



DEPARTMENT OF MECHANICAL ENGINEERING
Haldia, PurbaMedinipur, West Bengal
HALDIA INSTITUTE OF TECHNOLOGY

PRACTICAL MANUAL
(Assessment Instrument and Instruction Items)

Course Name	Heat Transfer Lab
Course Code	PC –ME 593
Laboratory Name	Heat Transfer Laboratory
Programme	B. Tech in Mechanical Engineering
Semester / Year	[5 th / 3 rd Year]
Academic Session	2026–27
Faculty-in-Charge & Technical Staff	
Faculty-in-Charge	Dr. Abhishek Samanta
Co-Faculty (if any)	Dr. Manas Bhukta
Technical Staffs	Mr. Ramkrishna Maity



VISION

To impart quality, industry-relevant teaching-learning that blends knowledge and skill to produce industry-ready mechanical engineering graduates.

Mission Statements

M1: To create qualified and proficient technocrats having contemporary skills through outcome-based and self-learning strategies.

M2: To encourage innovation-oriented and problem-based research capabilities among young engineers through higher studies, in order to nurture the progress of society.

M3: To instill strong ethical values and good professional behaviour, enabling graduates to adopt and absorb emerging changes in the engineering profession.

Program Educational Objective

Graduates of B. Tech. Mechanical Engineering program, four years after graduation will

PEO1: Specify, design, supervise, test, and evaluate engineering skills to design, develop, and implement innovative solutions, systems, and applications in Mechanical Engineering and allied industries.

PEO2: Utilize Mechanical Engineering knowledge to address real-world and societal challenges while pursuing higher studies, research, and professional development.

PEO3: Demonstrate effective individual and collaborative capabilities in multidisciplinary professional environments, with a commitment to lifelong learning and adaptability to evolving technological, industrial, and societal requirements.

Program Specific Outcomes (PSOs)

PSO1: Design, analyze and evaluate mechanical components and systems such as thermal, fluid, manufacturing, design systems and allied engineering solutions.

PSO2: Utilize and evaluate modern engineering tools, software, and techniques to model, analyze, and solve real-world mechanical engineering problems.

PSO3: Demonstrate professional and ethical responsibility, effective communication, and the ability to work in multidisciplinary teams to address societal, industrial, and environmental challenges through sustainable mechanical engineering solutions.



PC-ME 593	Category: Professional Core Courses	PCIE Marks	40
Heat Transfer Lab	Semester :Fifth	PSEE Marks	60
L-T-P:0-0-3	Credit: 1.5	Total Marks	100
Pre-Requisites: Thermodynamics, Heat Transfer			
Examination (PSEE): Theory/ Drawing Assignment/ Practical/ Viva-voce/Team work/ others			

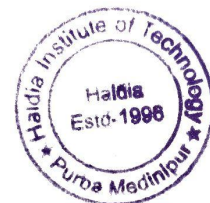
Course Content:

Experiments are to be framed based on the following units

Unit	Topics	Hours	CO
UNIT I	Steady-State Heat Conduction: Determination of thermal conductivity of a metal rod; measurement of temperature distribution and heat transfer rate.	6	CO1
UNIT II	Thermal Insulation: Determination of thermal conductivity of insulating powder and evaluation of its insulating characteristics.	6	CO2
UNIT III	Thermal Radiation: Determination of emissivity of a test plate using constant surface-temperature and constant input-power methods.	6	CO3
UNIT IV	Heat Exchanger: Experimental investigation and performance evaluation of a shell-and-tube heat exchanger using temperature and flow-rate measurements.	9	CO4
UNIT V	Forced Convection: Determination of heat-transfer coefficient under forced-convection conditions using experimental measurements and correlations.	9	CO5
UNIT VI	Thermal Radiation Laws: Experimental determination of the Stefan-Boltzmann constant and comparison with its theoretical value.	6	CO6
Total		42	

Suggested Reference Books

- J. P. Holman, Heat Transfer, 10th Edition, McGraw-Hill Education.
- P. K. Nag, Heat and Mass Transfer, McGraw-Hill Education.
- Yunus A. Çengel and Afshin J. Ghajar, Heat and Mass Transfer: Fundamentals & Applications, McGraw-Hill Education.



Course Outcomes:

Upon successful completion of the course, students will be able to:

CO CODES	CO Statement	Knowledge Categories	Cognitive Level
PC-ME 593.1	Determine the thermal conductivity of a metal rod under steady-state heat conduction conditions using measured temperature and heat-flow data with appropriate experimental calculations.	P	Ap
PC-ME 593.2	Determine the thermal conductivity of insulating powder under steady-state conduction conditions using measured temperature data and evaluate its thermal insulation characteristics.	P	An
PC-ME 593.3	Determine the emissivity of a test plate using constant surface-temperature and constant-input-power methods and compare the experimentally obtained values.	P	An
PC-ME 593.4	Evaluate the performance of a shell-and-tube heat exchanger using measured temperature and flow-rate data and determine its heat-transfer characteristics.	P	An
PC-ME 593.5	Determine the heat-transfer coefficient under forced-convection conditions using experimental temperature and flow measurements and appropriate heat-transfer correlations.	P	Ap
PC-ME 593.6	Determine the Stefan-Boltzmann constant experimentally from thermal-radiation measurements and compare the result with the theoretical value.	P	An



ALIGNING OF COS IN [CL × KC] METRIC

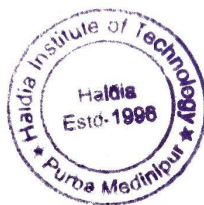
Cognitive Levels (CL)	Knowledge Categories (KC)							
	Factual	Conceptual	Procedural	Meta-cognitive	Fundamental Design Principles	Criteria & Specifications	Practical Constraints	Design instrumentalities
Remember (R)								
Understand (U)								
Apply (Ap)			CO1, CO5					
Analyze (An)			CO2, CO3, CO4, CO6					
Evaluate (E)								
Create (C)								

Assessment Pattern and Assessment Instruments for PCIE & PSEE

Marks allotted	PCIE								PSEE (60)	
	PCAI (40)				PCAI (40)					
	10	10	10	10	10	10	10	10	40	20
CO	EX1	EX 2	EX 3	VIVA I	EX 4	EX 5	EX 6	VIVA II	GR-A	GR-B (Viva)
CO1	10			10/3					40/6	20/6
CO2		10		10/3					40/6	20/6
CO3			10	10/3					40/6	20/6
CO4					10			10/3	40/6	20/6
CO5						10		10/3	40/6	20/6
CO6							10	10/3	40/6	20/6

CO-PO & CO-PSO Articulation Matrix

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PSO1	PSO2	PSO3
PC-ME 593.1	3	2	–	3	2	–	1	–	1	1	–	3	2	2
PC-ME 593.2	3	2	–	3	2	1	2	–	1	1	–	3	2	2
PC-ME 593.3	3	2	–	3	2	1	2	–	1	1	–	3	2	2
PC-ME 593.4	3	3	2	3	2	1	2	–	2	2	2	3	3	2
PC-ME 593.5	3	3	–	3	2	1	1	–	1	1	1	3	3	2
PC-ME 593.6	3	2	–	3	2	1	2	–	1	1	–	3	2	2
Average	3.00	2.33	2.00	3.00	2.00	1.00	1.67		1.17	1.17	1.50	3.00	2.33	2.00





HEAT TRANSFER LAB (PC-ME 593)

LIST OF ASSESSMENT ITEMS, INSTRUCTION ITEMS

Experiment No.	Name of the experiment	Instruction Item	CO Congruence
EX1-I	Experimental Determination of Thermal Conductivity of a Metal Rod under Steady-State Heat Conduction	II1	CO1
EX2-I	Experimental Determination of Thermal Conductivity of an Insulating Powder by Steady-State Heat Conduction	II2	CO2
EX3-I	Experimental Determination of Emissivity of a Test Plate by Maintaining Constant Surface Temperature	II3	CO3
EX3-II	Experimental Determination of Emissivity of a Test Plate by Maintaining Constant Electrical Input Power		
EX4-I	Experimental Investigation and Performance Evaluation of a Shell-and-Tube Heat Exchanger	II4	CO4
EX5-I	Experimental Determination of Heat Transfer Coefficient under Forced Convection Conditions	II5	CO5
EX6-I	Experimental Determination of the Stefan–Boltzmann Constant Using Thermal Radiation Measurements	II6	CO6





INSTRUCTION ITEM-1(II-1)			
EX1	Experimental Determination of Thermal Conductivity of a Metal Rod under Steady-State Heat Conduction	II1	CO1



Fig. 1.1 – Thermal Conductivity of Metal Rod Apparatus

Description

Conduction is a process of heat transfer through solids, liquids, and gases. When a temperature gradient exists in a body, experience shows that there is a transfer of heat from the high-temperature region to the low-temperature region. The heat transfer rate per unit area is proportional to the temperature gradient in the direction of heat flow:

$$\frac{Q}{A} \propto \frac{dT}{dx}$$

where Q is the heat transfer rate (W), A is the area of heat transfer (m^2), and dT/dx is the temperature gradient in the direction of heat flow ($^{\circ}C/m$). The proportionality constant is a property of the material, known as the *thermal conductivity*, K :

$$Q = -KA \left(\frac{dT}{dx} \right)$$

The negative sign indicates that heat transfer takes place in the direction of decreasing temperature. The coefficient of thermal conductivity has units of $W/m^{\circ}C$. Its numerical value indicates how fast heat will flow through a given material.

Experimental Procedure

1. Start the water circulation through the water jacket.



2. Switch on the heater supply.
3. Adjust the current supply with the help of the dimmerstat.
4. Wait for steady state. Steady state can be observed from the temperature reading at one or all points on the surface of the metal rod – it is reached when these temperatures stop changing with time.
5. Under steady-state conditions, note down the temperature at each point on the surface of the rod as well as the temperature of the surrounding.
6. Repeat the above procedure for several values of power input.

Data

Specific heat of water, $C_p = 4186 \text{ J/kg}^\circ\text{C}$ · Density of water, $\rho_w = 1000 \text{ kg/m}^3$ · Diameter of metal rod, $d = 0.0254 \text{ m}$

Sensor positions along the rod (from heater end): $X_1 = 0.040 \text{ m}$, $X_2 = 0.066 \text{ m}$, $X_3 = 0.092 \text{ m}$, $X_4 = 0.118 \text{ m}$, $X_5 = 0.144 \text{ m}$, $X_6 = 0.170 \text{ m}$

Observation Table

Voltmeter reading, $V =$ _____ Volts Ammeter reading, $I =$ _____ Amp

Sr. No.	Vol. of water F (ml)	Time to collect, t (s)	Water inlet T7 ($^\circ\text{C}$)	Water outlet T8 ($^\circ\text{C}$)	T1 ($^\circ\text{C}$)	T2 ($^\circ\text{C}$)	T3 ($^\circ\text{C}$)	T4 ($^\circ\text{C}$)	T5 / T6 ($^\circ\text{C}$)
1									
2									
3									

Results

Report all the results obtained from the experiment and write down the discussions in your journal.

Conclusions

Using the results obtained from your experiment, comment on the thermal conductivity of the given metal rod with respect to temperature.

Precautions

- Use only a stabilized AC single-phase power supply.
- Do not disturb any electrical connections of the experimental setup.

Viva-Voce Questions

1. What is thermal conductivity?
2. How does the thermal conductivity of metals vary with temperature?
3. Compare the thermal conductivities of different metals.



INSTRUCTION ITEM-1(II-2)			
EX2	Experimental Determination of Thermal Conductivity of an Insulating Powder by Steady-State Heat Conduction	II2	CO2



Fig. 2.1 – Thermal Conductivity of Insulating Powder Apparatus

Description

The apparatus consists of two thin-walled concentric copper spheres. The inner sphere houses the heating coil. Insulating powder (asbestos powder – a lagging material) is packed between the two shells. Power supply to the heating coil is regulated using a dimmerstat and measured by a voltmeter and ammeter. Chromel–Alumel thermocouples are used to measure temperatures: thermocouples (1) to (4) are embedded on the inner sphere, and (5) to (10) are located on the outer sphere. These temperature readings enable determination of the thermal conductivity of the insulating powder, treated as an isotropic material.

Consider the transfer of heat by conduction through the wall of a hollow sphere formed by the insulating powder layer packed between the two thin copper spheres. Let:

- r_i = radius of inner sphere (m); r_o = radius of outer sphere (m)
- T_i = average temperature of the inner sphere ($^{\circ}\text{C}$); T_o = average temperature of the outer sphere ($^{\circ}\text{C}$)

$$T_i = \frac{T_1 + T_2 + T_3 + T_4}{4}$$

From the experimental values of heat input (q), T_i , and T_o , the unknown thermal conductivity K of the powder can be determined as:

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

Experimental Procedure

1. Start the main switch of the control panel.



2. Slowly increase the input to the heater using the dimmerstat, starting from the zero-volt position.
3. Adjust the input to a maximum of 40 W using the voltmeter and ammeter (Wattage, $W = V \times I$).
4. Ensure that this input remains constant throughout the experiment.
5. Wait until fairly steady-state conditions are reached; this can be checked by monitoring thermocouples (1) to (10) for changes in readings with time.
6. Note down the readings in the observation table.

Data

Radius of inner sphere, $r_i = 0.05$ m Radius of outer sphere, $r_o = 0.10$ m

Observation Table

Voltmeter reading, $V =$ _____ V Ammeter reading, $I =$ _____ A Heater input, $W = V \times I =$ _____ W

Sr. No.	V (V)	I (A)	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	T5 (°C)	T6 (°C)	T7 (°C)	T8/T9 (°C)	T10 (°C)
1											
2											

Calculation

$q = 0.86$ W (kcal/hr, MKS units) or $q = V \times I$ (W, SI units)

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

Precautions

- Keep the dimmerstat at the zero-volt position before and after the experiment; verify this before switching on the supply.
- Handle the changeover switch of the temperature indicator gently.

Exercise / Viva-Voce Questions

1. Note down the thermal conductivity values of various insulating materials from the literature.
2. Compare the experimentally obtained value of K for the insulating powder with the value reported in the literature.



INSTRUCTION ITEM-1(II-3)			
EX3-I	Experimental Determination of Emissivity of a Test Plate by Maintaining Constant Surface Temperature	II3	CO3
EX3-II	Experimental Determination of Emissivity of a Test Plate by Maintaining Constant Electrical Input Power		



Fig. 3.1 – Emissivity Measurement Apparatus

Introduction

Radiation is one of the modes of heat transfer that does not require any material medium for its propagation; the mechanism is electromagnetic in nature and results from a temperature difference. Thermodynamic considerations show that an ideal radiator, or black body, emits energy at a rate proportional to the fourth power of its absolute temperature. When two bodies exchange heat by radiation, the net heat exchange is given by:

$$Q = \sigma A T^4$$

All bodies emit and absorb thermal radiation to and from their surroundings; the rate of thermal radiation depends on the temperature of the body. When thermal radiation strikes a body, part of it is reflected, part absorbed, and part transmitted through the body. The fraction reflected is called reflectivity (ρ), the fraction absorbed is called absorptivity (α), and the fraction transmitted is called transmissivity (τ). For a black surface, $\rho + \alpha + \tau = 1$. The radiant flux emitted from a surface is called its emissive power (E).

Experimental Procedure

1. Gradually increase the heater input to the black plate, adjust it to a chosen value, and set the test plate heater input slightly less than that of the black plate.
2. Check the temperature of both plates at regular intervals and adjust the input of the test plate accordingly (a trial-and-error process).
3. After attaining steady state, record all readings.



Data

Stefan–Boltzmann constant, $\sigma = 5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$ Emissivity of black plate, $\epsilon = 1$ Diameter of black plate, $D_B = 0.10 \text{ m}$
Diameter of test plate, $D_S = 0.10 \text{ m}$

Observation Table

Sl. No.	Black body V(V) / I(A) / $Q_b = VI$	Test plate V(V) / I(A) / $Q_s = VI$	Black plate T_b (°C)	Test plate T_s (°C)	Surrounding T_3 (°C)
1					
2					
3					

From Steady-State Readings

$$T_b = \frac{t_1 + t_2}{2} + 273 \text{ K}$$

$$T_a = t_s + 273 \text{ K}$$

Emissivity = $E_{\text{grey body}} / E_{\text{black body}}$

$$E_S = E_B - \frac{Q_b - Q_s}{A \times \sigma \times (T_s^4 - T_a^4)} \quad \dots\dots\dots \text{Method 1}$$

$$\epsilon_S = \frac{\epsilon_b (T_b^4 - T_a^4)}{(T_s^4 - T_a^4)} \quad \dots\dots\dots \text{Method 2}$$

Results

Report all the results obtained from the experiment and write down the discussions in your journal.

Conclusions

Using the results obtained from your experiment, comment on the emissivity of the radiating surface.

Precautions

- Keep the system in a clean and dry place.
- Use a single-phase 230 V AC, 50 Hz supply for the unit.
- Check all wire connections visually before starting.
- Do not touch the wires when the system is in the ON position.
- After completion of the experiment, switch off the load.
- Clean the equipment before and after the experiment with a dry cloth.

Viva-Voce Questions

1. Explain the different mechanisms of heat transfer from the human body (a) through the skin and (b) through the lungs.
2. How does radiation transfer through a participating medium differ from that through a non-participating medium?
3. How does the wavelength distribution of radiation emitted by a gas differ from that of a surface at the same temperature?



INSTRUCTION ITEM-1(II-4)

EX4	Experimental Investigation and Performance Evaluation of a Shell-and-Tube Heat Exchanger	II4	CO4
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Fig. 4.1 – Shell and Tube Heat Exchanger Apparatus

Introduction

A heat exchanger is a device in which heat is transferred from one fluid to another. This necessity arises in a multitude of industrial applications. Common examples of heat exchangers include the radiator of a car, the condenser at the back of a domestic refrigerator, and the steam boiler of a thermal power plant. Heat exchangers are classified into three categories: (1) Transfer type, (2) Storage type, and (3) Direct-contact type.

Theory

A transfer-type heat exchanger is one in which both fluids pass simultaneously through the device, and heat is transferred through separating walls. In practice, most heat exchangers used are of the transfer type. Transfer-type exchangers are further classified according to flow arrangement as (1) Single Pass and (2) Multiple Pass. A simple example is a tube-type arrangement in which one fluid flows through the inner tube and the other through the surrounding annulus; heat transfer takes place across the walls of the inner tube.

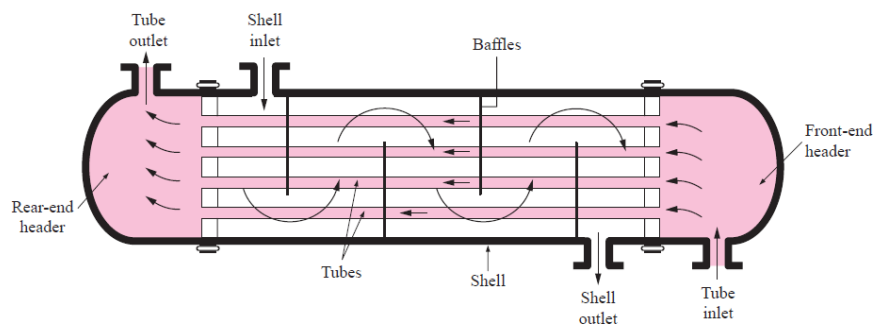


Fig. 4.2 – Construction of a Shell and Tube Heat Exchanger

The heat lost by the hot fluid is calculated as:



$$q_h = m_h C_{ph} (T_{hi} - T_{ho})$$

The heat gained by the cold fluid is calculated as:

$$q_c = m_c C_{pc} (T_{co} - T_{ci})$$

$$Q_{avg} = \frac{q_c + q_h}{2}$$

Description

The apparatus consists of a 1–2 pass shell-and-tube heat exchanger. The hot fluid is hot water obtained from a geyser, which flows through the inner tube, while cold water flows through the annulus. Flow rates are measured using a measuring jar for both hot and cold water. Temperature is measured through a digital temperature indicator.

Experimental Procedure

Starting Procedure

1. Clean the apparatus and make the geyser free from dust.
2. Close all the drain valves provided.
3. Fill the geyser with clean water, ensuring no foreign particles are present.
4. Connect the cold water supply to the shell.
5. Ensure that all ON/OFF switches on the panel are at the OFF position.
6. Switch on the main power supply.
7. Switch on the heater using the main switch on the panel.
8. Open the flow control valve for the hot water supply.
9. Adjust the hot water flow rate using the flow control valve.
10. Record the temperature of the hot and cold water inlet and outlet once steady state is achieved.

Closing Procedure

1. When the experiment is over, switch off the heater first.
2. Switch off the power supply to the panel.
3. Stop the cold water supply using the flow control valve.

Data

$D_i = 13 \text{ mm}$ $D_o = 16 \text{ mm}$ $L = 50 \text{ cm}$ N (no. of tubes) = 24

Observation Table

S.No.	F_h (LPS)	T_{hi} (°C)	T_{ho} (°C)	F_c (LPH)	T_{ci} (°C)	T_{co} (°C)
1						
2						
3						

Calculations

Quantity	Formula
T_h (mean hot water temp.)	$(T_{ho} + T_{hi}) / 2$
T_c (mean cold water temp.)	$(T_{co} + T_{ci}) / 2$
C_{ph} (sp. heat of hot water)	4181 J/kg°C
C_{pc} (sp. heat of cold water)	4178 J/kg°C
ρ_h (density of hot water)	990.2 kg/m ³
ρ_c (density of cold water)	994.1 kg/m ³
Q_h (heat lost by hot water)	$M_h C_{ph} (T_{hi} - T_{ho})$
M_h (mass flow rate, hot)	$(F_h \times 10^{-3} \times \rho_h) / 3600 \text{ kg/s}$



Mc (mass flow rate, cold)	$(F_c \times 10^{-3} \times \rho_c) / 3600 \text{ kg/s}$
Q (average heat transfer)	$(Q_h + Q_c) / 2$
ΔT_m (log mean temp. diff.)	$(\Delta T_2 - \Delta T_1) / \ln(\Delta T_2 / \Delta T_1)$
ΔT_1	$T_{hi} - T_{co} \text{ (}^\circ\text{C)}$
ΔT_2	$T_{ho} - T_{ci} \text{ (}^\circ\text{C)}$
A_i (inside heat transfer area)	$N \pi D_i L \text{ (m}^2\text{)}$
A_o (outside heat transfer area)	$N \pi D_o L \text{ (m}^2\text{)}$
U_i (inside overall heat transfer coeff.)	$Q / (A_i \Delta T_m) \text{ W/m}^2\text{C}$
U_o (outside overall heat transfer coeff.)	$Q / (A_o \Delta T_m) \text{ W/m}^2\text{C}$

Nomenclature

Symbol	Meaning
A_i, A_o	Inside / outside heat transfer area (m^2)
D_i, D_o	Inner / outer diameter of tube (m)
C_{ph}, C_{pc}	Specific heat of hot / cold fluid at mean temperature ($\text{J/kg}^\circ\text{C}$)
F_h, F_c	Flow rate of hot / cold water (LPH)
L	Length of tube (m)
M_h, M_c	Mass flow rate of hot / cold water (kg/s)
N	Number of tubes
Q	Average heat transfer from the system (W)
T_{hi}, T_{ho}	Inlet / outlet temperature of hot water ($^\circ\text{C}$)
T_{ci}, T_{co}	Inlet / outlet temperature of cold water ($^\circ\text{C}$)
ΔT_m	Log mean temperature difference ($^\circ\text{C}$)
U_i, U_o	Inside / outside overall heat transfer coefficient ($\text{W/m}^2\text{C}$)

Precautions & Maintenance Instructions

1. Never run the apparatus if the power supply is below 180 V or above 230 V.
2. Never switch ON the power supply before ensuring that all ON/OFF switches on the panel are in the OFF position.
3. Operate the selector switch of the temperature indicator gently.
4. Always keep the apparatus free from dust.

Results

Report the values of Q, ΔT_m , U_i and U_o obtained from the experiment and write down the discussions in your journal.

Conclusions

Using the results obtained, comment on the performance of the shell-and-tube heat exchanger and compare U_i and U_o with standard/theoretical values.



INSTRUCTION ITEM-1(II-5)

EX5	Experimental Determination of Heat Transfer Coefficient under Forced Convection Conditions	II5	CO5
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Fig. 5.1 – Forced Convection Apparatus

Introduction

It is well known that a hot metal plate cools faster in front of a fan than when exposed to still air. The heat is said to be 'convected away', and the process is called convective heat transfer. The velocity at which air blows over the hot plate clearly influences the heat transfer rate.

Convection is the process of heat transfer by the combined action of heat conduction and mixing motion. Convective heat transfer is further classified as Natural Convection and Forced Convection. Natural convection is associated with the molecular transport mechanism occurring due to buoyancy, arising from temperature-induced density differences. If the bulk motion is induced by some external means, such as a pump or a blower, the process is known as forced convection.

In many practical situations and equipment, fluid flow in tubes is common – for example, in boilers, superheaters and condensers of a power plant, automobile radiators, and water or air heaters/coolers. The knowledge and evaluation of the forced convection heat transfer coefficient for fluid flow in tubes is essential for the optimal design of thermal systems.

Theory

As air flows into the heated pipe at a high flow rate, the heat transfer rate increases, and the temperature of the air rises from its bulk (inlet) value. For the tube, the total energy can be expressed in terms of the bulk temperature difference:

$$q = m C_p (T_{b2} - T_{b1}) \quad \text{and, in terms of the heat transfer coefficient:} \quad q = h A (T_{b2} - T_{b1})$$

A traditional expression for the heat transfer coefficient in fully turbulent flow through a smooth tube is the Dittus–Boelter equation:

$$Nu_D = 0.023 Re^{0.8} Pr^n \quad (n = 0.4 \text{ for heating, } n = 0.3 \text{ for cooling of the fluid})$$

Experimental Procedure

Starting Procedure

1. Clean the apparatus and make it free from dust.
2. Fill manometer fluid (water) in the manometer connected to the Pitot tube.
3. Ensure all ON/OFF switches on the panel are at the OFF position.
4. Ensure the variac knob is at the zero position.



5. Switch on the main power supply (220 V AC, 50 Hz).
6. Switch on the panel using the mains ON/OFF switch.
7. Fix the power input to the heater using the variac, voltmeter, and ammeter provided.
8. Switch ON the blower using the rotary switch on the panel.
9. Adjust the air flow rate with the air-flow control valve in the air line.
10. After 30 minutes, record the temperature at various points in the test section every 5 minutes.
11. Assume steady state has been achieved once temperature readings repeat for three consecutive intervals.
12. Record the final temperatures and the manometer readings.

Data

Diameter of test section, $D = 28$ mm Length of test section, $L = 400$ mm Orifice diameter = 14 mm Coefficient of discharge, $C_d = 0.62$

Specific heat of air, $C_p = 1003.2$ J/kg°C Density of air, $\rho_a = 1.205$ kg/m³

Observation Table

Sl. No.	V (V)	A (A)	W (W)	T1 – Air inlet (°C)	T6 – Air outlet (°C)	Orifice ΔP (cm H ₂ O)	T2 (°C)	T3, T4 (°C)	T5 (°C)
1									
2									

Observations and Calculations

Average surface temperature,

$$T_s = \frac{T_2 + T_3 + T_4 + T_5}{4}$$

Average air temperature,

$$T_a = \frac{T_1 + T_6}{2} \quad \text{Surface area of pipe, } A = \pi d L$$

Theoretical Value of h

Properties of air are evaluated at the bulk (mean) air temperature T_a , typically taken from standard air property tables (ρ , ν , Pr , K , C_p).

- Head of air: $H_{air} = (\rho_w / \rho_a) \times h_w$
- Discharge of air: $Q = A \cdot C_d \cdot \sqrt{2 g H_{air}}$ where A = orifice area = $(\pi/4) d^2$
- Velocity of flow: $V = Q / (\text{area of pipe})$
- Reynolds number: $Re = V d / \nu$ ($Re > 2000 \rightarrow$ turbulent flow)
- Nusselt number: $Nu = 0.023 Re^{0.8} Pr^{0.3}$
- $h_{theo} = Nu \cdot K / d$

Experimental Value of h

$$Q = h_{exp} A (T_a - T_s)$$

Results

Report all the results obtained from the experiment and write down the discussions in your journal.

Conclusions

Compare the experimental heat transfer coefficient obtained with the theoretical heat transfer coefficient.

Viva-Voce Questions

1. What is forced convection?
2. What are the different correlations available for the heat transfer coefficient in forced convection?
3. Compare the heat transfer coefficients in natural versus forced convection, and give your comments.



INSTRUCTION ITEM-1(II-6)

EX6	Experimental Determination of the Stefan–Boltzmann Constant Using Thermal Radiation Measurements	II6	CO6
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Introduction

All substances, at all temperatures, emit thermal radiation. Thermal radiation is an electromagnetic wave and does not require any material medium for propagation. All bodies can emit radiation and also have the capacity to absorb all, or part, of the radiation incident on them from their surroundings.

Theory

The most commonly used law of thermal radiation is the Stefan–Boltzmann law, which states that the thermal radiation heat flux, or emissive power, of a black surface is proportional to the fourth power of the absolute temperature of the surface:

$$\frac{Q}{A} = E_b = \sigma * T^4 \text{ W/m}^2 \text{ K}^4$$

The constant of proportionality is called the Stefan–Boltzmann constant and has the value $5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$. The Stefan–Boltzmann law can be derived by integrating Planck's law over the entire spectrum of wavelengths from 0 to ∞ . The objective of this experimental setup is to measure the value of this constant fairly closely using a simple arrangement.



Fig. 7 – Construction of Stefan–Boltzmann Constant experiment

Experimental Setup

The apparatus is centred on a flanged copper hemisphere B, fixed on a flat, non-conducting plate A. The outer surface of B is enclosed in a metal water jacket, used to heat B to a suitable constant temperature. An RTD PT-100 type temperature sensor is attached to the inner wall of hemisphere B to measure its temperature, read through a temperature indicator.

A disc D, mounted in an insulating bakelite sleeve S, is fitted into a hole drilled at the centre of the base plate A. A Chromel/Alumel temperature sensor measures the temperature of D (TD), mounted on the disc to study the rise in its temperature. The emissivity of the enclosure and the disc are assumed to be unity, owing to black-surface characteristics. The radiation energy emitted by the disc to the enclosure is given by:



$$mC_p \left(\frac{dT}{dt} \right)_{t=0} = \sigma A_D (T_s^4 - T_D^4)$$

where T/dt is the rate of increase in temperature ($^{\circ}\text{C/s}$) at the instant the disc is inserted into the setup. The Stefan–Boltzmann constant is obtained using the relationship:

$$\sigma = \frac{mC_p \left(\frac{dT}{dt} \right)_{t=0}}{A_D (T_s^4 - T_D^4)}$$

Utilities Required

Electric supply: single phase, 220 V AC (2 kW). A table for the set-up support.

Experimental Procedure

1. Heat the water in the tank using the immersion heater to a temperature of about 90°C .
2. Remove the disc D before pouring the hot water into the jacket.
3. Pour the hot water into the water jacket.
4. Allow the hemispherical enclosure B and plate A to reach a uniform temperature; this happens quickly, and the thermal inertia of the hot water is adequate to prevent significant cooling during the experiment.
5. Insert disc D into A at a time when its temperature is T_D .
6. Note the temperature change every five seconds for one minute.

Specification

Hemispherical enclosure diameter = 200 mm Hemisphere base-plate (bakelite) diameter = 250 mm No. of temperature sensors on B = 1 No. of temperature sensors on D = 1, Mass of test disc, $m = 5.1 \text{ g}$ Specific heat of test disc, $S = 418 \text{ J/kg}^{\circ}\text{C}$

Observation Table

Sl. No.	Time (s)	Temperature T_D ($^{\circ}\text{C}$)
1		
2		
3		
4		
5		
6		
7		

Precautions

1. Start the cooling circuit before switching ON the heaters, and adjust the flow rate so that there is practically no temperature rise in the circulating fluid.
2. The apparatus should be cleaned before and after the experiment; clean water should be used.
3. The black body (disc) should be removed when not being heated.

Applications

1. Determination of the temperature of the Sun from its energy flux density.
2. The temperature of stars other than the Sun, and their radius relative to the Sun, can be approximated by similar means.



3. The temperature of the Earth can be found by equating the energy received from the Sun with the energy transmitted by the Earth.

Results

Report the value of the Stefan–Boltzmann constant obtained from the experiment, and compare it with the standard value ($5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$).

Conclusions

Comment on the accuracy of the experimentally determined Stefan–Boltzmann constant compared with the standard value, and discuss possible sources of error.

Viva-Voce Questions

1. What does the view factor represent? When is the view factor from a surface to itself not zero?
2. Why is the radiation analysis of enclosures consisting of black surfaces relatively easy? How is the rate of radiation heat transfer between two surfaces expressed in this case?
3. What are the two methods used in radiation analysis? How do these two methods differ?