubble formation as well as the number of locations where they are formed increase. Some of the bubbles now rise all the way to the free surface.

With increasing temperature difference, a stage is finally reached when the rate of formation of bubbles is so high, that they start to coalesce and blanket the surface with a vapour film. This is the beginning of region (III) viz. film boiling. In the first part of this region (III - a) the vapor film is unstable, so that film boiling may be occurring on a portion of the heated surface area, while nucleate boiling may be occurring on the remaining area. In the second part (III - b) a stable film covers the entire surface. At the end of region (II) the boiling curve reaches a peak (Point A). Beyond this, in region (III-A) in spite of increasing temperature difference, the heat flow increases with the formation of a vapor film. The heat flux passes through a minimum (point B) at the end of region (III-a). It starts to increase again with (Tw - Ts) only when stable film boiling begins and radiation becomes increasingly important.

It is of interest to note how the temperature of the heating surface changes as the heat flux is steadily increased from zero. Upto the point A, natural convection Boiling and then -

nucleate boiling occurs and the temperature of the heating surface is obtained by reading off the value of (Tw - Ts) from the boiling curve and adding to it the value of Ts.

If the heat flux is increased even a little beyond the value of A, the temperature of the surface will shoot up to the value corresponding to the point C. It is apparatus from Fig. 1. that the surface temperature corresponding to point C is high.

For most surface, it is high enough to cause the material to melt. Thus in most practical situations, it is undesirable to exceed the value of heat flux corresponding to point A . This value is therefore of considerable engineering significance and is called the critical or peak heat flux. The pool boiling curve as described above is known as Nukiyam pool boiling curve. The discussions so far have been concerned with the various type of boiling which occurring saturated pool boiling. If the liquid is below the saturation temperature, we say that sub-cooled pool boiling is taking place. Also in many practical situations, e.g. steam generators, one is interested in boiling in a liquid flowing through tubes. This is called forced convection boiling may also be saturated or subcooled and of the nucleate or film type.

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

DESCRIPTION

The ' GLS ' apparatus consists of a cylindrical glass housing the test heater and heater coil for heating of the water. This heater coil is direct connected to the mains (Heater R1) and the test wire is also connected to mains via. variac. An ammeter is connected in series while a voltmeter across it to read the current and voltage respectively.

The glass container is kept on a stand. There is provision of observing the test heater wire with the help of a lamp light from back and the heater wire can be viewing a lense.

SPECIFICATION

Glass Container	: Diameter 250 mm Height - 100 mm
Heater for Initial Heating	: Nichrome Heater (R-1) - 1 KW
Test Heater (R-2)	: Nichrome wire size diameter- 0. 18 mm (to be calculated according to wire used say 36 SWG to 40 SWG.)
Length of test Heater (R-2)	: 100 mm
Dimmerstat	: 10 AMP, 230 volts
Voltmeter	: 0-100V
Ammeter	: 0 to 10 Amps
Thermometer	: 0 to 100°C

PROCEDURE

1) Take enough distilled water in the container.
2) See that both the heaters are completely submerged.
3) Connect the heater coil R-1 (1 Kw Nichrome coil) and test heater wire across the studs and make the necessary electrical connections.
4) Switch on the heater R-1(Let variac be at O position.)
5) Keep it ON till you get the required bulk temperature of water in the container say 50^0C, 60^0C, 70^0C temperature.
6) Switch off the heater R-1.
7) Very gradually increase the voltage across test heater by slowly changing the variac position and stop a while at each position to observe the boiling Phenomenon on wire.
8) Go on increasing the voltage till wire brakes and carefully note the voltage and current at this point.
9) Repeat this experiment by altering the bulk temperature of water.

PRECAUTION

1) Keep the variac to zero voltage position before starting the experiments.
2) Take enough distilled water in the container so that both the heaters are completely immersed.
3) Connect the test heater wire across the stud
4) Do not touch the water or terminal points when the main switch ON.
5) Operate the variac gently in steps and sufficient time in between.
6) After the attainment of critical heat flux decrease slowly the voltage and bring it to zero position.

OBSERVATION

1) Diameter of test heater wire, d = 0.17 m.m = m.
2) Length of the test heater, L = 0.1 m
3) Surface area. $A = \pi . d . L$ = m^2

OBSERVATION TABLE

Bulk Temperature of water ^{0}C	Ammeter Reading (I Amps)	*Voltmeter Reading (V Volts)*
40^0 C 50^0 C 60^0C 70^0 C		

NOTE - The ammeter and voltmeter readings are to be note down when wire melts.

CALCULATION

1) Diameter of test heater wire, d = ____ m.m.
2) Length of the test heater, L = _____ m
3) Surface area. $A = \pi.d.L$ = _____ m^2
4) Ammeter reading, I = _____ Amps
5) Voltmeter reading V = _____ volts
6) Bulk temp. of water = _______ ^{0} c
7) q = V. I = ______ watts
8) $h_{act} = q/A$ = _________ w / m^2.

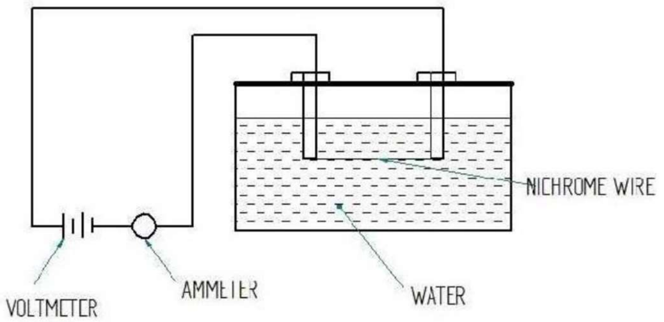
Zuber has given following equation for calculating peak heat flux in saturated pool boiling

$$q/A = 0.18\, hfg \left[(\rho_{LV} .\ g\ (\rho_L - \rho_V) \right]^{1/4} \left[\frac{\rho_V .\ \rho_L}{\rho_V - \rho_L} \right]^{1/2}$$

hfg = Latent heat of vaporisation = __________ J/Kg
ρ_{LV} = Liquid Vapour surface tension = _________ N/m
ρ_L = Density of Liquid = 1000 Kg / m^3
ρ_V = Density of vapour = 1/ Vg = ______ Kg / m^3.

q/A = _______ w/ m^2

DIAGRAM OF EXPERIMENTAL SET UP

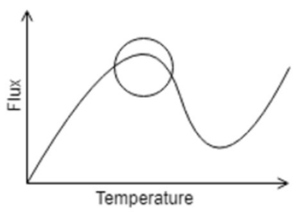


RESULT & CONCLUSION

1.The Critical Heat Flux (Peak heat flux) in saturated pool boiling is________ w/ m^2

QUESTIONS

1. Enlist the boiling curve regions.
2. The phenomenon of minimum heat flux in stable film boiling when heating a fluid with a tube is known as ___________.
3. What is the name of the point circled in the following boiling curve of water?



4. The burnout phenomenon for boiling of water occurs at a temperature at about ____________ degree Celsius.
5. The temperature of the liquid is below the saturation temperature and boiling takes place only in vicinity of the heated surface, then which type of boiling is this?