A Laboratory Manual for

Heat Transfer (BE05000291)

B.E. Semester 5 (Mechanical)

Directorate of Technical Education, Gandhinagar, Gujarat

Lukhdhirji Engineering College, Morbi

Certificate

This is to certify that Mr./Ms. ____ _________ Enrollment No. _________________ of B.E. Semester V Mechanical Engineering of this Institute (031) has satisfactorily completed the Practical / Tutorial work for the subject **Heat Transfer (BE05000291)** for the academic year **2026-27.**

Place: ___________
Date: ___________

Name and Sign of Faculty member

Preface

Main motto of any laboratory/practical/field work is for enhancing required skills as well as creating ability amongst students to solve real time problem by developing relevant competencies in psychomotor domain. By keeping in view, GTU has designed competency focused outcome-based curriculum for engineering degree programs where sufficient weightage is given to practical work. It shows importance of enhancement of skills amongst the students and it pays attention to utilize every second of time allotted for practical amongst students, instructors and faculty members to achieve relevant outcomes by performing the experiments rather than having merely study type experiments. It is must for effective implementation of competency focused outcome-based curriculum that every practical is keenly designed to serve as a tool to develop and enhance relevant competency required by the various industry among every student. These psychomotor skills are very difficult to develop through traditional chalk and board content delivery method in the classroom. Accordingly, this lab manual is designed to focus on the industry defined relevant outcomes, rather than old practice of conducting practical to prove concept and theory.

By using this lab manual students can go through the relevant theory and procedure in advance before the actual performance which creates an interest and students can have basic idea prior to performance. This in turn enhances pre-determined outcomes amongst students. Each experiment in this manual begins with competency, industry relevant skills, course outcomes as well as practical outcomes (objectives). The students will also achieve safety and necessary precautions to be taken while performing practical.

This manual also provides guidelines to faculty members to facilitate student centric lab activities through each experiment by arranging and managing necessary resources in order that the students follow the procedures with required safety and necessary precautions to achieve the outcomes. It also gives an idea that how students will be assessed by providing rubrics.

Given specification of equipments of experiments for sample calculation only. Use specification as per the equipment available in concern laboratory for the calculation.
Utmost care has been taken while preparing this lab manual however always there is chances of improvement. Therefore, we welcome constructive suggestions for improvement and removal of errors if any.

Practical – Course Outcome matrix

Course Outcomes (COs):

CO-1 To classify the heat transfer problems and to apply the principles of steady state one dimensional heat transfer, extended surface and unsteady state conduction for commonly encountered Mechanical engineering problems.

CO-2 To identify the type of convection problems and to apply concepts of natural and forced convection for related problems.

CO-3 To explain various laws of radiation heat transfer and to determine the radiation heat transfer between black and grey surfaces of simple Mechanical systems.

CO-4 To practice LMTD and effectiveness-NTU method for simple heat exchange device.

CO-5 To identify types of boiling and condensation heat transfer process and to use the same to estimate heat transfer coefficient for simple cases.

Sr. No.	Objective(s) of Experiment	CO 1	CO 2	CO 3	CO 4	CO 5
0.	Write Institute and Department Vision Mission and Course objectives.					
1.	To determine thermal conductivity of Insulating Powder.	√				
2.	Heat Transfer through Lagged Pipe.	√				
3.	To determine the thermal conductivity of the given composite walls.	√				
4.	To determine Stephan Boltzmann constant experimentally			√		
5.	To determine the emissivity of gray body.			√		
6.	To find out heat transfer rate and total resister for critical radius of insulation for a cylinder.	√				
7.	To determine heat transfer co-efficient by natural convection.(V-Lab)		√			
8.	To study and compare the performance of heat pipe with two geometrical similar pipes of copper and stainless steel.				√	
9.	To find out critical heat flux.					√
10.	To determine overall heat transfer coefficient of concentric tube type heat exchanger for (i) parallel (ii) counter flow configuration.				√	

Industry Relevant Skills

The following industry relevant competencies are expected to be developed in the student by undertaking the practical work of this laboratory.

1. Students will be able to understand and apply basics of conduction, convection and radiation mode of heat transfer in engineering applications.
2. Students will be able to calculate design and performance parameters of heat exchangers for simple geometries.

Guidelines for Faculty members

1. Teacher should provide the guideline with demonstration of practical to the students with all features.
2. Teacher shall explain basic concepts/theory related to the experiment to the students before starting of each practical
3. Involve all the students in performance of each experiment.
4. Teacher is expected to share the skills and competencies to be developed in the students and ensure that the respective skills and competencies are developed in the students after the completion of the experimentation.
5. Teachers should give opportunity to students for hands-on experience after the demonstration.
6. Teacher may provide additional knowledge and skills to the students even though not covered in the manual but are expected from the students by concerned industry.
7. Give practical assignment and assess the performance of students based on task assigned to check whether it is as per the instructions or not.
8. Teacher is expected to refer complete curriculum of the course and follow the guidelines for implementation.

Instructions for Students

1. Students are expected to carefully listen to all the theory classes delivered by the faculty members and understand the COs, content of the course, teaching and examination scheme, skill set to be developed etc.
2. Students shall organize the work in the group and make record of all observations.
3. Students shall develop maintenance skill as expected by industries.
4. Student shall attempt to develop related hand-on skills and build confidence.
5. Student shall develop the habits of evolving more ideas, innovations, skills etc. apart from those included in scope of manual.
6. Student shall refer technical magazines and data books.
7. Student should develop a habit of submitting the experimentation work as per the schedule and s/he should be well prepared for the same.

Common Safety Instructions

1. Maintain clean and orderly laboratory and work area.
2. Read the laboratory manual carefully before performing any experiment.
3. Prepare an observation and result table before performing any experiment.
4. Do not touch anything without the permission of the instructor/ laboratory assistant.
5. Do not tamper with the measuring instruments.
6. Switch off the power supply to the experimental setup on completion of the experiment.

7. Be aware of all the controls to be used for each experiment.
8. Do not leave running experimental setup unattended.
9. Close the water tap and disconnect the water supply after completion of the experiment.
10. In the case of an injury, immediately report to the instructor/lab assistant for proper care.

Index (Progressive Assessment Sheet)

Sr. No.	Objective(s) of Experiment	Page No.	Date of performance	Date of submission	Assessment Marks	Sign. of Teacher with date	Remarks
0.	Write Institute and Department Vision Mission and Course objectives.						
1.	To determine thermal conductivity of Insulating Powder.						
2.	Heat Transfer through Lagged Pipe.						
3.	To determine the thermal conductivity of the given composite walls.						
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6.	To find out heat transfer rate and total resister for critical radius of insulation for a cylinder.						
7.	To determine heat transfer co-efficient by natural convection.(V-Lab)						
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9.	To find out critical heat flux.						
10.	To determine overall heat transfer coefficient of concentric tube type heat exchanger for (i) parallel (ii) counter flow configuration.						
	Annexure 1: Properties of air						
	Reference						
	Total						

Experiment No: 1

To determine thermal conductivity of Insulating Powder.

Date:

Competency and Practical Skills:

Relevant CO: 1

Objectives: Study of the phenomenon of heat transfer by conduction for powder.

Introduction:

Thermal conductivity is one of the important properties of the materials and its knowledge is required for analyzing heat conduction problems. Physical meaning of Thermal Conductivity is how quickly heat passes through a given material. Thus the determination of their property is of considerable engineering significance. There are various methods of determination of Thermal Conductivity of various materials available in powder form as well as in slabs also.

Apparatus:

This apparatus is suitable for determining the thermal conductivity of materials in the powder form. It consists of two concentric hollow spheres. An electric heater is fitted inside the inner sphere. The gap between inner and outer sphere is filled with insulating powder whose thermal conductivity is to be measured. The arrangement of heater and thermocouple in two spheres is shown in **Fig.-1.**

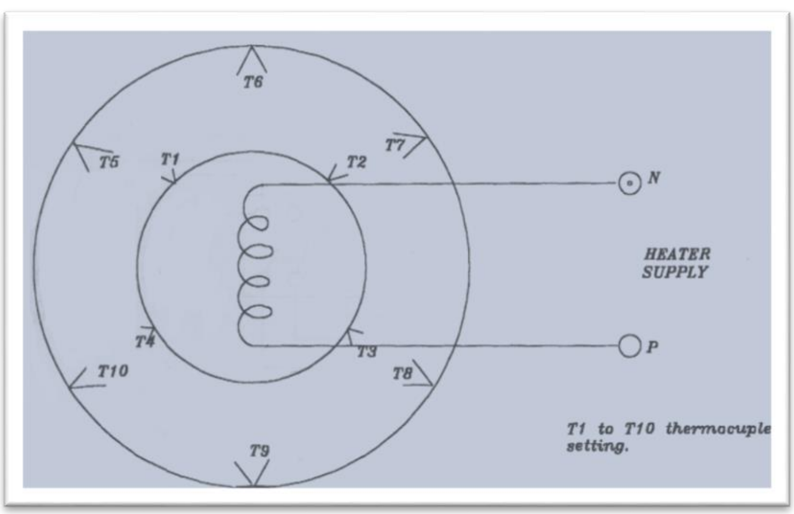


Fig.-1: The arrangement of heater and thermocouples in sphere

The heat generated by heater flows through the powder to the outer sphere. The outer sphere losses heat to the atmosphere. The input to heater is controlled by dimmerstat. Four thermocouples are provided on outer surface of inner sphere and six are on inner surfaces of outer sphere. Average of outer and inner sphere surface temperature gives temperature difference across the layer of powder. **Fig.-2** shows experimental set up.

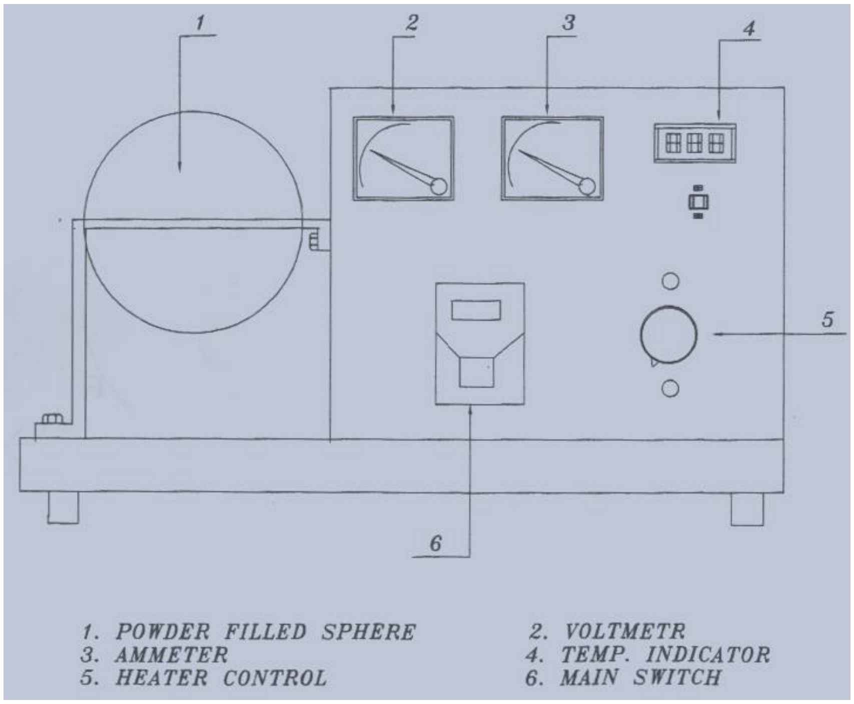


Fig.-2: Experimental set up for thermal conductivity of insulation powder

Specification:

1. Inner Sphere - 100 Mm O. D. , Halved Construction.
2. Outer Sphere - 200 Mm I. D., Halved Construction.
3. Heater - Mica Flat Heater, Fitted Inside Inner Sphere.
4. Controls - A) Main Switch - 30 A, B) Dimmerstat - 0-230 Volts, 2a Capacity.
5. Measurements -A) Voltmeter - 0 - 200 Volts B) Ammeter - 0 - 1 Amp. C) Multichannel Digital Temperature Indicator Calibrated For Cr / A1 Thermocouples
6. Insulating Powder: Asbestos magnesia powder packed between the two spheres.

Experimental procedure:

1. The dimmerstat knob was kept at ZERO position and the equipment was switched ON.

2. Slowly the dimmerstat knob was rotated, so that voltage was applied across the heater.
3. The readings were taken after the steady state was achieved.
4. The temperatures and input of heater in terms of volts and current was noted down.

Observation table:

Sr.	Time, Sec	Temperature on surface of inner sphere,°C				Temperature on surface of outer sphere, °C						Heater input	
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Volt,V	Amp, A
1													
2													
3													

Calculation:

1. Average outer sphere surface temperature:

$$T_o = \frac{T_5 + T_6 + T_7 + T_8 + T_9 + T_{10}}{6} \ {}^0\mathrm{C}$$

2. Average inner sphere surface temperature:

$$T_i = \frac{T_1 + T_2 + T_3 + T_4}{4} \ {}^0\mathrm{C}$$

3. Heat transfer rate,

$$q = V \times I \qquad \mathrm{W}$$

4. Heat transfer rate,

$$q = \frac{4\pi K r_i r_o (T_i - T_o)}{(r_o - r_i)} \quad \mathrm{W}$$

Result

Sr No	Volt,V	Amperage,A	Thermal Conductivity,k W/m^{o}C
1			
2			
3			

Conclusion:

The thermal conductivity of powder insulation comes out to be _____ W/m.^{0}C at mean temperature of _______ ^{0}C.

Exercises

1. What is a thermal resistance?
2. What is a thermal conductance?
3. Which type of powder is used to measure the thermal conductivity.
4. Explain the one-dimension heat flow in metal road.
5. What is heat transfer coefficient?
6. State the assumptions made in the experiment.
7. Describe the setup and explain the procedure of experiment.
8. Compare the experimental results with the standard ones and justify the possible deviation.

Rubric wise marks obtained:

Criteria	**Ability to conduct experiment (Max 3)**	**Data collection, analysis and interpretation (Max 4)**	**Subject Knowledge (Max 3)**	**Total**

Signature of lab teacher

Experiment No: 2

Heat Transfer through Lagged Pipe.

Date:

Competency and Practical Skills:

Relevant CO: 1

Objectives:

1. To estimate the actual rate of heat transfer through composite Cylinders
2. To determine the effective thermal conductivity of composite Cylinders

Theory:

In heat transfer, conduction (or heat conduction) is a mode of transfer of energy within and between bodies of matter, due to a temperature gradient. Conduction means collisional and diffusive transfer of kinetic energy through particles of ponderable matter (as distinct from photons). Conduction takes place in all forms of ponderable matter, such as solids, liquids, gases and plasmas. Heat spontaneously tends to flow from a body at a higher temperature to a body at a lower temperature. In the absence of external driving fluxes, temperature differences, over time, approach thermal equilibrium.

A direct application of Fourier Law is the plane wall.

Fourier's Equation

$$q = -\frac{kA(T_2 - T_1)}{\Delta X}$$

When the thermal conductivity is considered constant, the wall thickness is ΔX and T_1 and T_2 are the face temperatures, if more than one material is present, as in the multilayer wall, the analysis would proceed as follows:

The temperature gradient in the three materials, the heat flow may be written

$$q = -\frac{k_A A(T_2 - T_1)}{\Delta X_A} = -\frac{k_B A(T_3 - T_2)}{\Delta X_B} = -\frac{k_C A(T_4 - T_{31})}{\Delta X_C}$$

The heat flow must be the same through all the sections.

Solving these equations simultaneously, the heat flow is written as

$$q = -\frac{k_A A(T_1 - T_{41})}{\Delta X_A / k_A A + \Delta X_B / k_B A = \Delta X_C / k_C A}$$

Cylindrical Shells:

Conduction through cylindrical shells (e.g. pipes) can be calculated from the internal radius, r_1, the external radius, r_2, the length, ℓ, and the temperature difference between the inner and outer wall, $T_2 - T_1$.

The surface area of the cylinder is $A_r = 2\pi r\ell$

When Fourier's equation is applied:

$$\dot{Q} = -kA_r\frac{\mathrm{d}T}{\mathrm{d}r} = -2k\pi r\ell\frac{\mathrm{d}T}{\mathrm{d}r}$$

and rearranged:

$$\dot{Q}\int_{r_1}^{r_2}\frac{1}{r}\mathrm{d}r = -2k\pi\ell\int_{T_1}^{T_2}\mathrm{d}T$$

then the rate of heat transfer is:

$$\dot{Q} = 2k\pi\ell\frac{T_1 - T_2}{\ln(r_2/r_1)}$$

the thermal resistance is:

$$R_c = \frac{\Delta T}{\dot{Q}} = \frac{\ln(r_2/r_1)}{2\pi k\ell}$$

$$Q = 2\pi k l r_m\left(\frac{T_1 - T_2}{r_2 - r_1}\right)$$

Where, $$r_m = \frac{r_2 - r_1}{\ln\left(\frac{r_2}{r_1}\right)}$$

Description:

The setup is Designed & fabricated to Study the lagging phenomenon in case of pipes. It consists of three concentric pipes of small thickness as compared to diameter and are arranged concentrically, & Closed with the help of two discs. Two Different Insulating materials fills the annuli between the cylinders compactly. Temperature Sensors are fitted to measure the temperature of pipe walls for radial outward heat flow measurement. Inside the inner pipe, a nichrome wire heater is placed axially, Heat input to the heater given through variac & measured by digital Voltmeter & digital Ammeter. By varying the Heat Input Rates, Wide Range of Experiments Can the Performed.

Procedure:

1. Switch on The power supply
2. Start the supply of heater by varying the dimmerstat; adjust the power input at the desired value.
3. Take readings of all the temperature sensors after fairly steady temperatures are achieved and the rate of rise is neglible.
4. Note down the readings in the observation table.

Nomenclature:

Nom	Column Heading	Units	Type
T_i	Avearage Temperature of Inner wall =	°C	Calculated
T_m	Avearage Temperature of Middle wall	°C	Calculated
T_o	Avearage Temperature of outer wall	°C	Calculated
r	Radius of pipe	m	Given
r_m	Mean Radius	m	Calculated
K_{eff}	Effective Thermal conductivity of lagged	W/m °C	Calculated

	pipe		
R_t	Thermal resistance of lagged pipe	K/Watt	Calculated
Q	Heat input	W	Calculated
t	Time	sec	Measured
T_1- T_6	Temperature of lagged pipe	°C	Measured
V	Volt meter reading	volts	Measured
I	Ammeter reading	Amp	Measured

Specification:

1.Pipes:

Radius of Inner Pipe r_1 = 0.025 m

Radius of Middle Pipe r_2 = 0.050m

Radius of Outer Pipe r_3 = 0.075 m

Length of pipes 1m.

2. HEATER-Nichrome wire heater (cartridge type) placed centrally having suitable capacity 400 watts,

3. CONTROL PANEL comprising of –

i) Single phase Dimmerstat 0 – 230 volts . . . 1 No.

ii) Voltmeter 0 – 100 / 200 V. . . . 1 No.

iii) Ammeter 0 – 2 Amps. . . . 1 No.

4. TEMPERATURE INDICATOR WITH THERMOCOUPLES - :

Range 0 – 300^{O}C using chrome, alumel thermocouples – 1 No. s

Service required – A. C. single phase 230Velectric supply.

Observation Table: -

Sr. No	V (Volts)	I (Amp)	t (sec)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)
1									
2									
3									

Calculations:

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

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

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

$$Q = V \times I$$

$$K_1 = \frac{Q \ln\left({}^{r_2}\!/_{r_1}\right)}{2\pi L\left(T_i - T_m\right)}$$

$$K_1 = \frac{Q \ln\left({}^{r_3}\!/_{r_2}\right)}{2\pi L\left(T_m - T_0\right)}$$

$$Q = \frac{T_i - T_o}{\frac{r_2 - r_1}{k_1 2\pi r_{m1} L} + \frac{r_3 - r_2}{k_2 2\pi r_{m2} L}}$$

$$r_{m1} = \frac{r_2 - r_1}{\ln\left(\frac{r_2}{r_1}\right)}$$

$$r_{m2} = \frac{r_3 - r_2}{\ln\left(\frac{r_3}{r_2}\right)}$$

$$R_t = \frac{\Delta T}{Q} = \frac{T_i - T_o}{Q}$$

$$k_{eff} = \frac{\ln\left(r_3 / r_1\right)}{2\pi L R_t}$$

Result:

Calculation Table:-		
Sr. No.	**Q (W)**	**K (W/m °C)**
1		
2		
3		

Conclusion:

Exercises

1. What is Critical thickness? Why an insulated small diameter wire has a higher current carrying capacity than an uninsulated one?
2. Explain the physical significance of critical thickness of insulation considering the example of small diameter wire and steam pipe.
3. State the assumptions made in the experiment.
4. Describe the setup and explain the procedure of experiment.
5. Compare the experimental results with the standard ones and justify the possible deviation.
6. To determine the thermal conductivity of the given composite walls.

Rubric wise marks obtained:

Criteria	Ability to conduct experiment (Max 3)	Data collection, analysis and interpretation (Max 4)	Subject Knowledge (Max 3)	Total

Signature of lab teacher

Experiment No: 3

To determine the thermal conductivity of the given composite walls.

Date:

Competency and Practical Skills:

Relevant CO: 1

Objectives:

1. The overall thermal resistance(R) for a composite wall and to compare with theoretical value.
2. Temperature distribution across the width of the composite wall.
3. Find thermal conductivity of different material.

Apparatus:

The apparatus consists of slabs of different materials sandwiched between two end plates. Three types of slabs are provided on both sides of heater which form 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 power is carried out by a Voltmeter and Ammeter. Thermocouples are embedded between interfaces of slabs, to measure the temperatures at the surfaces.

Fig.-1: Thermocouple location in composite wall

Specification:(Given specification of an equipment for sample calculation only. Use specification as per the equipment available in laboratory for the calculation.)

1) Slabs Size:

a) M. S. - 250 mm, Dia.=25 mm. thick

b) Brass - 250 mm, Dia.=10 mm. thick

c) Bakelite - 250 mm, Dia.=10 mm. thick

2) Nichrome heater wound on mica former with control unit of capacity 300 watt.

3) Heater control unit: 0- 230 V, 0 - 2 Amp. Single phase dimmerstat (1 Nos.)

4) Voltmeter: 0 – 100-200 Volts.

5) Ammeter: 0 - 1 Amps.

6) Temperature indicator: Digital type 0-200 ^{0}C

Experimental procedure:

1. The plates were arranged (symmetrical) on both side of heater plate.
2. Hand press was operated properly to ensure perfect contact between the plates
3. The cover of the box was closed to achieve steady environmental conditions.
4. Supply of heater was turned on. By varying the dimmer stat, the input was adjusted. (Range 30 - 70 Watts).
5. The readings were taken of all the thermocouples at an interval of 10 minutes and ensured steady state operation of set up.
6. The readings were tabulated in the observation table.

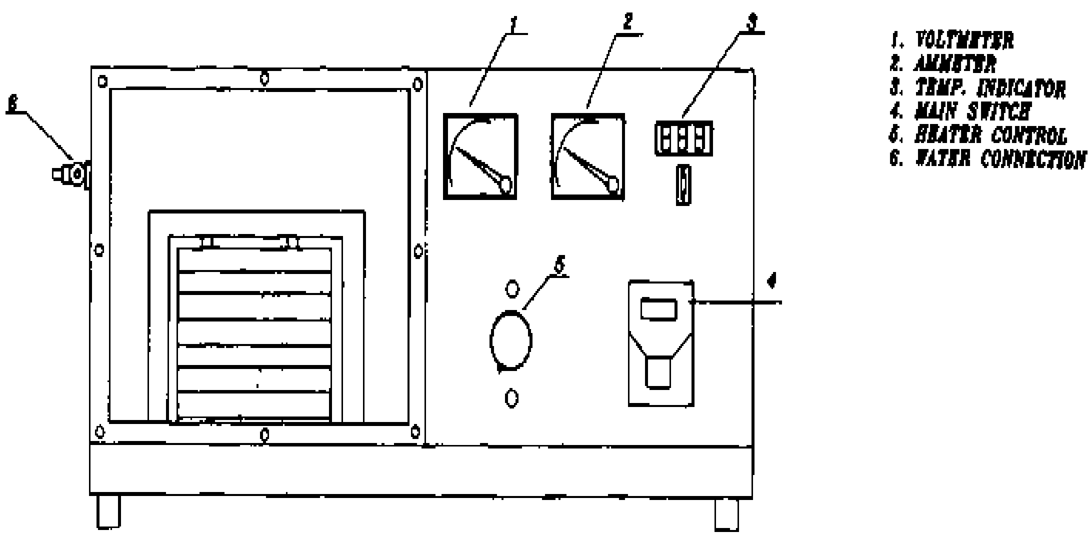


Fig.-2: Experimental Set up

Observations:

Sr.	Time, Min	Heat Supplied, W		Temperature, ^{0}C							
		Volt	Ampere	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8

Calculation:

1. Mean temperature:

$$T_A = \frac{T_1 + T_2}{2} = {}^0\text{C}$$

$$T_B = \frac{T_3 + T_4}{2} = {}^0\text{C}$$

$$T_C = \frac{T_5 + T_6}{2} = {}^0\text{C}$$

$$T_D = \frac{T_7 + T_8}{2} = {}^0\text{C}$$

2. Rate of heat supplied:

$Q = V \times I$, W

3. Heat flux:

$q = \dfrac{Q/2}{A}$, W/m^2, Q/2 in each direction, i.e. Upward and Downward in Slab.

Where,

$$A = \frac{\pi}{4} \times d^2$$

(Slab diameter of plate, d= 0.3 m, half of it is to be considered in calculation of A)

$$A = \frac{\pi}{4} \times (0.15)^2 = 0.017671 \quad \text{m}^2$$

4. Total thermal resistance of composite wall

$$R = \frac{T_A - T_E}{q} \quad \text{m}^2\text{K/W}$$

5. Thermal conductivity of composite wall:

$$k = \frac{qb}{T_A - T_D} \quad \text{W/mK}$$

b= total thickness = 0.03 m

6. Thermal Conductivity of each plate:

$$k_{MS} = \frac{qb_{MS}}{T_A - T_B}, k_{BL} = \frac{qb_{BL}}{T_B - T_C}, k_W = \frac{qb_W}{T_C - T_D}$$

Where,

k_{MS} , k_{Br}, and k_{Bk} are thermal conductivity of Mild Steel, Brass and Bakelite respectively. Script b stands for thickness of respective plate.

Result:

Material	**Thermal Conductivity**	**Thermal Resistance**

Conclusion:

Exercises

1. Why there is a negative sign in the Fourier's law of heat conduction?
2. What is meant by one-dimensional steady state heat conduction?
3. List some good conductors of heat; some poor conductors.
4. State the assumptions made in the experiment.
5. Describe the setup and explain the procedure of experiment.

6. Compare the experimental results with the standard ones and justify the possible deviation.

Rubric wise marks obtained:

Criteria	Ability to conduct experiment (Max 3)	Data collection, analysis and interpretation (Max 4)	Subject Knowledge (Max 3)	Total

Signature of lab teacher

Experiment No: 4

To determine Stephan Boltzmann constant experimentally

Date:

Competency and PracticalSkills:

Relevant CO: 3

Objectives: To determine Stefan-Boltzmann constant.

Introduction:

All the substances emit thermal radiation. When heat radiation is incident over a body, part of radiation is absorbed, transmitted through and reflected by the body. A surface which absorbs all thermal radiation incidents over it is called black surface. For black surface, transmissivity and reflectivity are zero and absorptivity is unity. Stefan Boltzmann Law states that emissivity of a surface is proportional to fourth power of absolute surface temperature i.e.

$$e \propto T^4$$

or $$e = \sigma . \varepsilon . T^4$$

Where,

e = emissive power of surface.

T = absolute temperature.

σ = Stefan Boltzmann Constant = 5.667 X 10^{-8} W / m^2 K^4

ε = Emissivity of the surface

For black surface, ε = 1, hence above equation reduces to

$$e = \sigma . T^4$$

Apparatus:

The apparatus consists of a water heated jacket of hemispherical shape. A copper test disc is fitted at the center of jacket. The hot water is obtained from a hot water tank, fitted to the panel, in which water is heated by an electric immersion heater. The hot water is taken around the hemisphere, so that hemisphere temperature rises. The apparatus is shown in Fig.-

2. The test disc is then inserted at the center. Thermocouples are fitted inside hemisphere as shown in Fig-1.

A timer with a small buzzer is provided to note down the disc temperatures at the time intervals of 5 seconds.

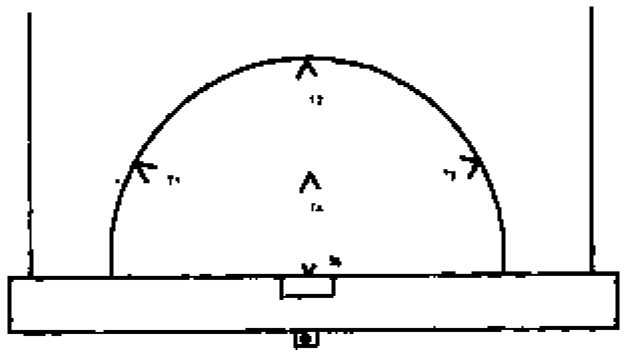


Fig.-1: Location of thermocouple

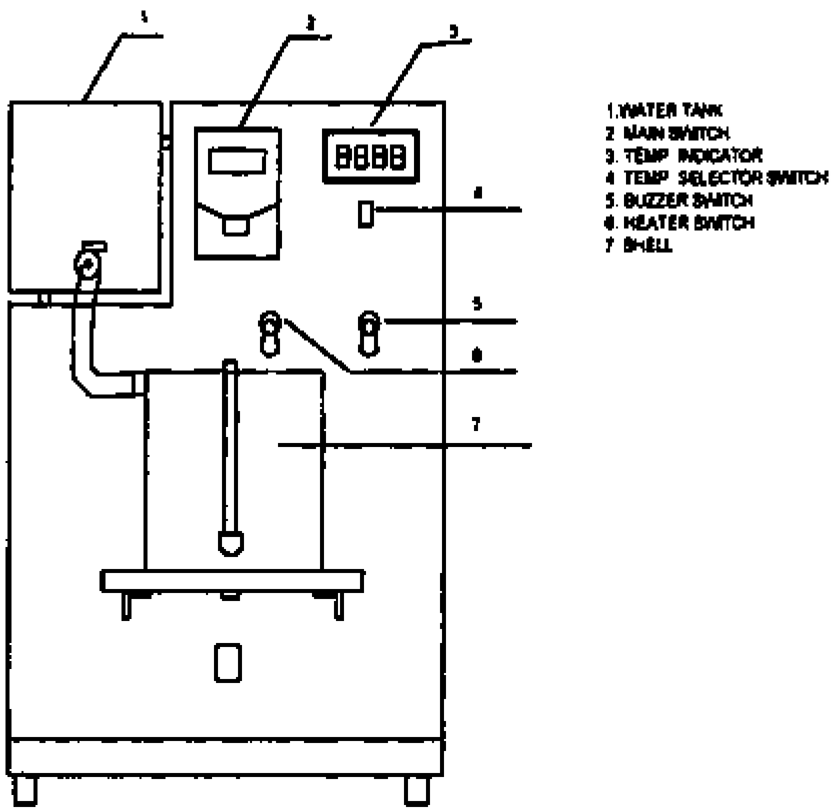


Fig.-2: Stefan-Boltzmann apparatus

Experimental procedure:

1. We ensured that water inlet cock of water jacket is closed and filled sufficient water in the heater tank. Then we have supplied power to heater.
2. Blacken the test disc with the help of lamp black & allowed it to get cool.
3. Put the thermometer in heater and checked water temperature.
4. Heated the water till it started boiling and then stopped the supply of power.
5. By opening water inlet cock, hot water is filled above the top of hemisphere (A piezometer tube is fitted to indicate water level over hemisphere)
6. Noted down the hemisphere temperatures (i.e. up to channel 1 to 4) and test disc temperature (i.e. channel No. 5)
8. Timer with buzzer was used to indicate the predefined interval of time. At the start of timer cycle, test disc is inserted into the hole at the bottom of hemisphere.
9. Noted down the temperature of disc at interval of predefined interval of time.

Specification: (Given specification of an equipment for sample calculation only. Use specification as per the equipment available in laboratory for the calculation.)

- Diameter of copper disc, d= 20mm
- Cross section of copper disc, A= 3.14 X10^{-4} m^2
- Mass of test disc= 6 X 10^{-3} kg
- Emissivity of disc, ε = 1
- Specific heat of copper, C_{pc}= 385 J/kg K

Observation table:

Sr.No.	Time interval, Sec	Hemisphere temperature,^{0}C					Test disc temperature,^{0}C
		T_1	T_2	T_3	T_4	T_6 (Waterbath Temp)	T_5
1	5						
2	10						
3	15						

4	20						
5	25						

Calculation:

1. Plot graph of rise of temperature of test disc to time. Find slope

$$\left(\frac{dT}{dt}\right)_{t=0} = \qquad \text{K /s}$$

2. Hemisphere temperature:

$$T_H = \frac{T_1 + T_2 + T_3 + T_4}{4} + 273 \qquad \text{K}$$

4. Initial test disc temperature, TD $= T_5$

5.

4. Heat gain by disc/sec.:

$$q = mC_{pc}\left(\frac{dT}{dt}\right) \qquad \text{W}$$

$$q = \sigma\varepsilon A\left(T_H{}^4 - T_D{}^4\right) \qquad \text{W}$$

$$\sigma = \frac{mC_{pc}\left(\frac{dT}{dt}\right)}{\varepsilon A\left(T_H{}^4 - T_D{}^4\right)}$$

Result:

Conclusion:

Exercises

1. What is Stefan Boltzmann law?
2. What is the absorptivity?
3. Explain gray, opaque and black body?
4. What is thermal radiation?

5. State the assumptions made in the experiment.
6. Describe the setup and explain the procedure of experiment.
7. Compare the experimental results with the standard ones and justify the possible deviation.

Rubric wise marks obtained:

Criteria	Ability to conduct experiment (Max 3)	Data collection, analysis and interpretation (Max 4)	Subject Knowledge (Max 3)	Total

Signature of lab teacher

Experiment No: 5

To determine the emissivity of gray body.

Date:

Competency and Practical Skills:

Relevant CO: 3

Objectives: Determine emissivity of a test plate by emissivity measurement apparatus:

Introduction:

All the bodies emit and absorb the thermal radiation to and from surroundings. The rate of thermal radiation depends upon the temperature of body. Thermal radiation is electromagnetic waves and they do not require any medium for propagation.

When thermal radiation strikes a body, part of it is reflected, part of it is absorbed and part of it is transmitted through body. The fraction of incident energy, reflected by the surface is called reflectivity (ρ). The fraction of incident energy, absorbed by the surface is called absorptivity (α) and the fraction of incident energy transmitted through body is called transmissivity (τ)

The surface which absorbs all the incident radiation is called a black surface. For a black surface, $\rho + \alpha + \tau = 1$

The radiant flux, emitted from the surface is called emissive power (e).

The emissivity of a surface is ratio of emissive power of a surface to that of black surface at the same temperature.

Experimental set up:

The apparatus uses comparator method for determining the emissivity of test plate. It consists of two aluminum plates, of equal physical dimensions. Mica heaters are provided inside the plates. The plates are mounted in an enclosure to provide undisturbed surroundings. **Fig.-1** shows the experimental set up.

One of the plates is blackened outside for use as a comparator (because black surface has $\varepsilon = 1$). Another plate is having natural surface finish. Input to heaters can be controlled by separate dimmerstat. Heater input is measured by ammeter and voltmeter. One thermocouple is fitted on surface of each plate to measure the surface temperature with digital temperature indicator. By adjusting input to the heaters, both the plates are brought to same temperature, so that conduction and convection losses from both the plates are equal and difference in input is due to different emissivities.

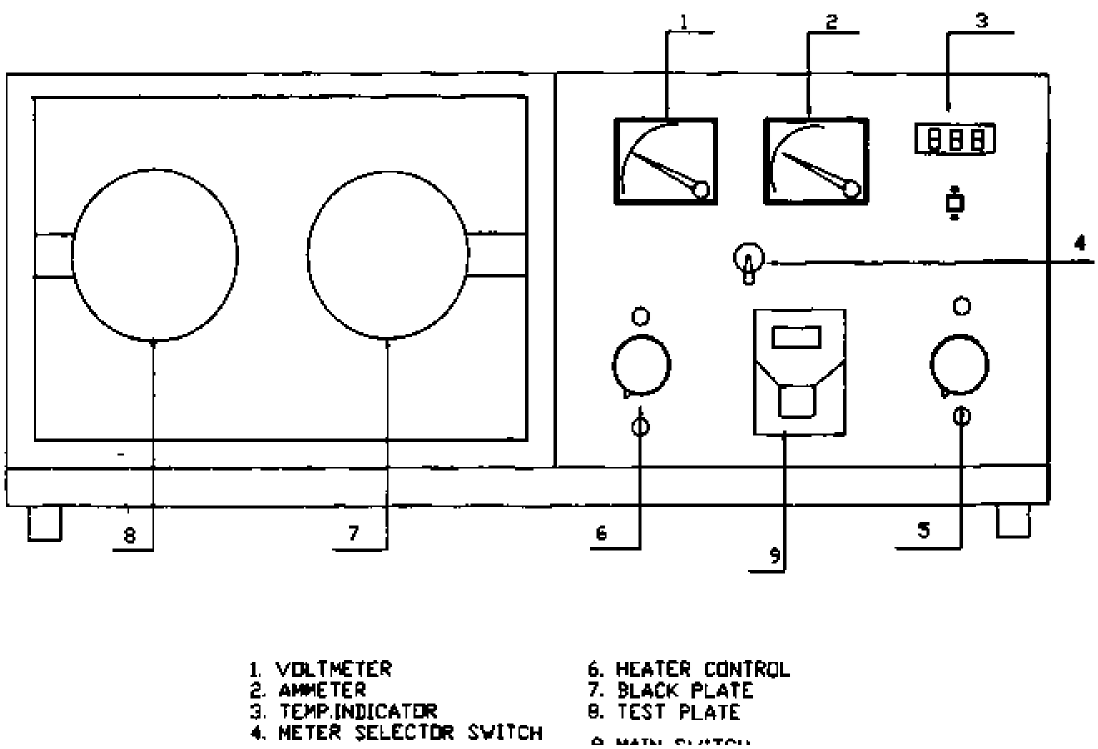


Fig.-1: An apparatus for Emissivity measurement

Experimental Procedure:

1. Blacken one of the plates with the help of lamp black.
2. The power is supplied to both the heaters (i.e. inside black plate and test plate)
3. Adjusted the supply voltage to black plate, around 120 V.
4. Adjusted test plate voltage slightly less than that of black plate i.e., 100 V.

5. Checked the temperatures and voltage supplied adjusted with help of dimmerstat so that temperatures of both the plates be equal and steady. Very minor adjustments were required for this.
9. Noted down the readings after the plate temperatures reached steady state.

Specification:

1. Diameter of plate: 0.16 m
2. Thickness of plate ,t :0.009 m
3. Surface area, A: $2\times\frac{\pi}{4}\times D^2+\pi Dt$ m^2
4. Stefan Botlzmann constant, $\sigma=5.667\times10^{-8}$ W/m^2K^4

Nomenclature:

Q_b: Heat input to black plate, W

Q_t: Heat input to test plate, W

A_b: Surface area of black plate

A_t: Surface area of test plate

D: Diameter of plates

Q_{cvb}: Heat loss due to convection from black plate, W

Qcdb: Heat loss due to conduction from black plate,W

Q_{rb}: Heat loss due to radiation from black plate,W

Q_{cvt}: Heat loss due to convection from test plate, W

Q_{cdt}: Heat loss due to conduction from test plate, W

Q_{rt}: Heat loss due to radiation from test plate,W

Observation:

Plate	Surface temperature, ^0C	Input	
		Volt, V	Amp., A
Black plate	T_1:		
Test plate	T_2:		
Enclosure temperature	T_3:		

Calculation:

1. Plate surface temperature, $Ts = T_1 = T_2 =$ ^0C
2. Heat input to black plate and test plate

   $Q_b = V \times I$ W

   $Q_t = V \times I$ W

3. $Q_b = Q_{cvb} + Q_{cdb} + Q_{rb}$
4. $Q_t = Q_{cvt} + Q_{cdt} + Q_{rt}$

Both plate have same physical dimensions, same material and same temperature so $Q_{cvb} = Q_{cvt}$; $Q_{cdb} = Q_{cdt}$, subracting relation (4) from (3)

$$Q_b - Q_t = Q_{rb} - Q_{rt}$$

$$= \sigma A \varepsilon_b \left(T_s{}^4 - T_E{}^4\right) - \sigma A \varepsilon_t \left(T_s{}^4 - T_E{}^4\right)$$

$$= \sigma A \left(T_s{}^4 - T_E 4\right)\left(\varepsilon_b - \varepsilon\right)$$

(For black surface $\varepsilon_b = 1$)

$$Q_b - Q_t = \sigma A \left(T_s{}^4 - T_E{}^4\right)\left(1 - \varepsilon\right)$$

From this relation one can find emissivity for test plate.

Result: -

Conclusion:

Exercises

1. What is the emmisivity?
2. What is Emmissive power for black body?
3. Explain Planck’s law?
4. Explain the Kirchhoff’s law?
5. State the assumptions made in the experiment.
6. Describe the setup and explain the procedure of experiment.
7. Compare the experimental results with the standard ones and justify the possible deviation.

Rubric wise marks obtained:

Criteria	Ability to conduct experiment (Max 3)	Data collection, analysis and interpretation (Max 4)	Subject Knowledge (Max 3)	Total

Signature of lab teacher

Experiment No: 6

Critical Radius of Insulation for A Cylinder.

Date:

Competency and Practical Skills:

Relevant CO: 1

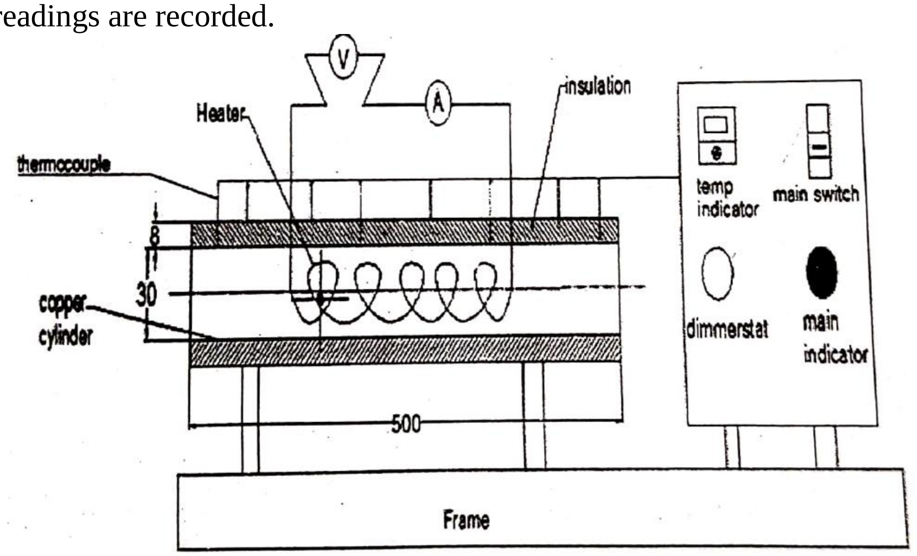
Objectives: To find out heat transfer rate and total resister for critical radius of insulation for a cylinder.

Introduction:

Thermal conductivity is one of the important properties of the materials and its knowledge is required for analyzing heat conduction problems. Physical meaning of the thermal conductivity is how quickly it passes through a given materials, thus, the determination of this property is of considerable engineering significance, there are various methods of determination of thermal conductivity but it is suitable for finding out the thermal conductivities of the material in the powdered form.

Apparatus:

The apparatus consists of one metal cylinder in which heater is fitted. The insulating material (asbestos belt) as lagging material is covered around the cylinder. Again the total assembly is insulated by glass wool & aluminum foil. The heat supplied to inner cylinder through heating coil by using a by a dimmerstat & is measured by Voltmeter & Ammeter. Cromial alumel thermocouples are used to measure the temperatures, thermocouples 1 to 5 are embedded on metal cylinder and thermocouples 6 to 10 are embedded on the external side of insulating material. Position 1 to 10, are as shown on change over switch of temperature indicator. Under steady state condition, the temperatures 1 to 10 are rated and also the voltmeter and ammeter readings are recorded.



These readings, in turn enables as to find out the thermal conductivity of the insulating powder packed between two shells like assume the insulating powder as are isotropic material and the value of thermal conductivity to be constant. The apparatus assume one dimensional radial heat conduction across the powdered layer and thermal conductivity can be determined as above under steady state condition.

Specification:

1. Pipe No.1 Copper pipe φ33mm insulating material asbestos rope 3 mm thick outer total φ36 mmx 360 mm long.
2. Pipe No.2 Copper pipe φ33mm insulating material asbestos rope 6 mm thick outer total φ39 mmx 360 mm long.
3. Pipe No.3 Copper pipe φ33mm insulating material asbestos rope 9 mm thick outer total φ42 mmx 360 mm long.
4. Pipe No.4 Copper pipe φ33mm insulating material asbestos rope 12 mm thick outer total φ45 mmx 360 mm long.
5. Voltmeter and ammeter
6. Digital Temperature indicator

Procedure - :

1. Keep dimmerstat knob at ZERO position and switch ON the equipment.
2. Slowly rotate the dimmerstat knob, so that voltage is applied across the heater. Let the temperatures rise.
3. Wait until steady state is reached.
4. Note down all the temperatures and input of heater in terms of volts and current.
5. Repeat the procedure for different heat inputs.

Obseration table: -

Pipes			1		2		3		4	
Sr No	Voltage	Current	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
1										

Calculations

For 1st Pipe

1) Thermal Conductivity of insulating Material k = 0.15 W W/m K

2) Outside Diameter of Pipe= 0.36m
3) T_{air} = ^{o}C
4) Properties of air at 1 atm pressure and T_{air} = ^{o}C

   ρ=

   Cp=

   k_{air}=

   w=

   υ =

   Pr=
5) r_2= (r_1+ thickness of insulation) mm
6) Mean Temp Tm = Ts = T_1+ T_2 / 2
7) β = I/ Tm
8) Ra = $(g\beta(Ts - Tair)D^3/ \upsilon^2)$ X Pr
9) $$Nu = \frac{0.6 + 0.387\, Ra^{1/6}}{[1 + (0.559/Pr)^{9/16}]^{8/27}}$$
10) h = k Nu / D
11) Qconv = h A (Ts –Tair)
12) $r_{cr} = h/k_{insulation}$
13) $$Qcond = \frac{(Ts - Tair)}{\ln(r2/r1)/2\pi kL + 1/2\pi Hh\, r2\, L}$$
14) Total Resistance = ln(r2/r1)/2πkL + 1/2πHh r2 L

Same calculations can be done for 2nd, 3rd and 4th Pipe.

Results:

Pipe	**1**	**2**	**3**	**4**
Qconv				
Qcond				
r_{cr}				

Conclusions:

Exercise:

1. What is critical radius of insulation?
2. State the assumptions made in the experiment.
3. Explain the experimental procedure.
4. State the assumptions made in the experiment.

Rubric wise marks obtained:

Criteria	Ability to conduct experiment (Max 3)	Data collection, analysis and interpretation (Max 4)	Subject Knowledge (Max 3)	Total

Signature of lab teacher

Experiment No: 7

To determine heat transfer co-efficient by natural convection. (V-Lab)

Date:

Competency and Practical Skills:

Relevant CO: 2

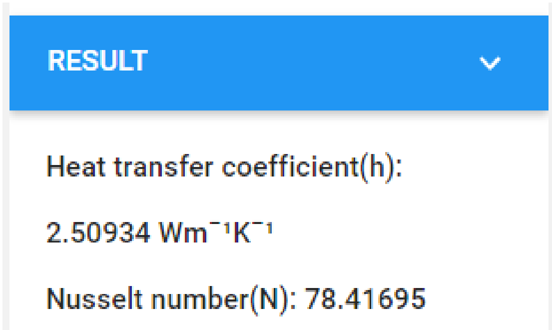
Objectives: To determine heat transfer coefficient of given test cylinder.

Lab name: Physical Science/ Virtual Heat & Thermodynamics Lab (IIT Bombay-VLab)

Experiment procedure:

1) Experiment is performed on VLAB IIT Bombay portal on the link : htv.au.vlabs.ac.in/heatthermodynamics/Heat_Transfer_by_Natural_Convection/experiment.html
2) Select the material of test cylinder on the screen
3) Select the width of wooden box
4) Select the height of wooden box
5) Select the diameter of cylinder
6) Select the length of cylinder
7) Select the thickness of cylinder
8) "On", power button
9) Get the result for three different material

Apparatus layout:



Observation table:

Sr No	**Material**	width of wooden box in cm	height of wooden box in cm	diameter of cylinder in cm	length of cylinder in cm	thickness of cylinder in cm
1	Iron					
2	Aluminum					
3	Copper					

Result table:

Sr No	**Material**	Heat Transfer Coefficient	Nussuelt Number
1	Iron		
2	Aluminum		
3	Copper		

Conclusion:
Experiment result shows that heat transfer coefficient of ____________ cylinder is higher than other material.

Rubric wise marks obtained:

Criteria	Ability to conduct experiment (Max 3)	Data collection, analysis and interpretation (Max 4)	Subject Knowledge (Max 3)	Total

Signature of lab teacher

Experiment No: 8

To study and compare the performance of heat pipe.

Date:

Competency and Practical Skills:

Relevant CO: 5

Objectives: To study and compare the performance of heat pipe with two geometrical similar pipes of copper and stainless steel.

Introduction:

To study and compare the performance of heat pipe with two geometrical similar pipes of copper and stainless steel.

The heat pipe is a device of very high thermal conductance. It transfers heat by boiling a fluid at one end & condensing it at another. The evaporation & condensation processes are responsible for the nearly isothermal working of the heat pipe. The condensed liquid is transferred back to the boiling area by the capillary action through a wick structure in the heat pipe. It is the use capillary action for pumping the liquid back, which the unique characteristic of the heat pipe. The thermo syphon in many ways resembles a heat pipe, except that the return of the liquid to the evaporation is due to gravity. The effective thermal conductivity of the device is found to be a few hundred times that of solid copper of similar mass.

Apart from high thermal conductance, the heat pipe is characterized by:

1. Very high thermal conductance.
2. The ability to act as a thermal flux transformer.
3. An isothermal surface of low thermal impedance.
4. Variable thermal impedance.
5. Thermal diode & Switches.

Principle of heat pipe:

Heat from the source evaporates the working fluid & converts it into vapour. These vapors travel through the vapour core to the other end of the heat pipe source end by the surface tension forces developed in the wick. Thus that cycle continues. The heat transfer from the source to the sink is affected mainly by the following simultaneous & independent process:

1. Heat Transfer from the source through the container wall & wick-liquid matrix to the liquid-vapour inter face.
2. Evaporation of the liquid-vapour interface in the evaporator.
3. Transport of the vapour in the core from the evaporator to the condenser.
4. Condensation of the vapour on the liquid-vapour interface in the condenser.
5. Heat Transfer from the liquid-vapour interface through the wick-liquid matrix, & container wall to the sink.
6. Return flow to the condensate from the condenser to the evaporator caused by the capillary action of the wick.

Apparatus Description

Heat pipe is basically consists of pipe sealed at both the ends. It is evaluated and fitted partially with distilled water. A stainless steel wire mesh is provided at inside periphery of the pipe. When heat is applied at the lower end of the heat pipe, water inside it evaporates and Vapour passes to upper end of pipe. The heat is taken by the medium surrounding upper portion of heat pipe. The Vapour condenses, giving its latent heat of evaporation to the surrounding medium. The condensed Vapour returns to bottom through the mesh packing. Thus, because of circulation of Vapour, heat pipe operates at near to isothermal operation, and conducts much heat than conventional conductors.

The apparatus consists of three pipes viz. a heat pipe copper pipe and a stainless pipe. All the pipes have same physical dimensions. Copper and stainless steel pipes serve the purpose of comparison of heat pipe performance with copper pipe as good conductor of heat and with stainless steel pipe as same material .All pipes are mounted with a band heater at one end and a water filled heat sink at other end. When heaters start heating the pipes, pipes begin to transfer the heat to heat sinks. Rapid rise of temperature of water in the heat pipe to heat sink demonstrates (apparent) thermal conductivity of heat pipe. Nearly isothermal operation of heat pipe is clearly visualized from longitudinal distribution of pipes.

Specification:

1. Stainless steel pipe size-25mm.O.D; 300 mm long, with both side closed, evacuated and filled with distilled water along fine stainless steel mesh inside the wall.
2. Copper and stainless steel pipe of same size as that of heat pipe one no.
3. Equal capacity heater at bottom end of each pipe.
4. Water filled heat sinks at other end of each pipe.
5. Measurement & controls
6. Dimmer stat : 4amps
7. Ammeter Selector Switch : Standard.
8. Heater : Band Heater.
9. Digital Temperature Indicator: 0-300^{0}C Channel with cold junction Compensation to measure temp.
10. Thermocouples : Chromel alumel Thermocouples.
11. Voltmeter : 0 – 230 volts.
12. Ammeter : 0-2 Amp.

Experimental Procedure

1. First the heat pipe & other two units of demonstrator are fully instrumented & set up in the rig, heat applied to the evaporator section.
2. Preferably that input should be applied at first in steps, building up to design capability & allowing the temperature along the heat pipe to achieve, a steady state before adding more power.
3. Tests were carried out with the heat pipe operating vertically with gravity assistance.
4. Now a known steady input is supplied to the heating section of three units of the demonstrator. Known volume of water with help of beaker was kept in each condenser tank. The temperatures are noted at successive time intervals.
5. The above procedure was performed for various time intervals

Observation Table:

1] Heat Sink Temperature.

Time	S.S.Pipe	Cu.Pipe	Heat Pipe
Min	0^0C heat sink	0^0C heat sink	0^0C heat sink
5			
10			
15			
20			
25			
30			

2] Longitudinal Temperature Distribution: -

Cu.Pipe	**5min**	**10min**	**15 min**	**20 min**	**25 min**
T_1 =					
T_2 =					
T_3=					
T_4 =					

SS Pipe	**5min**	**10min**	**15 min**	**20 min**	**25 min**
T_5 =					
T_6 =					
T_7=					
T_8 =					

Heat Pipe	**5min**	**10min**	**15 min**	**20 min**	**25 min**
T_9 =					
T_{10} =					

T_{11}=					
T_{12} =					

Graphs:

1) Plot the graph of heat sink water temperature rise upto 30min.
2) Plot longitudinal temperature distribution of pipes.

Conclusion:

Exercises:

1. What is Heat Pipe?
2. State the assumptions made in the experiment.
3. Describe the setup and explain the procedure of experiment.
4. Compare the experimental results with the standard ones and justify the possible deviation.

Rubric wise marks obtained:

Criteria	Ability to conduct experiment (Max 3)	Data collection, analysis and interpretation (Max 4)	Subject Knowledge (Max 3)	Total

Signature of lab teacher

Experiment No: 9

To find out Critical Heat Flux.

Date:

Competency and Practical Skills:

Relevant CO: 5

Objectives: To find out Critical Heat Flux.

Introduction:

The phenomenon of boiling is characterized by different regimes. The 'SUPERSONIC' make CRITICAL HEAT FLUX APPARATUS consists of a test section in which tests wire surrounded by water of constant temperature. The surface temperature of test wire is heated by passing current through it. Due to the temperature difference between the wire surface and surroundings, the different regimes are observed till the burn out point.

Theory:

While 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 being dependent on the temperature difference between the surface and the liquid. The different types are indicated in Fig. 8.3 which illustrates a typical experimental boiling curve obtained in a saturated pool of liquid.

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 occurs at low temperature differences (of the order of 10^{o} C 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 commences. In this region bubbles begin to form at certain locations on the heated surface. Region II consists of two parts. In the first part, IIa, the bubbles formed are very few in number. These bubbles grow in size, separate from the heated surface and rise to the free surface. In the second part, IIb, the rate of bubble formation as well as the number of locations where they are formed increase.

With increasing temperature difference, a stage is finally reached when the high bubble formation rate causes them to coalesce and blanket the surface with a vapour film. This is the beginning of region III, namely, film boiling. In the first part of this region, IIIa, the vapor film is unstable; 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, IIIb, a stable film covers the entire surface. The temperature difference in this region is of the order of 1000^0 C and consequently radioactive heat transfer across the vapour film is also significant.

It will be observed from Fig. 8.3 that the heat flux does not increase in a regular manner with the temperature difference. In region I, the heat flux is proportional to (Tw - Ts) where n is slightly greater than unity (approximately 1.3). When the transition from natural convection to nucleate boiling occurs, the heat flux starts to increase more rapidly with temperature difference, the value of n increasing to about 3. At the end of region II, the boiling curve reaches a peak (Point A). Beyond this, in region IIIa, in spite of the increasing temperature difference, the head flux decreases because the thermal resistance to heat flow increases with the formation of a vapour film. The heat flux passes through a minimum (point B) at the end of region IIIa. It starts to increase again with (Tw - Ts) only when stable film boiling begins and radiation becomes increasingly significant.

It is of interest to note how the temperature of the heating surface changes as the heat flux steadily increased from zero. Up to the point A, natural convection boiling and then nucleate boiling occur and the temperature of the heating surface is obtained by reading off the value (Tw - Ts) from the boiling curve and adding to it the value of Ts. If the heat flux is increased a little beyond the value at A, the temperature of the surface shoots up to the value corresponding to the point C. It is apparent from Fig. 8.3 that the surface temperature corresponding to point C is high. For some surfaces, it is high enough to cause the material to melt. Thus in many practical situations, it is undesirable to exceed the value of heat flux corresponding to point A. This value is therefore of considerable significance in engineering and is called the critical or peak heat flux. Also it is called as 'Burn-out point'.

Specification:

1. Test wire - 40 gauge; Length = 10 cm.
2. Nichrome heater - 1 Kw capacity.
3. Glass trough of sufficient capacity.
4. Table light to observe the test wire.
5. Voltmeter & Ammeter to measure input to the test wire.
6. Dimmerstat to adjust the voltage.

Experimental procedure:

1. Fill up the glass trough with clean & pure water.
2. Clamp the test wire within the test bolts.
3. Close the glass bowl with the test section dipped in the water.
4. Before switching on the main switch; see that,
   (a) Both the heaters are well submerged under water. &
   (b) The dimmerstat is at '0' position.
5. Now, switch 'ON' the main switch. Put the toggle switch to the 'bulk heater' position. (This will only raise the water temp. in the bowl.) Heat the water till 40^{o}c.
6. Now, Put the toggle switch to the 'test wire ' position.(This will glow the lamp & keeps the test wire ready for testing.) Now, slowly rotate the dimmer in clockwise direction (about 10 degrees).
7. This increases the current in the test wire & correspondingly increases the wire surface temperature. Observe the test wire. Again increase the dimmer current and go on observing the test wire surface, till the burn-out point reaches. The pool boiling phases are observed on the wire surface till the burn-out point reaches. Note down the voltage & current at the instant of the burn-out point.
8. Repeat the process by increasing the bulk temperature.(Do not increase the bulk temperature above 80^{o}C)

Observation & Calculations:

Sr. no.	Bulk Temperature (^oC)	Voltage (Volt)	Current (Ampere)

Calculations:

A] An approximate empirical equation for the Critical heat flux is given by;

$$\therefore q_{max} = 0.18 \times h_{fg} \times \rho_v \left[\frac{\sigma \times g \{ \rho_L - \rho_v)}{\rho_v^2} \right]^{1/4}$$

Where

1) q_{max} = Critical heat flux in W / m^2
2) h_{fg} = Latent heat of evaporation J /kg = kJ/Kg X 10^3 = J/Kg
3) ρ_v = Density of vapour kg /m^3 = 1/ V_f kg /m^3
4) ρ_L = Density of liquid kg /m^3 = 1 /V_L X 10^3 kg/m^3
5) σ = Surface Tension = N/ m , = from chart value X 10^{-3} N/m

B] Experimental Critical Heat Flux =

$$\frac{Q}{A} = \frac{VI}{\pi DL}$$

=------W/m^2

Where,

Q = V I Watts

D = Dia.of wire in m

L = Length of wire in m.

Result:

Conclusion:

Exercises:

1. What is Critical heat flux?
2. What are the different boiling regimes?
3. State the assumptions made in the experiment.
4. Describe the setup and explain the procedure of experiment.

Rubric wise marks obtained:

Criteria	Ability to conduct experiment (Max 3)	Data collection, analysis and interpretation (Max 4)	Subject Knowledge (Max 3)	Total

Signature of lab teacher

Experiment No: 10

To determine overall heat transfer coefficient of concentric tube type heat exchanger for (i) parallel (ii) counter flow configuration.

Date:

Competency and Practical Skills:

Relevant CO: 4

Objectives: To determine overall heat transfer coefficient of concentric tube type heat exchanger for (i) parallel (ii) counter flow configuration.

Introduction:

Heat exchangers are the devices in which the heat is transferred from one fluid to another. Exchange of heat is required at many industrial operations as well as chemical processes. Common examples of heat exchangers are radiator of a car, condenser of a refrigeration unit or cooling coil of an air conditioner.

Heat exchangers are of basically three types - i) **Transfer type**: In which both fluids pass through the exchanger and heat gets transferred through the separating walls between the fluids ii **) Storage type**: In this firstly the hot fluid passes through a medium having high heat capacity and then cold fluid is passed through the medium to collect the heat. Thus hot and cold fluids are alternately passed through the medium, iii) **Direct contact type:** In this type, the fluids are not separated but they mix with each other and heat passes directly from one fluid to the other.

Transfer type heat exchangers are most widely used. In transfer type heat exchangers, three types of flow arrangements are used, viz. parallel, counter or cross flow. In parallel flow, both the fluids flow in the same direction while in counter flow; they flow in the opposite direction. In cross flow, they flow at right angles to each other.

Apparatus:

The apparatus consists of two concentric tubes in which fluids pass. The hot fluid is hot water which is obtained from an electric geyser. Hot water flows through the inner tube, in one direction. Cold fluid is air which is supplied by a centrifugal blower by flowing through the annulus. Control valves are provided so that direction of air can be kept parallel or opposite to that of hot water. Thus, the heat exchanger can be operated either as parallel or counter flow heat exchanger. The temperatures are measured with thermometers. Thus, the heat transfer rate, heat transfer coefficient, L.M.T.D. and effectiveness of heat exchanger can be calculated for both parallel and counter flow.

Specification:

1. Heat exchanger - a) Inner tube - Φ 16 mm O.D.,copp
   b) Outer tube - Φ 50 mm NB G.
   c) Length of heat exchanger is - 1.0 m.
2. Electric heater - 3 kw capacity to supply hot water.
3. Blower: centrifugal blower to force the air driven by single phase electric motor
4. Orifice with water manometer to measure the air flow. Orifice 14mm
5. Measuring cylinder 1 liter to measure water flow
6. Valves for flow and direction control.
7. Temperature Indicator to measure temperatures of hot and cold water
8. Copper fin size OD Φ16 mm X 16 mm length,6 nos.

Experimental procedure:

1. Start the water supply. Adjust the supply @ 2 lit/min and switch “ON” the geyser.
2. Start the blower, close the two diagonal gate valves and open the other diagonal gate valves in such a way that the air flows in the parallel of the hot water.
3. The temperatures will start rising. Wait till all the temperatures become steady and then note down the temperatures, manometer reading and water flow.
4. Different readings may be taken by changing the water and air flow.

Observation table:

Sr. No.	Type of flow	Hot water temperature, T_h, ^0C		Cold air temperature, $T_{c,}$ ^0C		Manometer Difference	Vol. flow rate, m^3/s
		$T_{h,i}$, ^0C	$T_{h,o}$, ^0C	$T_{c,i,}$ ^0C	$T_{c,o}$ ^0C		
1	parallel						
2	parallel						
3	counter						
4	counter						

Nomenclature:

$T_{h,i}$& $T_{h,o}$: Hot water temperature at inlet and outlet respectively

$T_{c,i}$& $T_{c,o}$: Cold air temperature at inlet and outlet respectively

Q_v: Volume flow rate of water, m^3/s

m_h: Mass flow rate of hot water, kg/s

m_c: Mass flow rate of cold air, kg/s

C_p: Specific heat of water= 4.2 kJ/ kg.K

ΔT_m: Logarith mean temperature difference

q_c: Rate of heat absorbed by cold water, W

q_h: Rate of heat rejected by hot water, W

U_i: Inside overall heat transfer coefficient , W/m^2K

U_o: Outside overall heat transfer coefficient,W/m^2K

A_i: Inside surface area of tube, m^2

A_o: Outside surface area of tube, m^2

L: Length of tube, m

Calculation:

1. Mass flow rate of hot and cold water:

$m_h = Q_{w,h} \times \rho_w$, kg/s

$m_c = Q_{w,c} \times \rho_w$, kg/s

2. Heat rejected by hot water:

$q_h = m_h C_{p,h}\left(T_{h,i} - T_{h,o}\right)$, W

3. Heat absorbed by cold air:

$q_c = m_c C_{p,c}\left(T_{c,o} - T_{c,i}\right)$, W

4. Logarithmic mean temperature difference, LMTD:

$$LMTD = \Delta T_m = \frac{T_i - T_o}{\ln\left(\frac{T_i}{T_o}\right)}$$

Where,

For parallel configuration $T_i = T_{h,i} - T_{c,i}$ and $T_o = T_{h,o} - T_{c,o}$.

For Counter configuration $T_i = T_{h,i} - T_{c,o}$ and $T_o = T_{h,o} - T_{c,i}$

$\left(\Delta T_m\right)_{parallel} =$

$\left(\Delta T_m\right)_{Counter} =$

5. Inside overall heat transfer coefficient, U_i:

$A_i = \pi d_i L = \pi \times 0.011 \times 1 = 3.45 \times 10^{-2}$

$q_{h,parallel/counter} = U_i\left(\Delta T_m\right)_{parallel/counter} \times A_i$

Calculate U_i for parallel and counter configuration from above relation.

6. Outside overall heat transfer coefficient, U_o:

$A_o = \pi d_o L = \pi \times 0.012 \times 1 = 3.76 \times 10^{-2}$ m^2

$q_{c,parallel/counter} = U_o \Delta T_{m,parallel/counter} A_o$

Calculate U_o for parallel and counter configuration form above relation.

7. Effectiveness of heat exchanger:

$$\varepsilon = \frac{Rate\_of\_heat\_transfer\_in\_heat\_exchanger}{Maximum\_possible\_heat\_transfer\_rate}$$

$$\varepsilon = \frac{m_h C_{p,h}\left(T_{h,i} - T_{h,o}\right)}{\left(mC_p\right)_s\left(T_{h,i} - T_{c,i}\right)}$$

Where $\left(mC_p\right)_s$ is smaller of two capacity rate of m_h or m_c.

Calculate effectiveness for both configuration.

Result:

Sr.	Configuration	LMTD	Heat transfer rate, W		Overall heat transfer coefficient, w/m^{2}K	
			q_h	q_c	U_i	U_o
1	Parallel					
2	counter					

Conclusion:

Exercises

1. Classify the heat exchanger?
2. Explain shell and tube heat exchanger?
3. What is LMTD?
4. What is Fouling factor?
5. Explain capacity ratio?
6. State the assumptions made in the experiment.
7. Describe the setup and explain the procedure of experiment.
8. Compare the experimental results with the standard ones and justify the possible deviation.

Rubric wise marks obtained:

Criteria	Ability to conduct experiment (Max 3)	Data collection, analysis and interpretation (Max 4)	Subject Knowledge (Max 3)	Total

Signature of lab teacher

ANNEXURE 1

PROPERTIES OF AIR

t °C	**ρ** kg/m³	**C_p** kJ/kg°C	**μ x 10⁶** N-Sec/m²	**K** W/m°C	**Pr**	**ν x 10⁶** m²/sec
0	1.293	1.005	17.2	0.0244	0.707	13.23
10	1.247	1.005	17.7	0.0251	0.705	14.16
20	1.205	1.005	18.1	0.0259	0.703	15.06
30	1.165	1.005	18.6	0.0267	0.701	16.00
40	1.128	1.005	19.1	0.0276	0.699	16.96
50	1.093	1.005	19.6	0.0283	0.698	17.95
60	1.060	1.005	20.1	0.0290	0.696	18.97
70	1.029	1.009	20.6	0.0297	0.694	20.02
80	1.000	1.009	21.1	0.0305	0.692	21.09
90	0.972	1.009	21.5	0.0313	0.690	22.10
100	0.946	1.009	21.9	0.0321	0.688	23.13
120	0.898	1.009	22.9	0.0334	0.686	25.45
140	0.854	1.013	23.7	0.0349	0.684	27.80
160	0.815	0.243	24.525	0.0313	0.682	30.09
180	0.779	0.244	25.310	0.0325	0.681	32.49
200	0.746	0.245	25.996	0.0338	0.680	34.85
250	0.646	0.248	27.370	0.0367	0.677	40.61
300	0.615	0.250	29.724	0.0396	0.674	48.33
350	0.566	0.253	31.392	0.0432	0.676	55.46
400	0.524	0.255	33.060	0.0448	0.678	63.09
500	0.456	0.261	36.199	0.0494	0.687	79.38
600	0.404	0.266	39.142	0.0535	0.699	96.89
700	0.362	0.271	41.790	0.0577	0.706	155.4
800	0.329	0.276	44.341	0.0617	0.713	134.8
900	0.301	0.280	46.695	0.0656	0.717	155.1
999	0.277	0.283	49.050	0.0694	0.719	177.1

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