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L-160389/2025

2. आवेदक का नाम, पता तथा राष्ट्रीयता  
Name, address and nationality of the applicant

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AUTHOR

4. कृति का वर्ग और वर्णन  
Class and description of the work

LITERARY/ DRAMATIC WORK LAB MANUAL FOR HEAT MASS TRANSFER

5. कृति का शीर्षक  
Title of the work

LAB MANUAL FOR HEAT MASS TRANSFER

6. कृति की भाषा  
Language of the work

ENGLISH

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डायरी संख्या/Diary Number: 25344/2024-CO/L  
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## Department of Mechanical Engineering



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# Title: Lab Manual for Heat Mass Transfer



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## Vision and Mission of the Institute

1. **Vision of the Institute-** To be a notable institution for providing quality technical education, ensuring ethical, moral, and holistic development of students.
2. **Mission of the Institute-** To nurture engineering graduates with highest technical competence, professionalism and problem solving skills to serve the needs of industry and society.

## Vision and Mission of the Department

### Department Vision:

To be a renowned mechanical engineering education provider for serving needs of industry and society.

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### Department Mission:

- 1 To provide quality technical education with an effective teaching learning process.
- 2 To bridge the gap between industry and academia by collaborative activities.
- 3 To develop students with research, innovation and entrepreneurship activities.
- 4 To advance graduates with professionalism and a sense of gratitude towards society.



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## Program Outcomes

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

**Life-long Learning:** Recognize the need for, and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.

*Prof. Dr. P. K. Singh*  
उज्ज्वल भविष्य



## Program Educational Objectives (PEOs)

1. To develop technical professionals in various domains of mechanical engineering to solve relevant problems.
2. To build foundation in engineering fundamentals to synthesize innovative solutions.
3. To inculcate the spirit for technical professional and social ethics with lifelong learning to make aware about latest trends.
4. To nurture communication, teamwork and interdisciplinary approach related to human values with ecology.

## Program Specifics Outcomes (PSO)

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**PSO 1** - Analyzing and designing optimal solution(s) in the fields of Design, Thermal, Manufacturing and Industrial Engineering according to industry needs.

**PSO 2**- Develop an aptitude of innovative product development & providing solution to live industrial problems by equipping with modern analytical tools.



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## Course Outcomes (CO)

|                |   |
|----------------|---|
| <b>ME302.1</b> | <b>ANALYZE &amp; APPLY</b> the modes of heat transfer equations for one dimensional thermal system.   |
| <b>ME302.2</b> | <b>DESIGN</b> a thermal system considering fins, thermal insulation and & Transient heat conduction.  |
| <b>ME302.3</b> | <b>EVALUATE</b> the heat transfer rate in natural and forced convection & validate with experimentation results.                                  |
| <b>ME302.4</b> | <b>INTERPRET</b> heat transfer by radiation between objects with simple geometries, for black and grey surfaces.                                  |
| <b>ME302.5</b> | <b>ABILITY</b> to analyze the rate of mass transfer using Fick's Law of Diffusion and understands mass diffusion in different coordinate systems. |
| <b>ME302.6</b> | <b>DESIGN &amp; ANALYSIS</b> of heat transfer equipments and investigation of its performance.  |

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## List of Experiments with Mapping

| Sr. No. | Name of the Experiment   | CO mapping              | Level of CO mapping |
|---------|--|-------------------------|---------------------|
| 1.      | Determination of Thermal Conductivity of Insulating Powder   | <b>ME302.1, ME302.2</b> | 3                   |
| 2.      | Determination of Thermal Conductivity of metal rod   | <b>ME302.1</b>          | 3                   |
| 3.      | Determination of heat transfer coefficient in Natural Convection   | <b>ME302.3</b>          | 3                   |
| 4.      | Determination of heat transfer coefficient in Forced Convection  | <b>ME302.3</b>          | 3                   |
| 5.      | Determination of Stefan Boltzmann Constant   | <b>ME302.4</b>          | 2                   |
| 6.      | Determination of Emissivity of a Test surface  | <b>ME302.4</b>          | 3                   |
| 7.      | Study of pool boiling phenomenon and determination of critical heat flux                                     | <b>ME302.4</b>          | 2                   |
| 8.      | Determination of heat transfer, overall heat transfer coefficient and effectiveness of Plate Heat Exchanger. | <b>ME302.6</b>          | 3                   |



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## Rubrics for Evaluation

| Sr. No | Evaluation Criteria  | Marks for each Criteria | Rubrics   |
|--------|----------------------|-------------------------|---|
| 1      | Timely submission    | 5 or 10                 | Punctuality reflects the work ethics.<br>Students should reflect that work ethics by completing the lab assignments and reports in a timely manner.   |
| 2      | Journal Presentation | 5 or 10                 | Students are expected to prepare the journal.<br>The journal presentation of the course should be complete, clear, and understandable.  |
| 3      | Performance          | 5 or 10                 | After performance, the students should have good knowledge of the experiment.   |
| 4      | Understanding        | 5 or 10                 | The student should be able to explain methodology used for designing and developing the program/solution.<br>Student should clearly understand the purpose of the assignment and its outcome. |
| 5      | Oral                 | 5 or 10                 | The student should be able to answer the questions related to the lab assignments.  |

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## LAB INSTRUCTIONS

1. Laboratory uniform, shoes are compulsory in the lab.
2. Student should wear college ID-card and must carry record and observation.
3. Take signature of lab in charge after completion of observation and record.
4. If any equipment fails in the experiment report it to the supervisor immediately.
5. Students should come to the lab with thorough theoretical knowledge.
6. Don't touch the equipment without instructions from lab supervisor.
7. Don't crowd around the experiment and behave in-disciplinary.
8. Students should carry their own stationary and required things.
9. Using the mobile phone in the laboratory is strictly prohibited.

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## Experiment No: 01

### 1. Aim:

To find out Thermal Conductivity of Insulating Powder in a Sphere.

### 2. Objectives:

To study following,

1. Study of Thermal Conductivity of Insulating Powder.
2. To find out thermal Conductivity of Insulating Powder.

### 3. Technical Description:

The apparatus consists of two thin walled concentric copper spheres as shown in Fig.1. The inner sphere houses the heating coil. The insulating powder filled in the annular gap between two copper spheres, takes the form of a hollow sphere. The power supply to the heating coil is adjusted by dimmer-stat and it is measured by voltmeter and ammeter. The eight PT100 sensors are used to measure the temperature at inner and outer surface of insulating powder sphere. The four thermocouples, numbered as **T1 to T4** are embedded on outer surface of the inner sphere and four sensors, numbered as **T5 to T8** are embedded on inner surface of the outer sphere. Experimental arrangement is shown in Fig.1.

### 4. Procedure:

1. Switch ON the electric supply and ensure the dimmer-stat position to supply a maximum to the heating coil.
2. Put ON the heater switches and adjusts the heater input through dimmer-stat .
3. Maintain this input constant throughout the experiment.
4. Wait for steady state to be attained.
5. Note down the reading of all thermocouples through selector switch, voltmeter and ammeter.
6. Repeat the procedure for different heat inputs.

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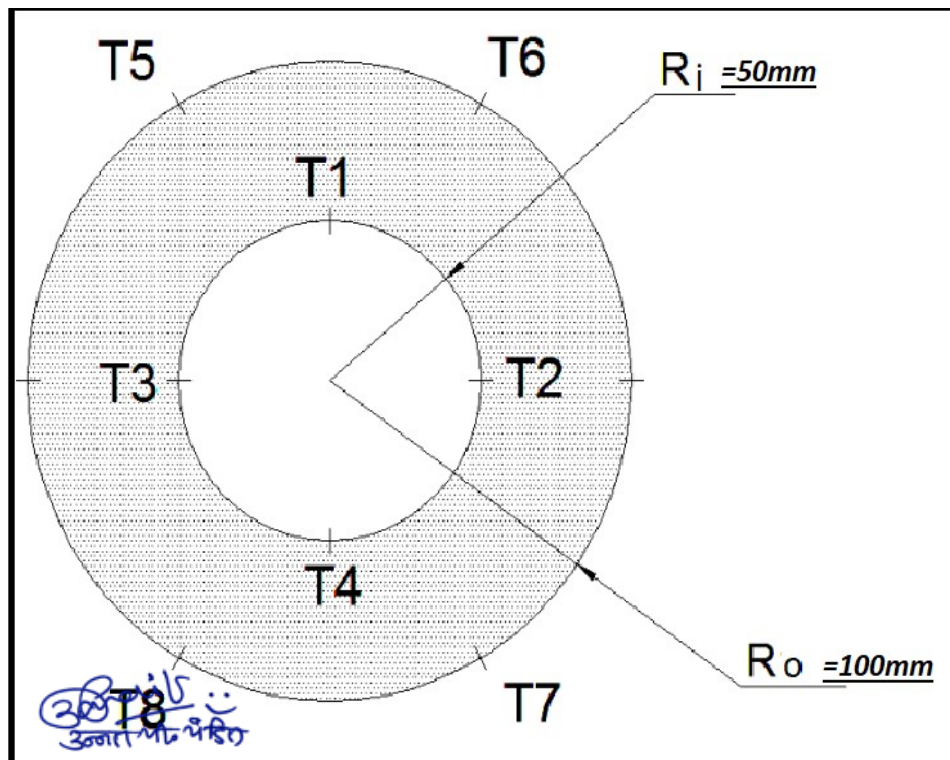


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5. Diagram:



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**6. Technical Specification:**

Electricity Supply: Single Phase, 220V AC, 50Hz.

Floor Area required: 1 m x 0.75 m

Heater Capacity = 200 Watt

Inner Sphere Diameter = 100 mm, Outer Sphere Diameter = 200 mm

Type of Insulating Powder used = Asbestos Powder

**Control Panel Comprises of:**

Standard make On/Off Switches, Mains Indicator, Temperature Scanner, Dimmer, Voltmeter, Ammeter, etc.

**7. Observation:**

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**Table No. 1 Heater Input = .....Watt**

| S. No. | Time in Mins | Heat Input |        | TEMPERATURE, °C |    |    |    |              |    |    |    |
|--------|--------------|------------|--------|-----------------|----|----|----|--------------|----|----|----|
|        |              |            |        | Inner Sphere    |    |    |    | Outer Sphere |    |    |    |
|        |              | V volts    | I amps | T1              | T2 | T3 | T4 | T5           | T6 | T7 | T8 |
| 1.     | 10           |            |        |                 |    |    |    |              |    |    |    |
| 2.     | 20           |            |        |                 |    |    |    |              |    |    |    |
| 3.     | 30           |            |        |                 |    |    |    |              |    |    |    |
| 4.     |              |            |        |                 |    |    |    |              |    |    |    |

**Table No. 2 Heater Input = .....Watt**

| S. No. | Time in Mins | Heat Input |        | TEMPERATURE, °C |    |    |    |              |    |    |    |
|--------|--------------|------------|--------|-----------------|----|----|----|--------------|----|----|----|
|        |              |            |        | Inner Sphere    |    |    |    | Outer Sphere |    |    |    |
|        |              | Vvolts     | I amps | T1              | T2 | T3 | T4 | T5           | T6 | T7 | T8 |
| 1.     | 10           |            |        |                 |    |    |    |              |    |    |    |
| 2.     | 20           |            |        |                 |    |    |    |              |    |    |    |
|        | 30           |            |        |                 |    |    |    |              |    |    |    |
|        |              |            |        |                 |    |    |    |              |    |    |    |

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**8. Calculations:**

1. Heat input =  $Q = V I =$  \_\_\_\_\_

2. **Avg Inner Sphere Surface temprature  $T_i = \frac{T_1+T_2+T_3+T_4}{4}$**

3.  $T_i =$

4. **Avg Outer Sphere Surface temprature  $T_o = \frac{T_5+T_6+T_7+T_8}{4}$**

5.  $T_o =$

The thermal conductivity of insulating powder can be determined as:

6.  **$k = \frac{Q(ro-ri)}{4\pi r_i r_o (T_i - T_o)}$  ..... in W/m k**

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**9. Prepare Result Table:**

| S.No. | Heat Input in Watt | $T_i$ | $T_o$ | K (W/m k) |
|-------|--------------------|-------|-------|-----------|
| 1.    |                    |       |       |           |
| 2.    |                    |       |       |           |
| 3.    |                    |       |       |           |

**10. Precaution:-**

1. Use stabilized A. C single-phase supply (preferably).
2. Always keep the dimmer stat at zero position before start.
3. Use the proper voltage range on VOLTMETER.
4. Gradually increase the heater inputs.
5. Operate selector switch of temperature indicator gently.

There is a possibility of getting absurd results if the supply voltage is fluctuating or if the input is not adjusted till the satisfactory steady state condition reached.

**Conclusion:-**

Thermal conductivity of Insulating Powder is found out to be \_\_\_\_\_.

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**Exercise:-**

1. How do you investigate thermal insulation?
2. What is the most effective thermal insulator?
3. What are 3 good thermal insulators?
4. How do insulators keep things warm?
5. What material is the best to keep heat in experiment?
6. How does density affect thermal insulation?
7. Why do we need thermal insulators?
8. Where is thermal insulation used? Does insulation Reduce heat?
9. Why do insulators not conduct heat?
10. How does thermal insulation work?

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## Experiment No: 02

**1. Aim:** Determination of Thermal Conductivity of metal rod.

**2. Objectives:**

- To calculate the thermal conductivity of metal rod.
- To plot the temperature distribution along the length of rod.
- To study the heat transfer through conduction in metal rod

**3. Apparatus:**

The experimental set up consists of the metal bar, one end of which is heated by an electric heater while the other end of the bar projects inside the cooling water jacket. The middle portion of the bar is surrounded by a cylindrical shell filled with the asbestos insulating powder. The temperature of the bar is measured at eight different sections while the radial temperature distribution is measured by separate thermocouples at two different sections in the insulating shell. The heater is provided with a dimmer stat for controlling the heat input. Water under constant heat condition is circulated through the jacket and its flow rate and temperature rises are noted.

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**4. Theory:**

Thermal energy may be conducted in solids by two modes:

1. Lattice Vibration.
2. Transport by free electrons.

In good electrical conductors a rather large number of free electrons move about in the lattice structure of the material. Just as these electrons may transport electric charge, they may also carry thermal energy from a high temperature region to a low temperature region. In fact, these electrons are frequently referred as the electron gas.

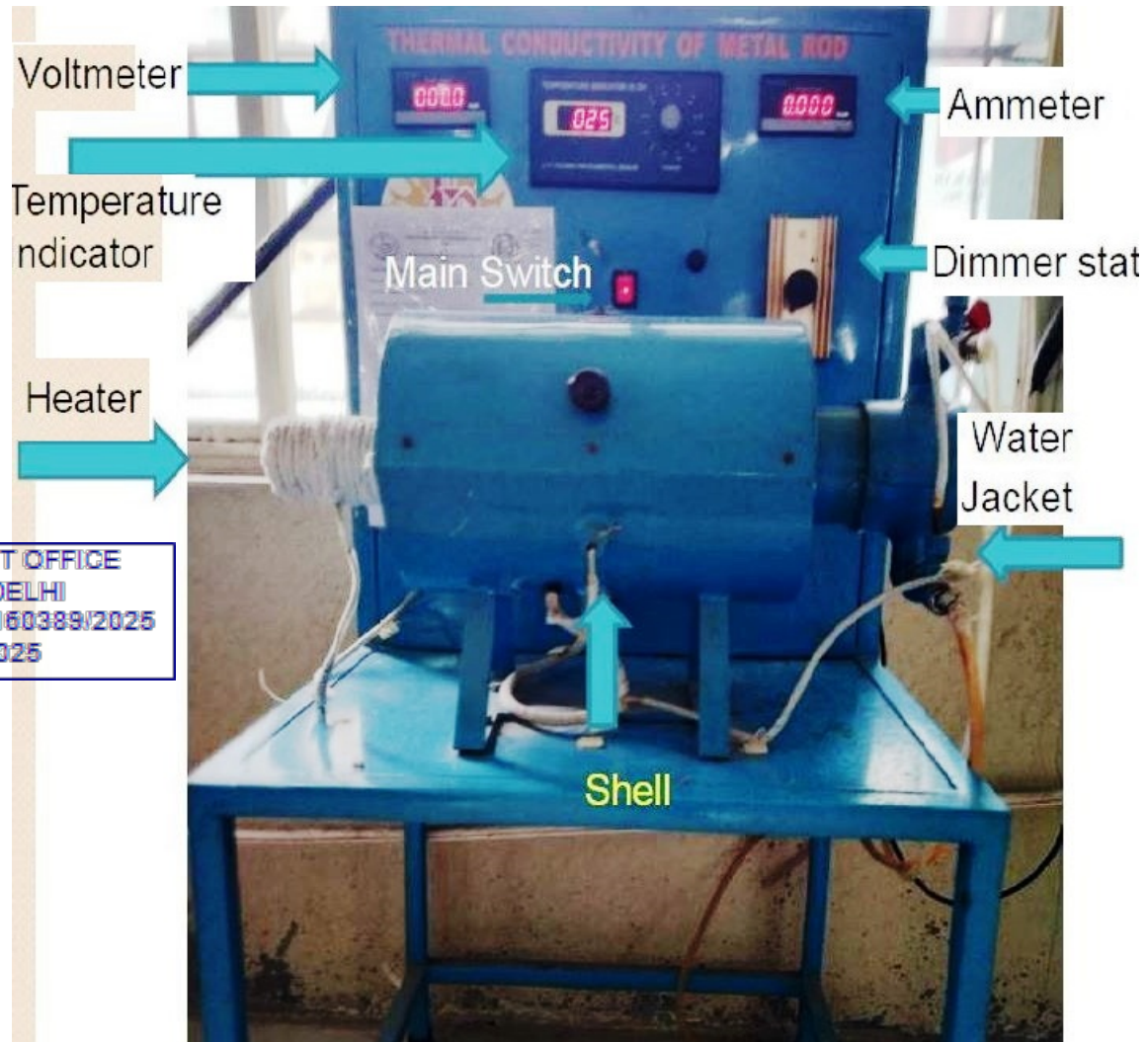
Energy may also be transmitted as vibration energy in the lattice structure of the material. In general, however, this latter mode of energy transfer is not as large as the electrons transport and it is for this reason that good electrical conductors are almost always good heat conductor viz. Copper, Aluminum and silver.

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



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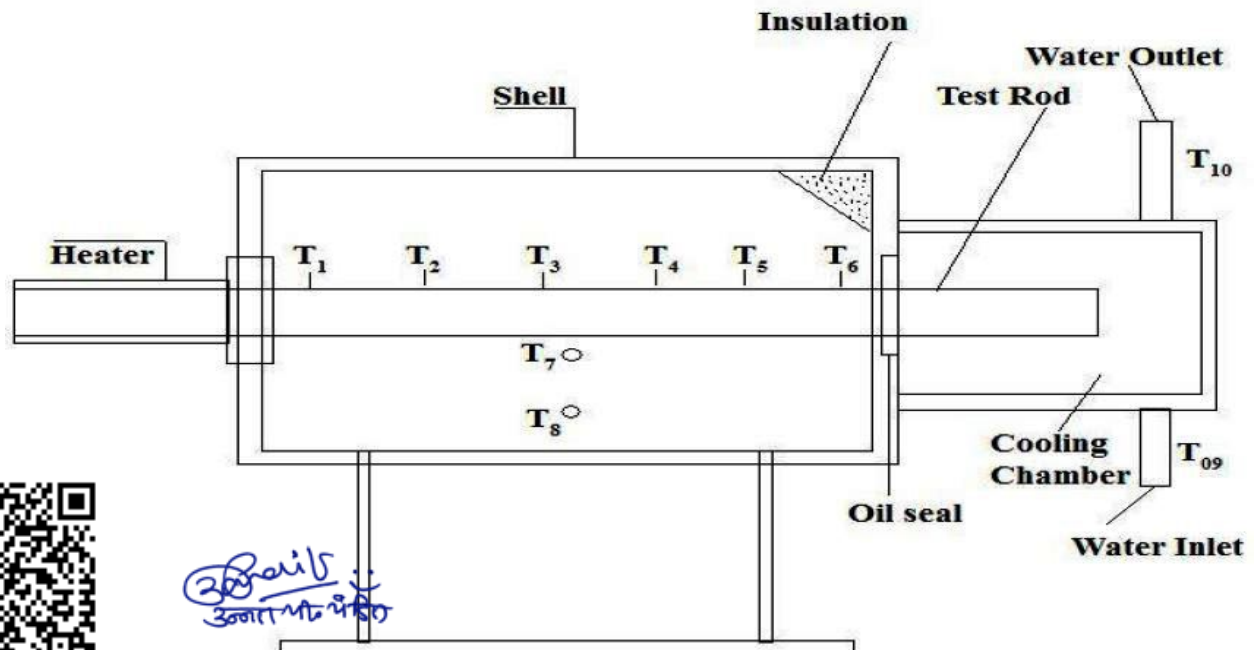
**5. Diagram:**



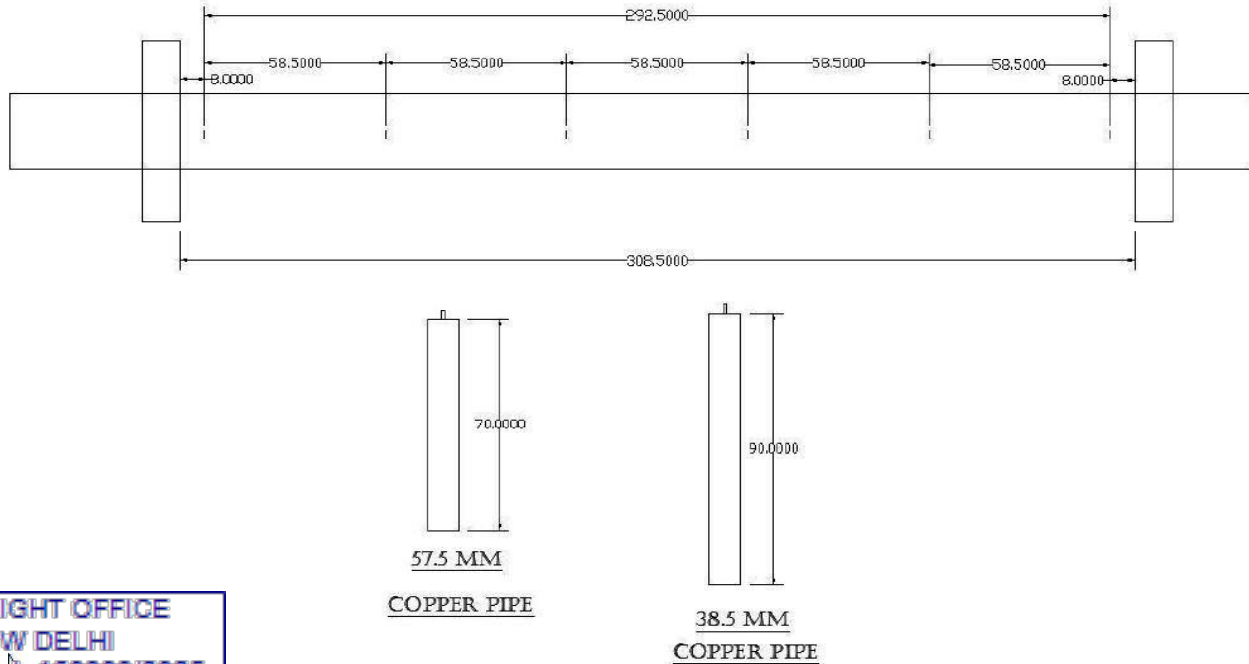
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Actual Apparatus Image

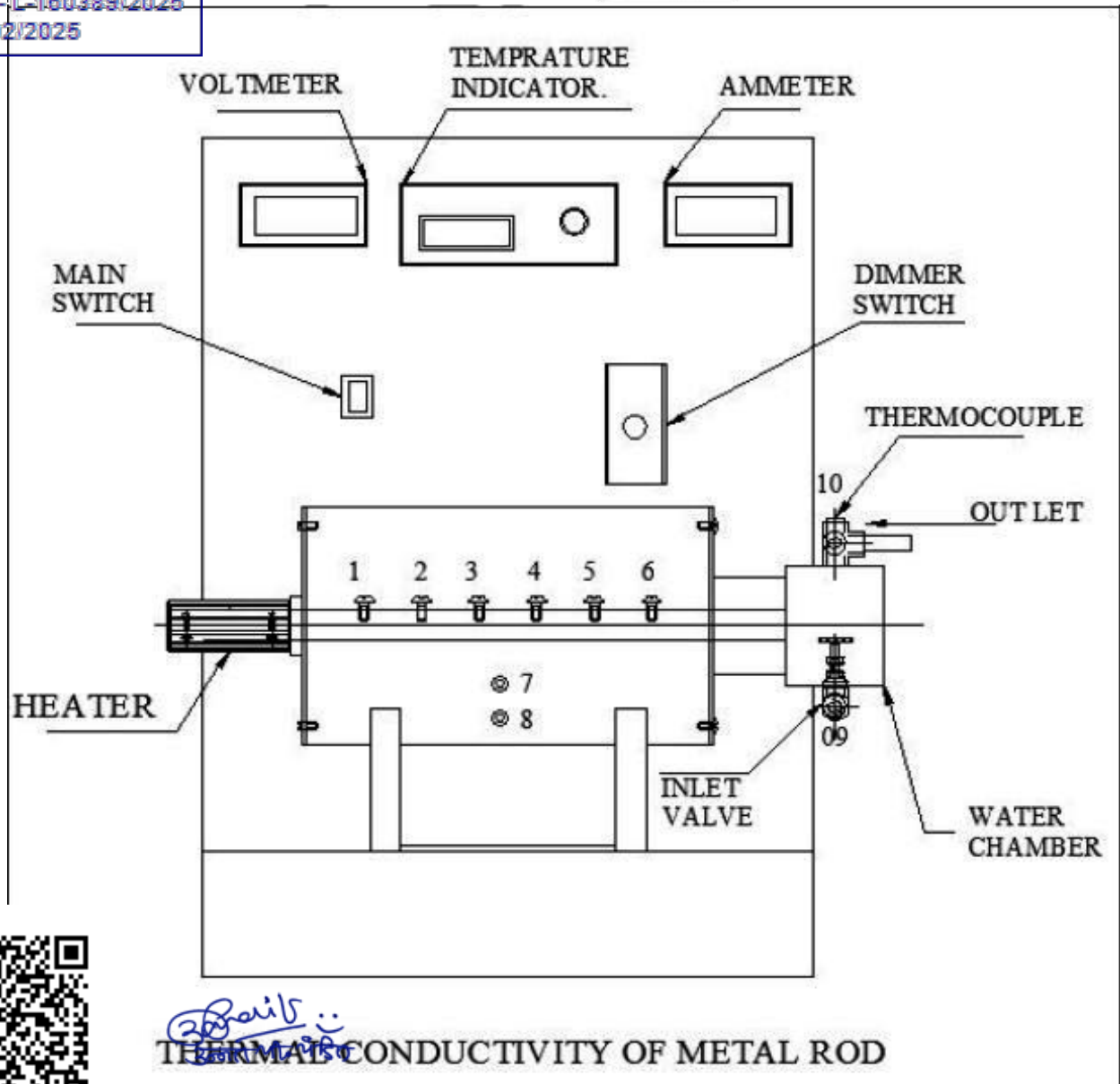
**5.2 Diagram:**



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## 6. Procedure:

- 1) Switch ON the mains.
- 2) Open the valve at the inlet of the cooling water jacket and maintain constant water flow rate.
- 3) Switch ON the heater.
- 4) Set the heat control or regulator and adjust the power input to the heater.
- 5) Wait for reasonable time till the temperatures T1 to T10 are fairly constant with time that is steady state is reached.
- 6) Read the temperatures T1 to T6 on the metal rod using channel selector and digital temperature indicator.
- 7) Read inlet and outlet water temperatures (T9 & T10) of the cooling water jacket.
- 8) Measure the cooling water flow rate using measuring jar and stop watch.
- 9) Using the measured temperatures and water flow rate, the temperature gradient along the length of the Copper rod and co-efficient of thermal conductivity of copper are calculated using the procedure given below.

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## 7. Observation Table:

| Thermocouple No. | V | I | T <sub>1</sub> | T <sub>2</sub> | T <sub>3</sub> | T <sub>4</sub> | T <sub>5</sub> | T <sub>6</sub> | T <sub>7</sub> | T <sub>8</sub> | T <sub>9</sub> | T <sub>10</sub> |
|------------------|---|---|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|
| Temperature °C   |   |   |                |                |                |                |                |                |                |                |                |                 |

## 8. Specification:

|  |                                |
|--|--------------------------------|
| Length of the metal bar (total)              | 510 mm                         |
| Material of Metal Bar                        | Copper                         |
| Size of the metal bar (diameter)             | 25.4 mm                        |
| Test length of the bar                       | 292.5 mm                       |
| Length of Shell                              | 308.5 mm                       |
| No. of thermocouple mounted on the Bar       | 6 No. (T1-T6)                  |
| No. of thermocouples in the insulation shell | 2 No. (T7-T8)                  |
| $K_{\text{(asbestos insulating powder)}}$    | 0.60 W/m°C                     |
| Heater coil                                  | Nichrome Bald type (1000 Watt) |
| Radial Distance                              | $r_o=57.5$ mm & $r_i=38.5$ mm  |
| Water jacket diameter                        | 75 mm                          |
| Temperature indicator, 12 channel:           | 200 °C.                        |
| Voltmeter                                    | 0 to 300 volts.                |
| Ammeter                                      | 0 to 2 Amps.                   |



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## 9. Calculations:

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**10. Precaution:-**

1. Use stabilized A. C single-phase supply (preferably).
2. Always keep the dimmer stat at zero position before start.
3. Use the proper voltage range on VOLTMETER.
4. Gradually increase the heater inputs.
5. Operate selector switch of temperature indicator gently.

There is a possibility of getting absurd results if the supply voltage is fluctuating or if the input is not adjusted till the satisfactory steady state condition reached.

**11. Conclusion:-**

Thermal conductivity of metal rod is found out to be \_\_\_\_\_.

**Exercises:-**

1. How do you find the thermal conductivity of a metal rod?
2. How do you calculate thermal conductivity?
3. What is the unit of the thermal conductivity of a rod?
4. What is thermal conductivity of a solid metallic rod?
5. What is the thermal conductivity of metal?
6. Which of the following factor of the thermal conductivity of a rod?
7. How is thermal conductivity formula derived?
8. How do you calculate thermal conductivity from thermal resistance?
9. What is thermal conductivity?
10. State Fourier's law of conduction.
11. What are the factors affecting the thermal conductivity?
12. Write down the three dimensional heat conduction equations in cylindrical coordinates.



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## Experiment No: 03

### 1. Aim:

Determination of local and average heat transfer coefficient in Natural Convection.

### 2. Objectives:

1. To demonstrate the basic principles of natural convection heat transfer including determination of the convective heat transfer coefficient.
2. To demonstrate the boundary layer character of external natural convection.

### 3. Apparatus:

The apparatus consist of a brass tube fitted in rectangular duct in a vertical fashion. The duct is open at the top & bottom & forms an enclosure & serves the purpose of undisturbed surrounding one side of the duct is made up of Perspex of visualization.

An electric heating element is kept in the vertical tube surface. The heat is lost from tube to the surrounding air by nature convection .The temperature of the vertical tube measured by seven thermocouples. The input to heater is measured by an ammeter & voltmeter, is varied by a Dimmer stat.

### 4. Theory:

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

There are certain situations in which the fluid motion is produced due to change in density resulting from temperature gradients. The mechanism of heat transfer in these situations is called free or natural convection. Free convection is the principal mode of heat transfer from pipes, transmission lines, refrigerating coils, hot radiators etc.

The movement of fluid in free convection is due to the fact that the fluid particles in the immediate vicinity of the hot object become warmer than the surrounding fluid resulting in a local change of density. The colder fluid creating convection currents would replace the warmer fluid. These currents originate when a body force (gravitational, centrifugal, electrostatic etc) acts on a fluid in which there are density gradients.

The force, which induces these convection currents, is called a buoyancy force that is due to the presence of a density gradient within the fluid and a body force. Grashoffs number a dimensionless quantity plays a very important role in natural convection.



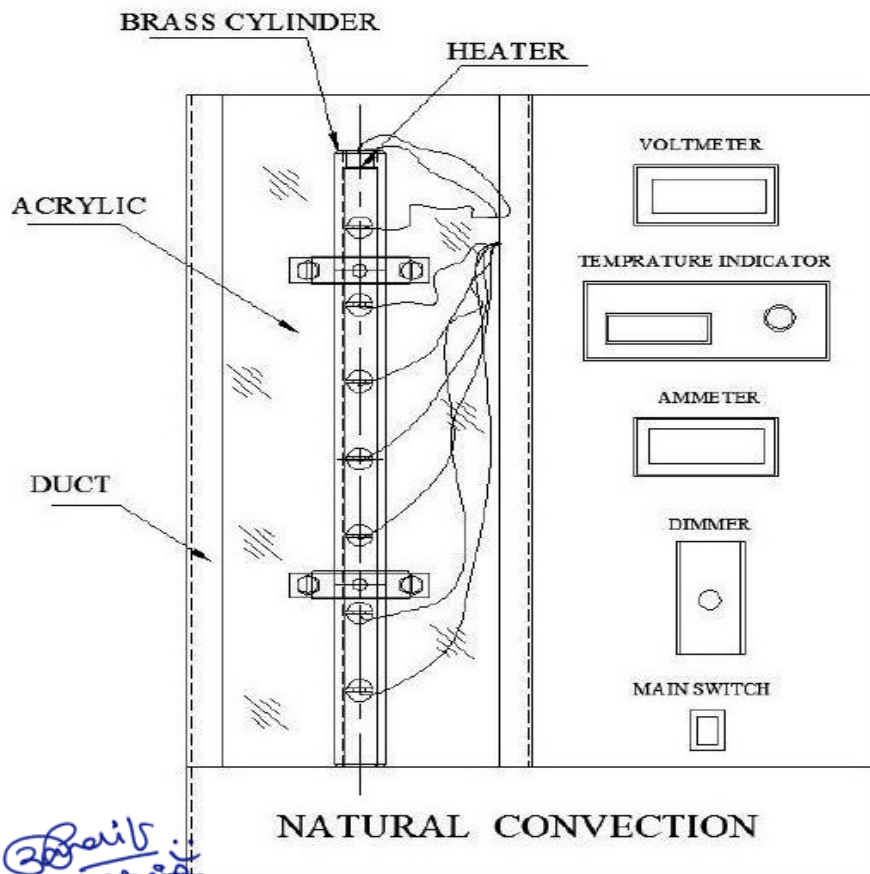
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5. Diagram:



Actual Apparatus Image

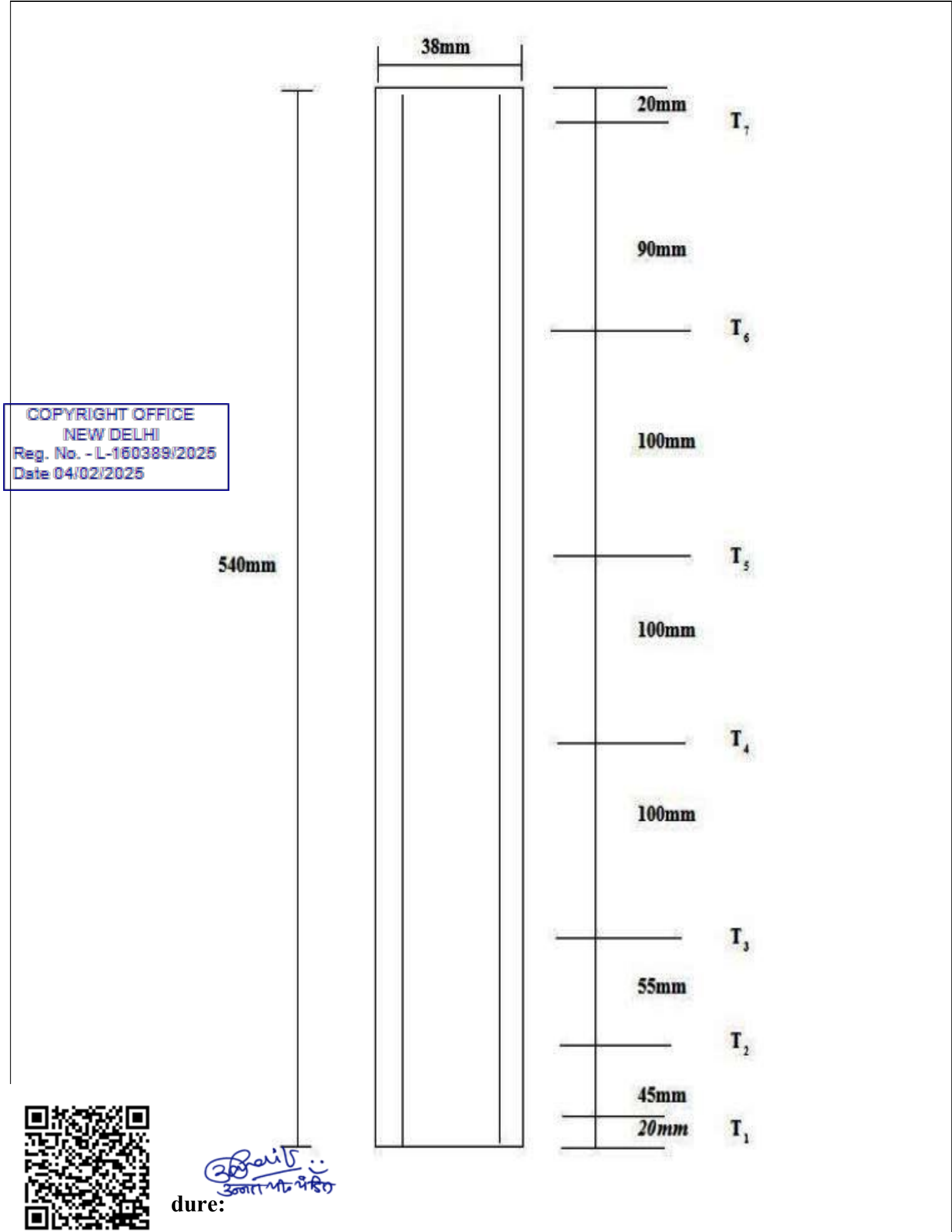
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ram:





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540mm

38mm

20mm

T<sub>7</sub>

90mm

T<sub>6</sub>

100mm

T<sub>5</sub>

100mm

T<sub>4</sub>

100mm

T<sub>3</sub>

55mm

T<sub>2</sub>

45mm

20mm

T<sub>1</sub>



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Signature:

- 1 First of all, switch ON the main supply and adjust the dimmer stat according to the required heat input.
- 2 Wait for the steady position in thermocouple in all the readings.
- 3 Now, record the surface temperature from T1 to T7, and the ambient temperature, T8.
- 4 Repeat the experiment to get the more accurate result by calculating the average temperature difference at different heat input.
- 5 Now, calculate the heat transfer coefficient by using the formula illustrated in the background section.

### 7. Observation Table:

| Thermocouple No. | V | I | T <sub>1</sub> | T <sub>2</sub> | T <sub>3</sub> | T <sub>4</sub> | T <sub>5</sub> | T <sub>6</sub> | T <sub>7</sub> | T <sub>8</sub> |
|------------------|---|---|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Temperature °C   |   |   |                |                |                |                |                |                |                |                |

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### 8. Calculations:



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### 8. Specification:

| Sr. | Component                       | Specification                |
|-----|---------------------------------|------------------------------|
| 01  | Diameter of Brass Cylinder      | 38mm or 0.038 m              |
| 02  | Length of Brass Cylinder        | 540 mm or 0.54 m             |
| 03  | Temperature indicator           | 0-300 <sup>0</sup> C         |
| 04  | Ammeter                         | 0-5A                         |
| 05  | Voltmeter                       | 0-300 V                      |
| 06  | Dimmerstat                      | 1000 watt                    |
| 07  | Heater                          | Cartridge type               |
| 08  | Thermocouple                    | 1-7 on Brass Cylinder        |
|     |                                 | 8 on Duct (Room) Temperature |
| 09  | Emissivity of Cylinder Material | 0.04                         |
|     | Surface Area of Cylinder        | 0.064 m <sup>2</sup>         |



ution: *Pratik*  
ie stabilized A. C single-phase supply (preferably).

2. Always keep the dimmer stat at zero position before start.
3. Use the proper voltage range on VOLTMETER.
4. Gradually increase the heater inputs.
5. Operate selector switch of temperature indicator gently.

There is a possibility of getting absurd results if the supply voltage is fluctuating or if the input is not adjusted till the satisfactory steady state condition reached.

### Determination of Theoretical heat transfer co-efficient:

The theoretical value of the natural heat transfer co-efficient is calculated given by:

Note down the properties of air  $t$  from data hand book

$$T_m = (T_s + T_\infty)/2 = \quad \text{°C}$$

At average temperature properties of air should be noted down from the HMT data hand book.

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$$k = \quad \text{W/mK}$$

$$Pr =$$

$$\beta = 1/(T_m + 273) = \quad \text{K}^{-1}$$

$$\Delta T = (T_s - T_\infty) = \quad \text{°C}$$

$$g = 9.81 \text{ m/s}^2$$

$$Gr \text{ (Grashoff No.)} = (g \beta L^3 \Delta T) / \nu^2 =$$

$Nu$  = choose the equation from data book based on  $Gr.Pr$


$$Nu = \quad hL/k,$$

$$h_{th} = \quad \text{W/m}^2\text{K}$$

### RESULTS

$$h = \quad \text{W/m}^2\text{K}$$



$h = \quad \text{W/m}^2\text{K}$   


Conclusion:-

Heat coefficient for a vertical tube losing heat by natural convection is found out to be.....

**Exercise:-**

1. What are 5 examples of convection that occur in everyday life?
2. What affects natural convection?
3. How many types of convection are there?
4. How is heat transferred through free or natural convection?
5. Can convection occur in solids?
6. Where does convection occur?
7. What is Newton Law of Cooling?
8. Difference between Local & Average Heat Transfer Coefficient?
9. What is the Unit of Heat Transfer Coefficient?
10. Can convection occur in a vacuum?
11. Why does convection only occur in liquids and gasses?
12. What is difference between free and forced convection?

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**Correlations:**

| Geometry   | Correlation for Nu   | Condition for applicability<br>Ra= Gr*Pr  | Characteristic Length |
|--|--|---|-----------------------|
| Vertical Plate or<br>Vertical Cylinder   | Nu=0.59 (Gr*Pr) <sup>0.25</sup><br>Nu=0.13 (Gr*Pr) <sup>1/3</sup>  | 10 <sup>4</sup> < Gr*Pr < 10 <sup>9</sup><br>10 <sup>9</sup> < Gr*Pr < 10 <sup>12</sup>       | Vertical Length       |
| Horizontal Plate<br>(Facing Up)<br>Square/Circular<br>Plate (Upper<br>Surface)   | Nu=0.54 (Gr*Pr) <sup>0.25</sup><br>Nu=0.15 (Gr*Pr) <sup>1/3</sup>  | 10 <sup>5</sup> < Gr*Pr < 2*10 <sup>7</sup><br>2*10 <sup>7</sup> < Gr*Pr < 3*10 <sup>10</sup> | L <sub>c</sub> = A/P  |
| Horizontal Plate<br>(Facing Down)<br>Square/Circular<br>Plate (Lower<br>Surface) | Nu=0.27 (Gr*Pr) <sup>0.25</sup>                                    | 3*10 <sup>5</sup> < Gr*Pr < 3*10 <sup>16</sup>  | L <sub>c</sub> = A/P  |
| Horizontal Cylinder  | Nu= 0.53 (Gr*Pr) <sup>0.25</sup><br>Nu=0.13 (Gr*Pr) <sup>1/3</sup> | 10 <sup>4</sup> < Gr*Pr < 10 <sup>9</sup><br>10 <sup>9</sup> < Gr*Pr < 10 <sup>12</sup>       | Diameter D            |
| here   | Nu=2+0.43 (Gr*Pr) <sup>0.25</sup>                                  | 1 < Gr*Pr < 10 <sup>5</sup>   | Diameter D            |



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Table 6 : Properties of Dry air at one atmospheric pressure (use  $b = 1/T$ )

| Temperature<br>T<br>(°C) | Density<br>$\rho$<br>(kg/m <sup>3</sup> ) | Kinematic<br>viscosity<br>$\nu \times 10^6$<br>(m <sup>2</sup> /s) | Prandtl<br>Number<br>Pr | Thermal<br>Diffusivity<br>$\alpha \times 10^3$<br>(m <sup>2</sup> /hr) | Specific<br>Heat<br>C <sub>p</sub><br>(kJ/kg K) | Thermal<br>Conductivity<br>K × 10 <sup>3</sup><br>(W/mK) |
|--------------------------|---|--|-------------------------|--|---|--|
| -50                      | 1.584                                     | 9.23   | 0.728                   | 45.7   | 1.013   | 20.36  |
| -40                      | 1.515                                     | 10.04  | 0.728                   | 49.6   | 1.013   | 21.17  |
| -30                      | 1.453                                     | 10.80  | 0.723                   | 53.7   | 1.013   | 21.98  |
| -20                      | 1.395                                     | 11.61  | 0.716                   | 58.3   | 1.009   | 22.79  |
| -10                      | 1.342                                     | 12.43  | 0.712                   | 62.8   | 1.009   | 23.61  |
| 0                        | 1.293                                     | 13.28  | 0.707                   | 67.7   | 1.005   | 24.42  |
| 10                       | 1.247                                     | 14.16  | 0.705                   | 72.2   | 1.005   | 25.12  |
| 20                       | 1.205                                     | 15.06  | 0.703                   | 77.1   | 1.005   | 25.93  |
| 30                       | 1.165                                     | 16.00  | 0.701                   | 82.3   | 1.005   | 26.75  |
| 40                       | 1.128                                     | 16.96  | 0.699                   | 87.5   | 1.005   | 26.56  |
| 50                       | 1.093                                     | 17.95  | 0.698                   | 92.6   | 1.005   | 28.26  |
| 60                       | 1.060                                     | 18.97  | 0.696                   | 97.9   | 1.005   | 28.96  |
| 70                       | 1.029                                     | 20.02  | 0.694                   | 102.8  | 1.009   | 29.66  |
| 80                       | 1.000                                     | 21.09  | 0.692                   | 108.7  | 1.009   | 30.47  |
| 90                       | 0.972                                     | 22.10  | 0.690                   | 114.8  | 1.009   | 31.28  |
| 100                      | 0.946                                     | 23.13  | 0.688                   | 121.1  | 1.009   | 32.10  |
| 120                      | 0.898                                     | 25.45  | 0.686                   | 132.6  | 1.009   | 33.28  |
| 140                      | 0.854                                     | 27.80  | 0.684                   | 145.2  | 1.013   | 34.89  |
| 160                      | 0.815                                     | 30.09  | 0.682                   | 158.0  | 1.017   | 36.40  |
| 180                      | 0.779                                     | 32.49  | 0.681                   | 171.0  | 1.022   | 37.80  |
| 200                      | 0.746                                     | 34.85  | 0.680                   | 184.9  | 1.026   | 39.31  |
| 250                      | 0.674                                     | 40.61  | 0.677                   | 210.6  | 1.038   | 42.68  |
| 300                      | 0.615                                     | 48.20  | 0.674                   | 257.6  | 1.047   | 46.05  |
| 350                      | 0.566                                     | 55.46  | 0.676                   | 294.7  | 1.059   | 49.08  |
| 400                      | 0.524                                     | 63.09  | 0.678                   | 335.2  | 1.067   | 52.10  |
| 500                      | 0.456                                     | 79.38  | 0.687                   | 415.1  | 1.093   | 57.45  |
|                          | 0.404                                     | 96.89  | 0.699                   | 499.0  | 1.114   | 62.22  |
|                          | 0.362                                     | 115.40   | 0.706                   | 588.2  | 1.135   | 66.87  |
|                          | 0.320                                     | 134.80   | 0.713                   | 682.0  | 1.156   | 71.76  |

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Table 5 : Properties of water in saturated state

| Temperature | Specific Heat   | Density                        | Kinematic viscosity                      | Thermal Conductivity      | Thermal Diffusivity                          |
|-------------|-----------------|--------------------------------|--|---------------------------|--|
| T<br>(°C)   | Cp<br>(kJ/kg K) | $\rho$<br>(kg/m <sup>3</sup> ) | $\nu \times 10^6$<br>(m <sup>2</sup> /s) | $K \times 10^3$<br>(W/mK) | $\alpha \times 10^3$<br>(m <sup>2</sup> /hr) |
| 0           | 4.128           | 999.8                          | 1.792                                    | 0.5619                    | 1.332  |
| 5           | 4.203           | 1000.0                         | 1.520                                    | 0.5723                    | 1.362  |
| 10          | 4.193           | 999.8                          | 1.308                                    | 0.5820                    | 1.389  |
| 15          | 4.187           | 999.2                          | 1.140                                    | 0.5911                    | 1.413  |
| 20          | 4.187           | 998.3                          | 1.004                                    | 0.5996                    | 1.436  |
| 25          | 4.180           | 997.1                          | 0.8933                                   | 0.6076                    | 1.458  |
| 30          | 4.180           | 997.1                          | 0.8933                                   | 0.6076                    | 1.478  |
| 35          | 4.179           | 994.1                          | 0.7238                                   | 0.6221                    | 1.497  |
| 40          | 4.179           | 992.3                          | 0.6582                                   | 0.6286                    | 1.516  |
| 45          | 4.182           | 990.2                          | 0.6021                                   | 0.6347                    | 1.233  |
| 50          | 4.182           | 998.0                          | 0.5537                                   | 0.6405                    | 1.550  |
| 55          | 4.184           | 985.7                          | 0.5116                                   | 0.6458                    | 1.566  |
| 60          | 4.186           | 983.1                          | 0.4748                                   | 0.6507                    | 1.581  |
| 65          | 4.187           | 980.5                          | 0.4424                                   | 0.6553                    | 1.596  |
| 70          | 4.191           | 977.7                          | 0.4137                                   | 0.6594                    | 1.609  |
| 75          | 4.191           | 974.7                          | 0.3881                                   | 0.6633                    | 1.624  |
| 80          | 4.195           | 971.6                          | 0.3653                                   | 0.6668                    | 1.636  |
| 85          | 4.201           | 968.4                          | 0.3448                                   | 0.6699                    | 1.647  |
| 90          | 4.203           | 965.1                          | 0.3264                                   | 0.6727                    | 1.659  |
| 95          | 4.210           | 961.7                          | 0.3097                                   | 0.6753                    | 1.668  |
| 100         | 4.215           | 958.1                          | 0.2945                                   | 0.6775                    | 1.677  |
| 120         | 4.246           | 942.8                          | 0.2461                                   | 0.6833                    | 1.707  |
| 140         | 4.282           | 925.9                          | 0.2118                                   | 0.6845                    | 1.727  |
| 160         | 4.339           | 907.3                          | 0.1869                                   | 0.6815                    | 1.731  |
| 180         | 4.411           | 886.9                          | 0.1684                                   | 0.6745                    | 1.724  |
| 200         | 4.498           | 864.9                          | 0.1545                                   | 0.6634                    | 1.706  |
| 220         | 4.608           | 840.4                          | 0.1439                                   | 0.6483                    | 1.674  |
| 240         | 4.770           | 813.6                          | 0.1358                                   | 0.6292                    | 1.622  |
| 260         | 4.991           | 783.9                          | 0.1295                                   | 0.6059                    | 1.549  |
| 280         | 5.294           | 750.5                          | 0.1245                                   | 0.5780                    | 1.455  |
| 300         | 5.758           | 712.2                          | 0.1205                                   | 0.5450                    | 1.329  |
| 320         | 6.566           | 666.9                          | 0.1174                                   | 0.5063                    | 1.156  |
| 340         | 7.234           | 610.2                          | 0.1151                                   | 0.4611                    | 0.918  |
| 360         | 16.138          | 566.2                          | 0.1139                                   | 0.4115                    | 0.485  |

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## Experiment No: 04

### 1. Aim:

Determination of local and average heat transfer coefficient in Forced Convection.

### 2. Objectives:

Determine the convective heat transfer coefficient and compare it with the theoretical values, in forced convection.

### 3. Apparatus:

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

Test pipe is connected to the delivery side of the blower along with the orifice to measure flow of air through the pipe. Input to the heater is given through a dimmer stat and measured by meters.

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

### 4. Theory:

If the motion of fluid is induced by some external means such as a pump or blower, then the heat transfer process is known as “Forced Convection” .

The Newton’s law of cooling in convective heat transfer is given by,

$$q = h A \Delta T$$

Where,

q = Heat transfer rate, in watts

A = Surface area of heat flow, in  $m^2$

$\Delta T$  = Overall temperature difference between the wall and fluid, in  $^{\circ}C$

h = Convection heat transfer co-efficient, in  $watts/m^2 \text{ } ^{\circ}C$

This set up has been designed to study heat transfer by forced convection.

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

Convection is the transfer of heat within a fluid by mixing of one portion of fluid with other. Convection is possible only in a fluid medium and is directly linked with the motion of medium itself. In forced convection, fluid motion is principally produced by superimposed velocity field like a fan, blower or a pump; the energy transport is said forced convection.

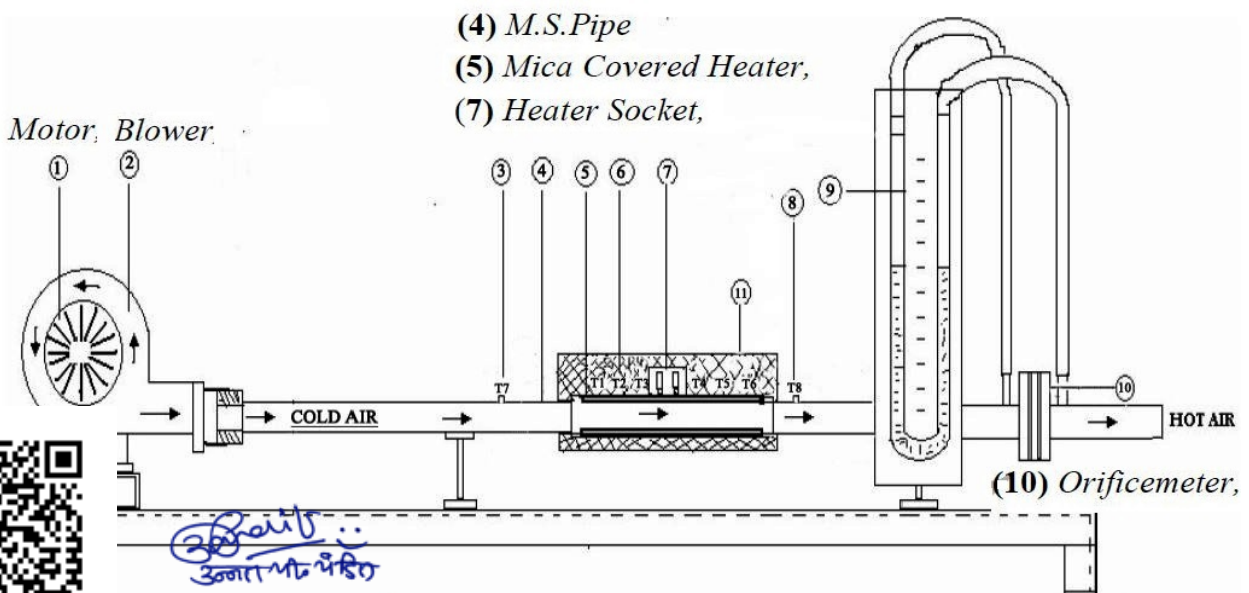


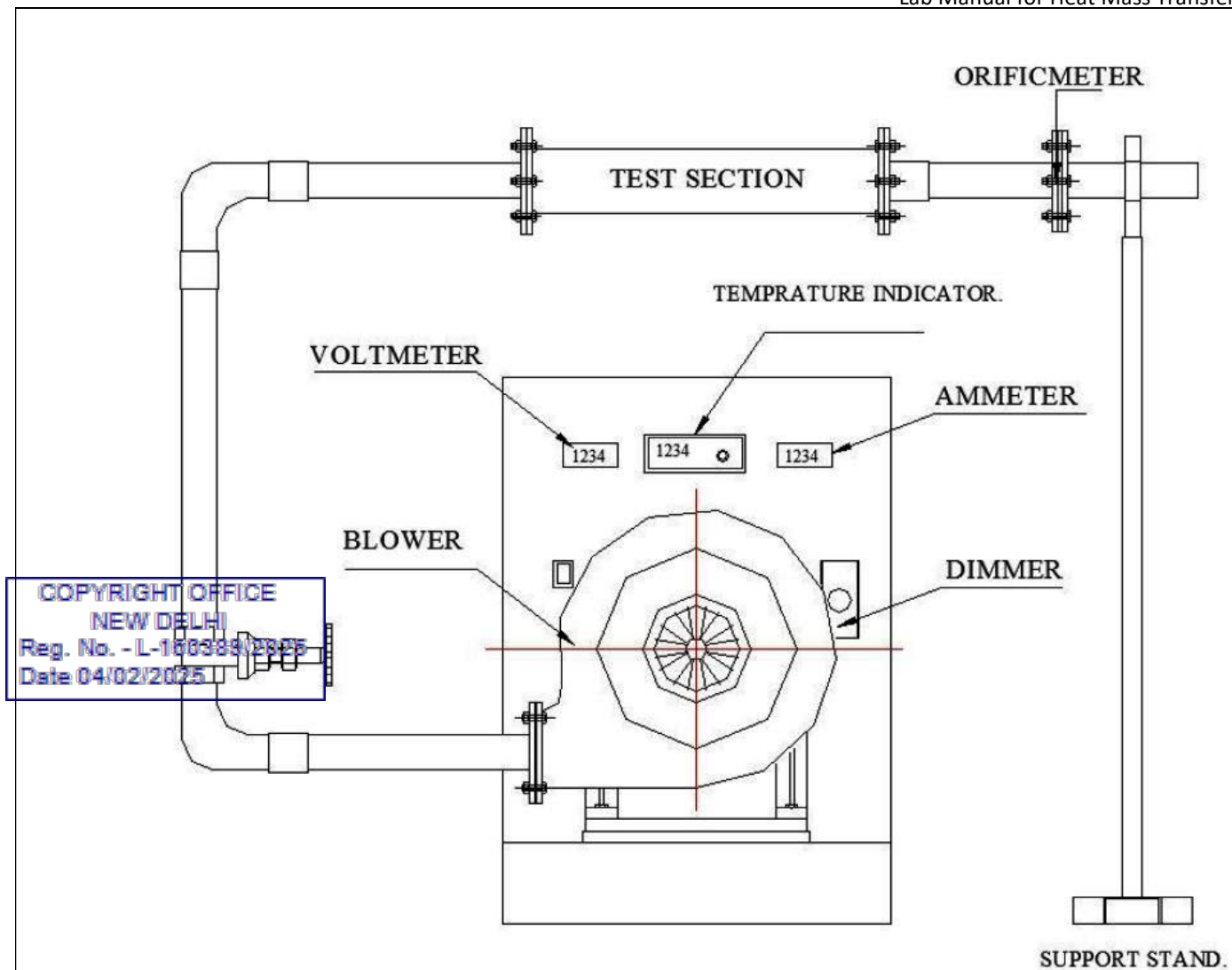
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5. Diagram:



Actual Apparatus Image





## FORCED CONVECTION APPARATUS.

### 6. Procedure:

- 1) Switch on the Main Switch and then console on switch to activate the control panel.
- 2) Switch on the blower unit first and adjust the flow of air using Gate valve of blower to a desired difference in manometer.
- 3) Switch on the heater and set the voltage (say 80V) using the heater regulator.
- 4) Wait for reasonable time to allow temperatures to reach steady state.
- 5) Measure the voltage, current and temperatures from T1 to T6 at known time interval.
- 6) Calculate the convective heat transfer co-efficient using the procedure given.
- 7) Repeat the experiment for different values of power input to the heater and blower air flow



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**7. Specification:**

| Sr. | Component                              | Specification                           |
|-----|--|---|
| 01  | Delivery Pipe Diameter ( $d_i$ )       | 0.032 m                                 |
| 02  | Length of Test Section (L)             | 0.44 m                                  |
| 03  | Orifice meter Diameter ( $d_o$ )       | 0.014 m                                 |
| 04  | Area of Test Section ( $A_s$ )         | 0.0442 m <sup>2</sup>                   |
| 05  | Coefficient of Orifice meter ( $C_d$ ) | 0.65                                    |
| 06  | Area of delivery pipe ( $a_1$ )        | 8.042 x 10 <sup>-4</sup> m <sup>2</sup> |
| 07  | Area of Orifice ( $a_2$ )              | 1.54x 10 <sup>-4</sup> m <sup>2</sup>   |
| 08  | Blower                                 | 1/3 H.P Single Phase with Motor         |
| 09  | Manometer                              | Water Manometer.                        |
| 10  | Test Section Insulation                | Asbestos Rope                           |
| 11  | Temperature indicator                  | 0-300 °C                                |
| 12  | Ammeter                                | 0-5A                                    |
| 13  | Voltmeter                              | 0-300 V                                 |
| 14  | Dimmerstat                             | 1000 watt                               |
| 15  | Heater                                 | Cartridge type                          |
| 16  | Thermocouple                           | Cromel-Alumel                           |
|     |  | 1-6 on the Test Section                 |
|     |  | 7 on Inlet of air to Test Section       |
|     |  | 8 on Outlet of air from Test Section    |

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**8. Observation Table:**

| Thermocouple No. | V | I | T <sub>1</sub> | T <sub>2</sub> | T <sub>3</sub> | T <sub>4</sub> | T <sub>5</sub> | T <sub>6</sub> | T <sub>7</sub> | T <sub>8</sub> |
|------------------|---|---|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Temperature °C   |   |   |                |                |                |                |                |                |                |                |

Thermocouples no 1 to 6 on the test section, Thermocouples no 7 inlet section, & Thermocouples no 8 exit section.



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### 9. Calculation :

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### 10. Precaution:

1. Use stabilized A. C single-phase supply (preferably).
2. Always keep the dimmer stat at zero position before start.
3. Use the proper voltage range on VOLTMETER.
4. Gradually increase the heater inputs.

Operate selector switch of temperature indicator gently.

There is a possibility of getting absurd results if the supply voltage is fluctuating or if the dimmer stat is not adjusted till the satisfactory steady state condition reached.



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Determination of Theoretical **heat transfer co-efficient** calculations

$$T_m = (T_s + T_\infty)/2 = \quad \quad \quad ^\circ\text{C}$$

Following properties of air from heat transfer data hand book at mean temperature are noted down

Kinematic viscosity of air,  $\nu = \quad \quad \quad \text{m}^2/\text{s}$

Thermal conductivity of air,  $k \quad \quad \quad \text{W/m k}$

$Pr =$

Calculation of velocity of air (V):

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$$A_1 = \pi/4 * D^2 = \quad \quad \quad \text{m}^2, \quad A_2 = \pi/4 * d^2 = \quad \quad \quad \text{m}^2$$

$$\rho_a P/RT = \quad \quad \quad \text{kg/m}^3$$

$$\rho_w h_w = \rho_a h_a, \quad h_a = \quad \quad \quad \text{m}$$

$$Q_a = [C_d A_1 A_2 \sqrt{2gh_a}] / (A_1^2 - A_2^2)^{1/2} = \quad \quad \quad \text{m}^3/\text{s}$$

$$V = Q_a / A_1 = \quad \quad \quad \text{m/s}$$

$$Re = (VD)/\nu =$$

If Reynolds No. value is more than 2300, flow is Turbulent otherwise flow is Laminar.

Usually for forced convection heat transfer experiment the value of Reynolds No. is more than 2300, hence flow is turbulent.

Choose the equation from data book based on Reynolds number.

$$hD/k = Nu,$$

$$Nu = (h x k)/D = \quad \quad \quad \text{W/m}^2\text{K}$$



**Conclusion:** *3000*   
 for coefficient in forced convection of air in a tube is found out to be -----

**Exercises:-**

1. What is an example of forced convection?
2. Which types of surfaces are used in the experiment for forced convection?
3. How does forced convection affect heat transfer?
4. Why is forced convection more efficient?
5. Why forced convection is faster than free convection explained?
6. Why is heat transfer faster in forced convection vs natural convection?
7. Can forced convection occur in gravity free space?
8. Where is forced convection used?
9. Is convection possible only in gases?
10. What is the most important parameter forced convection?

| <p><b>COPYRIGHT OFFICE</b><br/> <b>NEW DELHI</b><br/>                 Reg. No. - L-16088/2025<br/>                 Date 04/02/2025</p> | <p><b>Flow over flat plate</b></p>  | <p><b>Flow through pipes / conduits</b></p>   |
|--|---|---|
|  | <p><b>Laminar flow (Re &lt; 3 × 10<sup>5</sup>)</b><br/>                     Reynolds number.<br/> <math display="block">Re = \frac{\rho \cdot V_m \cdot x}{\mu} = \frac{V_m \cdot x}{\nu}</math></p>   | <p><b>1. Laminar flow (Re &lt; 2000)</b><br/>                     (i) <math>Re = \frac{\rho \cdot V_m \cdot D}{\mu} = \frac{V_m \cdot D}{\nu}</math> (circular pipe)<br/> <math>Re = \frac{V_m \cdot D_h}{\nu}</math> (Non-circular pipes)<br/>                     Hydraulic diameter <math>D_h = \frac{4 A_c}{P}</math></p> |
|  | <p>(ii) Critical length / entrance length<br/> <math display="block">L_c = (3 \times 10^5) \cdot \frac{\nu}{V}</math></p>   | <p>(ii) Entrance length,<br/> <math display="block">L_c = 0.0575 Re \cdot D</math></p>  |
|  | <p>(iii) Average drag or friction coefficient,<br/> <math display="block">C_f = \frac{1.328}{\sqrt{Re}} = 2 C_{fx}</math></p>   | <p>(iii) Average velocity, <math>V_m = \frac{V_{max}}{2}</math></p>   |
|  | <p>(iv) Drag force,<br/> <math display="block">F_D = \frac{\rho \cdot A \cdot V^2}{2} \times C_f</math></p>   | <p>(iv) Friction factor,<br/> <math display="block">f = \frac{16}{Re} = \frac{\Delta p}{4 \left(\frac{L}{D}\right) \left(\frac{\rho \cdot V^2}{2}\right)}</math><br/>                     where, <math>\Delta p = \frac{32 \mu V L}{D^2}</math> = Pressure drop</p>   |
|  | <p>(v) Velocity boundary layer thickness at distance 'x' from leading edge,<br/> <math display="block">\delta_x = \frac{4.64 x}{\sqrt{Re}}</math></p>   |   |
|  | <p><b>2. Turbulent flow (Re &gt; 5 × 10<sup>5</sup>)</b></p>  | <p><b>2. Turbulent flow (Re &gt; 4000)</b></p>  |
|  | <p>(i) <math>C_f = \frac{0.455}{\ln(Re_L^{2.58})} - \frac{C_1}{Re_L}</math><br/>                     where, C<sub>1</sub> = 1050 for change from laminar to turbulent flow<br/> <math display="block">C_{f_{turb}} = 0.072 (Re_L)^{-0.2}</math></p> | <p>(i) Friction factor,<br/> <math display="block">f = 0.046 (Re)^{-0.2} = \frac{\Delta p}{4 \left(\frac{L}{D}\right) \left(\frac{\rho \cdot V^2}{2}\right)}</math></p>   |
|  | <p>(ii) <math>\delta = \frac{0.39 x}{(Re)^{0.2}}</math></p>   | <p>(ii) Length of thermal entry region,<br/> <math display="block">(Le)_t = 10 &lt; \left(\frac{Le}{D}\right) \leq 60</math><br/>                     where hydrodynamic layer, <math>Le = 0.0575 Re_D \cdot D</math></p>   |
|  | <p>io of thermal boundary layer thickness, <math>\delta_t</math> to<br/>                     ocity boundary layer thickness, <math>\delta</math> :<br/> <math display="block">\frac{\delta_t}{\delta} = \frac{1}{1.026 Pr^{1/3}}</math></p>         |   |



|   |   |
|---|---|
| <p><b>3. Dimensionless Numbers</b></p> <p>Reynold's No. : <math>Re_L = \frac{\rho \cdot V L}{\mu}</math></p> <p>Prandtl No. : <math>Pr = \frac{\mu \cdot C_p}{k_f}</math></p> <p>Nusselt No. : <math>Nu = \frac{h \cdot D_R}{k_f}</math></p> <p>Stanton No. : <math>St = \frac{(Nu)}{Re \cdot Pr} = \frac{h}{\rho V C_p}</math></p> <p>Peclet No. : <math>Pe = Re \cdot Pr</math></p>               | <p><b>3. Dimensionless Numbers</b></p> <p>Reynold's No. : <math>Re_L = \frac{\rho \cdot V D_R}{\mu}</math></p> <p>Prandtl No. : <math>Pr = \frac{\mu \cdot C_p}{k_f}</math></p> <p>Nusselt No. : <math>Nu = \frac{h \cdot D_R}{k_f}</math></p> <p>Stanton No. : <math>St = \frac{(Nu)}{Re \cdot Pr} = \frac{h}{\rho V C_p}</math></p> <p>Peclet No. : <math>Pe = Re \cdot Pr</math></p>   |
| <p><b>4. Heat transfer co-relation</b></p> <p><b>A) Laminar flow :</b></p> <p>(i) Local Nusselt Number at distance x from leading edge.</p> <p><math>Nu_x = 0.332 (Re_x)^{1/2} \cdot (Pr)^{1/3}</math></p> <p>(ii) Average heat transfer coefficient,</p>   | <p><b>4. Heat transfer co-relation</b></p> <p><b>A) Laminar flow :</b></p> <p>For constant heat flux : <math>Nu = 4.36</math></p> <p>For constant wall temperature :</p> <p><math>Nu = 3.66</math></p>  |
| <p><b>B) Turbulent flow</b></p> <p>i) Local Nusselt Number</p> <p><math>Nu_x = \frac{h_x \cdot x}{k} = 0.332 (Re_x)^{1/2} \cdot (Pr)^{1/3}</math></p> <p><math>h_{av} = 2 \times h_L</math></p> <p><math>h_{av} = \frac{Nu_{av} \cdot k}{L}</math></p> <p><math>Nu_{av} = 0.664 (Re_L)^{1/2} \cdot (Pr)^{1/3}</math></p> <p>iii) For liquid metal :</p> <p><math>Nu = 1.13 (Re Pr)^{0.5}</math></p> |   |
| <p><b>B) Turbulent flow</b></p> <p>i) Local Nusselt Number</p> <p><math>Nu_x = 0.029 Re_x^{0.8} \cdot Pr^{1/3}</math></p> <p><math>Nu_{av} = 0.0366 Re_L^{0.8} \cdot Pr^{1/3}</math></p> <p>ii) Mean film temperature, <math>T_m = \frac{T_s + T_\infty}{2}</math></p>  | <p><b>B) Turbulent flow</b></p> <p><math>Nu = 0.023 Re^{0.8} \cdot Pr^{0.4}</math> (When fluid is heated)</p> <p><math>Nu = 0.023 Re^{0.8} \cdot Pr^{0.3}</math> (When fluid is cooled)</p>   |
| <p><b>C) Flow across a cylinder</b></p> <p>For const. Heat flux : <math>Nu_D = 0.62 Re_D^{0.505}</math></p> <p>For constant wall temperature : <math>Nu_D = C \times (Re_D)^n \cdot (Pr)^{1/3}</math></p> <p>For values of 'n' and 'C',</p> <p>Table 6.14.1 can be referred.</p>  | <p><b>C) Bulk mean temperature,</b></p> <p><math>T_m = \frac{T_{inlet} + T_{outlet}}{2}</math> (or, <math>\frac{T_1 + T_2}{2}</math>)</p>   |
|   | <p><b>D) For flow of liquid metals (<math>Pr &lt; 0.01</math>)</b></p> <p><math>Nu = 5 + 0.025 (Re Pr)^{0.8}</math> (for <math>T_w</math> is constant)</p> <p><math>Nu = 4.82 + 0.0185 (Pe)^{0.827}</math> (for constant heat flux)</p> <p><b>E) For flow of heavy oils</b></p> <p><math>Nu = 0.027 \cdot Re_x^{0.8} \cdot Pr^{0.33} (\mu / \mu_w)^{0.14}</math></p> <p>Where <math>\mu_w</math> = dynamic viscosity at wall temperature.</p> |

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## Experiment No: 05

1. **Aim:** - Determination of Emissivity of a Test surface.

2. **Objectives:**

The experiment is performed in a way that the input conductive and convective losses from both the plates are equal. Thus, a difference in the input on both plates is due to only the emissive factor. The main purpose of this experiment is to calculate the surface emissivity of the material.

3. **Apparatus :**

- 1) Two aluminums plates identical in all dimensions, one coated with lamp black
- 2) Heater
- 3) Heating coils.
- 4) Voltmeter
- 5) Dimmerstat

- 6) Thermocouples
- 7) Temperature indicator.

4. **Theory :**

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It is obvious from the Stefan Boltzmann’s Law that the prediction of emissive power of a surface requires knowledge about the values of its emissivity and therefore much experimental research in radiation has been concentrated on measuring the values of emissivity as function of surface temperature. The present experimental set up is designed and fabricated to measure the property of emissivity of the least test plate surface at various temperatures.

Table 1 gives approximate values of emissivity for some common materials for reference.

TABLE – 1

|             | MATERIAL  | TEMPERATURE             | EMISSIVITY                       |
|-------------|---|-------------------------|----------------------------------|
| Metals      | Polished copper, Steel, Stainless Steel, Nickel | 20 <sup>0</sup> C       | 0.15 increases with temperatures |
|             | Alluminium (Oxidised)                           | 90 - 540 <sup>0</sup> C | 0.20 to 0.33                     |
| Non- Metals | Brick, Wood, Marble, water                      | 20 – 100 <sup>0</sup> C | 0.80 to 1                        |

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

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

It is noted by E.

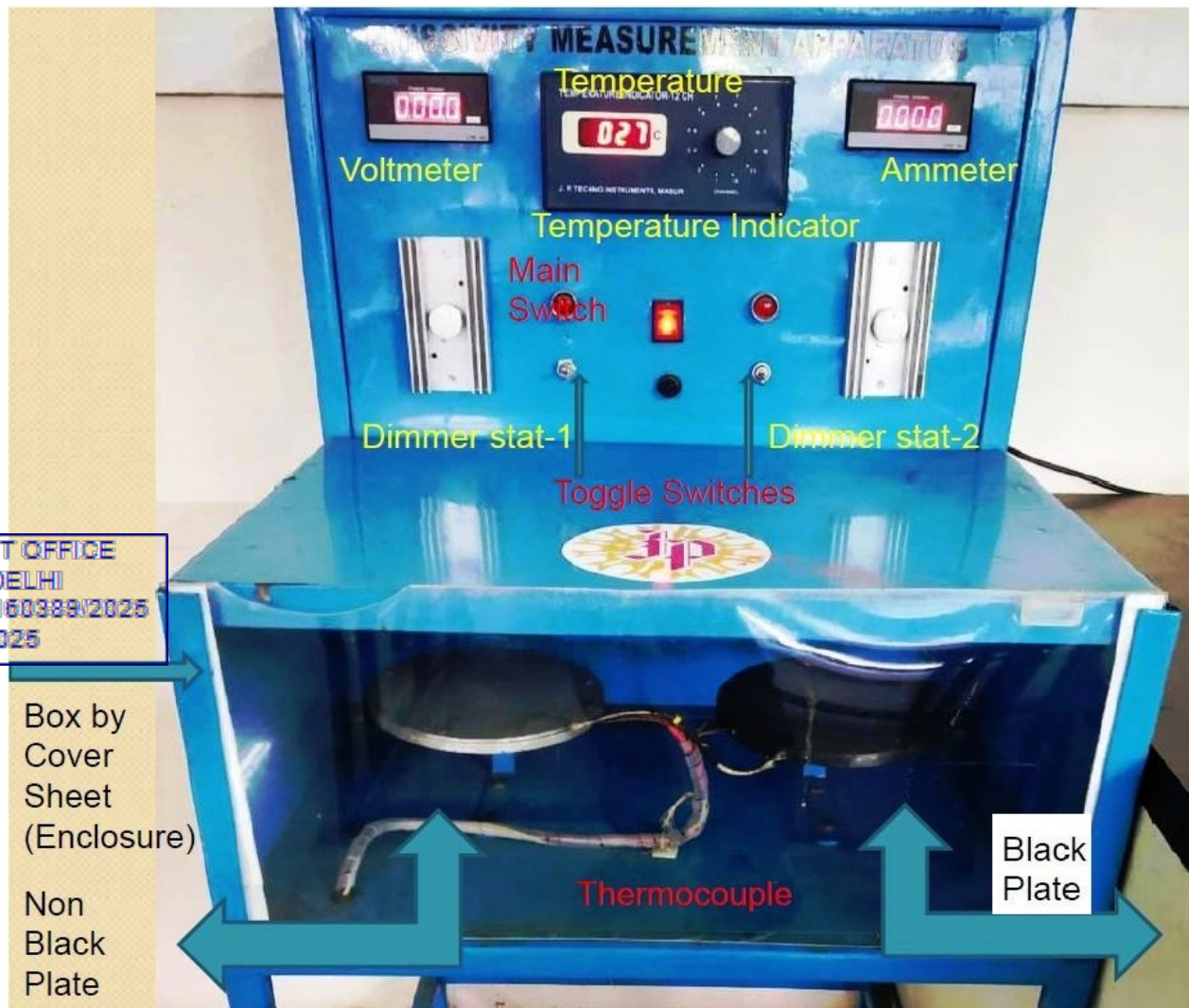
$$E = E_b + \dots$$

$E_b$

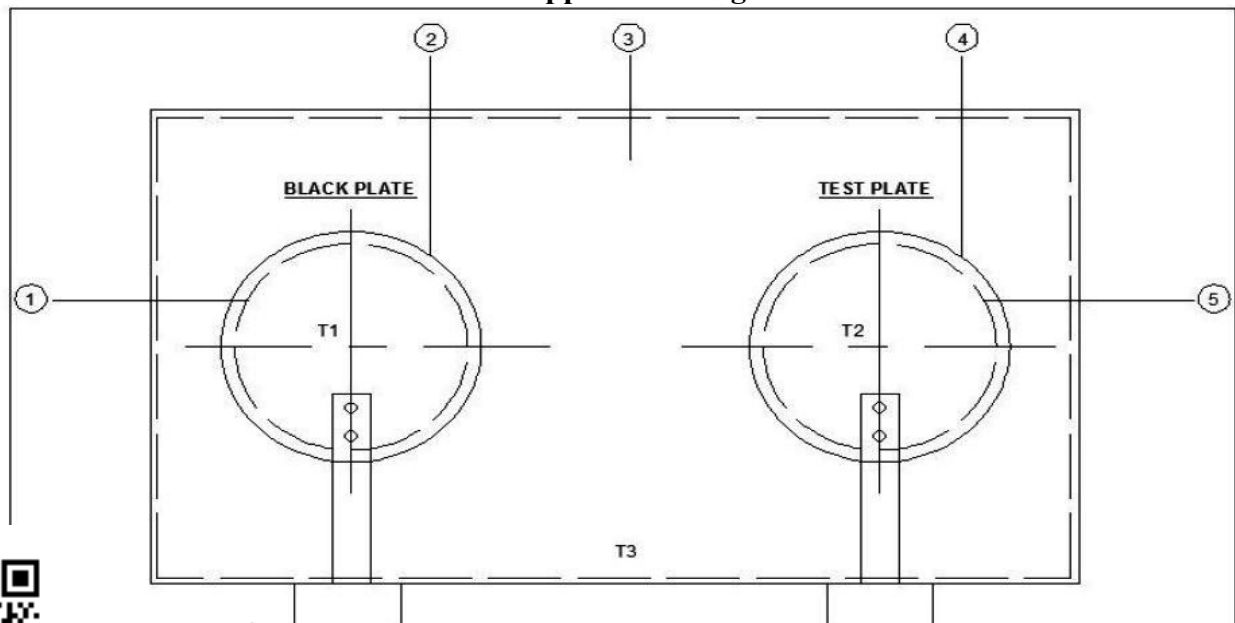
body absorptivity = 1 and by the knowledge of Kirchhoff’s Law emissivity of the y becomes unity. Emissivity being a property of the surface depends on the nature of  $\epsilon$  and temperature.



### 5. Schematic Diagram:

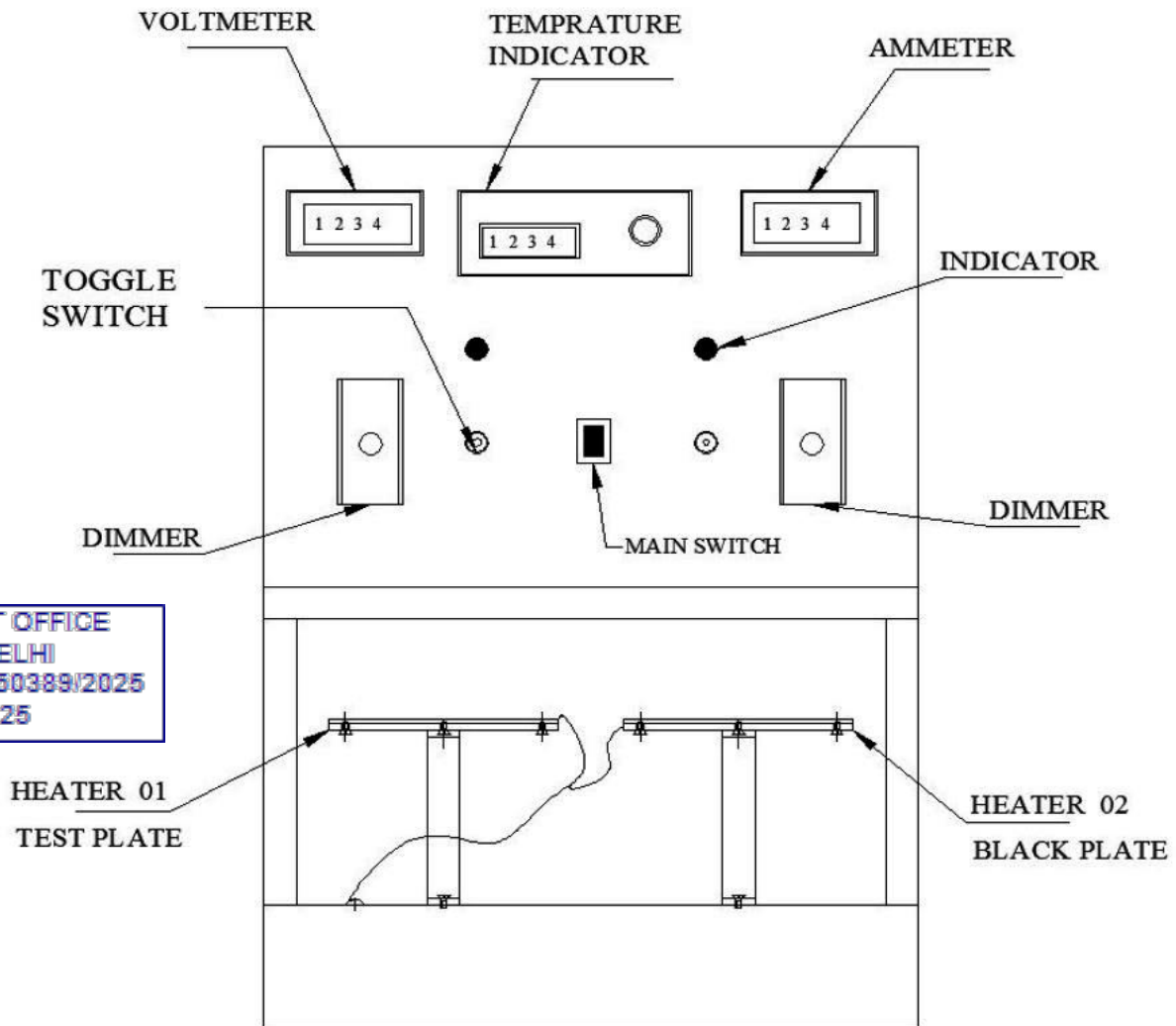


Actual Apparatus Image



- (1) *Black Plate Heater*, (2) *Black Plate*, (3) *Enclosure*, (4) *Test plate*, (5) *Test Plate Heater*





## 6. Procedure:

- 1) Switch on the mains.
- 2) Switch on the heater to the black body and adjust the power Input to the heater to a suitable value using regulator.
- 3) Switch on the heater to the test plate (Grey body) and keep the power input to a value less than that input to the black body.
- 4) Observe temperatures of the black body and test surface in close time intervals and adjust power input to the test plate heater such that both black body and test surface temperatures are same. This procedure requires trial and error method and one has to Wait Sufficiently long (one hour or longer) to reach a steady state.
- 5) After attaining steady state, record input powers to heaters by switch off any one regulator (and  $W_s$ ) and temperatures  $T_1, T_2$  and  $T_3$  ( $^{\circ}C$ ) of black body, test plate and the

sure

; the above measurements, calculate the emissivity of the test Surface using the procedure given below.



## 7. Specifications:

| Sr. | Component                   | Specification   |
|-----|-----------------------------|---|
| 01  | Diameter of Test Plate (d)  | 0.18 m Material Aluminum  |
| 02  | Diameter of Black Plate (d) | 0.18 m  |
| 03  | Thickness of the Plates (t) | 0.006 m   |
| 04  | Heater                      | Nichrome strip wound on mica sheet                                    |
| 05  | Dimmerstat for (1)          | 0 – 2A, 0 – 260V, 1000 Watt   |
| 06  | Dimmerstat for (2)          | 0 – 2A, 0 – 260V, 1000 Watt   |
| 07  | Enclosure size              | 580mm x 300mm x 300mm approximately<br>with one side of Acrylic sheet |
| 08  | Thermocouples               | Cromel-Alumel – (3Nos)  |
| 09  | Temperature indicator       | 0 – 300 °C  |
| 10  | Surface Area of Plates      | 0.054285 m <sup>2</sup>   |

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## 8. Observation Table:

| Sr.<br>No. | BLACK PLATE    |                |                | TEST PLATE     |                |                | ENCLOSURE TEMP.   |
|------------|----------------|----------------|----------------|----------------|----------------|----------------|-------------------|
|            | V <sub>1</sub> | I <sub>1</sub> | T <sub>b</sub> | V <sub>2</sub> | I <sub>2</sub> | T <sub>s</sub> | T <sub>a</sub> °C |
|            |                |                |                |                |                |                |                   |

### For SI Unit:

$$(W_b - W_s) = (E_b - E_s) A \varepsilon \sigma (T_s^4 - T_b^4)$$

Where,

$$\sigma = 5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$$

E = Emissivity of specimen to be determined (absorption)

## 9. Calculations:

$$(W_b - W_s) = (E_b - E_s) A \varepsilon \sigma (T_s^4 - T_b^4)$$



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**10. Precaution:**

1. Use stabilized A. C single-phase supply (preferably).
2. Always keep the dimmer stat at zero position before start.
3. Use the proper voltage range on VOLTMETER.
4. Gradually increase the heater inputs.
5. Operate selector switch of temperature indicator gently.

There is a possibility of getting absurd results if the supply voltage is fluctuating or if the input is not adjusted till the satisfactory steady state condition reached.

**11. Conclusion:-**

Emissivity of non black test plate surface is found out to be -----

**Exercise:-**

1. How do you calculate surface emissivity?
2. How does emissivity affect surface temperature?
3. Is emissivity a surface property?
4. What is the emissivity of the earth surface?
5. How is emissivity of a plate calculated?
6. What factors affect emissivity?
7. What is the emissivity of glass?
8. Which of the following has the highest emissivity?
9. Which object can be used as a radiation shield?
10. What is the value of emissivity for polished copper?
11. What is emissivity measured in?
12. Does color affect emissivity?
13. Does emissivity change with thickness?
14. Is surface emissivity intensive or extensive?
15. Do metals have high emissivity?

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## Experiment No: 06

**1. Aim:** Determination of Stefan Boltzmann Constant.

### 2. Objectives:

Other types of bodies (like a glossy painted surface or a polished metal plate) do not radiate as much energy as the black body but still the total radiation emitted generally follows temperature proportionality.

### 3. Apparatus:

The apparatus, as illustrated is centered 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 some suitable constant temperature. The hemispherical of B is chosen solely on the grounds that it simplifies the task of water between B & C. Four chromel alumel thermocouple are attached to various points on surface of B to measure its mean temperature.

A disk D, which is mounted in an insulating Bakelite sleeve S is fitted in hole drilled in the center of based plate A. The of S is conveniently supported for underside of A.

A chromel alumel thermocouple is used to measure the temperature of D ( $T_5$ ). Thermocouple is mounted on the disk to study the rise of its temperature. When the disk is inserted at the temperature  $T_5$  ( $T_5 > T$ ) i.e the temperature of the enclosure), the response of the temperature change of this with time is used to calculate the Stefan Boltzmann constant.

### 4. Theory:

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

$$Q = e b A = \sigma T^4 \text{ (kcal / hr.m}^2 \text{. k}^4 \text{) and SI unit (W/m}^2 \text{k}^4 \text{ where 1 W = 1 J/S)}$$

The constant of proportionality  $\sigma$  is called the Stefan Boltzmann Constant and has the value of:  $4.876 \times 10^{-8}$  (kcal / hr.m<sup>2</sup>. K<sup>4</sup>) and SI unit ( $5.67 \times 10^{-8}$  W/m<sup>2</sup> K<sup>4</sup>).

The Stefan Boltzmann law can be derive by integrating the planks law over the entire spectrum of wave length, through historically it is worth nothing that the Stefan Boltzmann law was independently developed before planks law.

The object of this experimental set up is to measure the value of this constant fairly close, by an easy arrangement.



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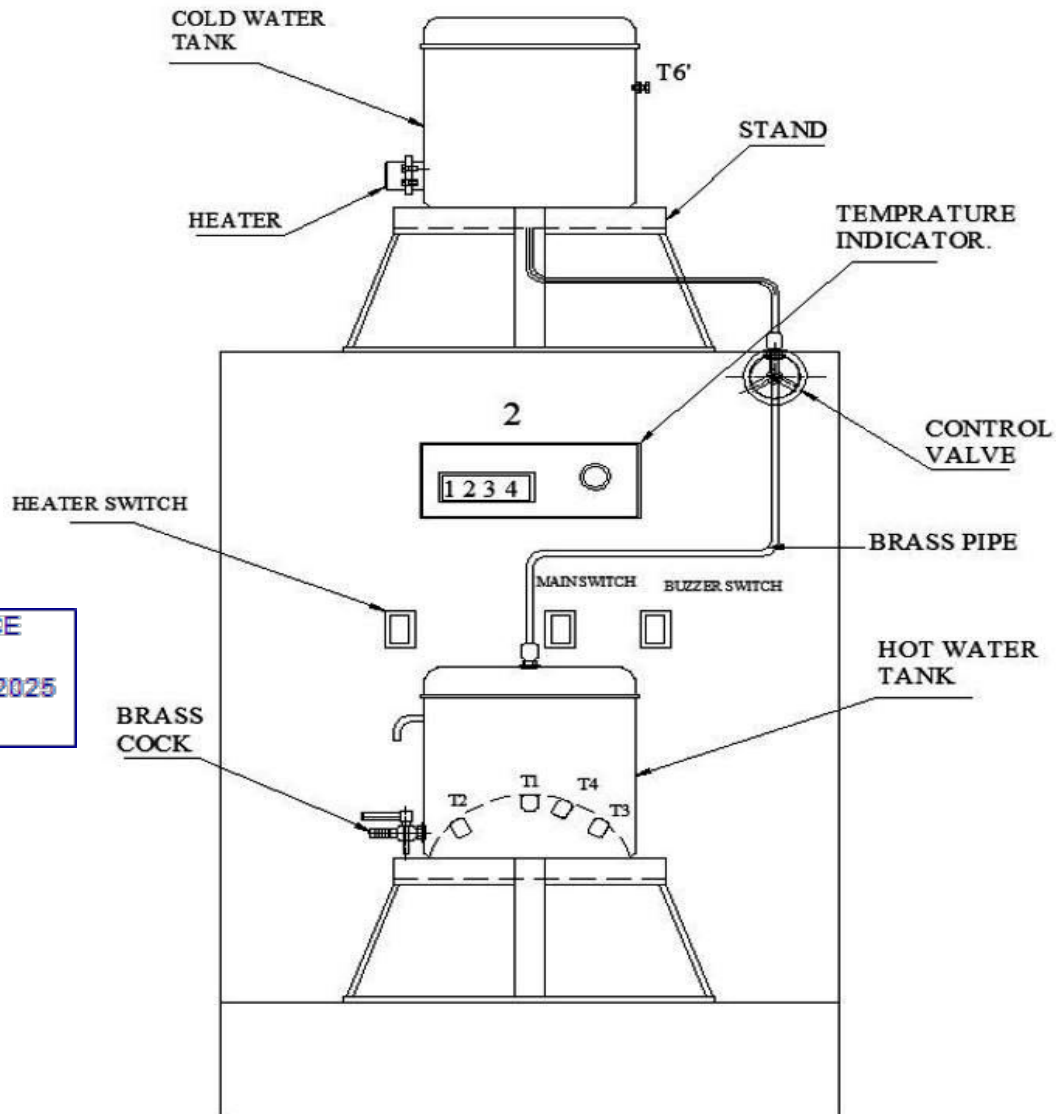
### 5. Schematic Diagram:



Actual Apparatus Image



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## 6. Procedure:

1. Switch- ON the Main and the Console.
2. Remove the disc (d) or test piece and Switch-ON the Water Heater.
3. After water attains the maximum temperature, open the valve and dump the water to the enclosure jacket.
4. Wait for about few seconds to allow hemispherical enclosure to attain uniform temperature the enclosure will soon reach thermal equilibrium.
5. Measure the enclosure temperature  $T_1$  to  $T_4$  using Channel Selector and digital temperature indicator.
6. Insert the disc (d) with the sleeve into its position and record the temperature of the disc ( $T_5$ ) at different instants of time using stop watch.

Plot the variation of disc temperature ( $T_5$ ) with time (sec) as shown and get the slope of temperature versus time variation .

Calculate the Stefan Boltzmann's constant.



**7. Specification:**

| Sr. | Component                                    | Specification                     |
|-----|--|-----------------------------------|
| 01  | Hemisphere Diameter                          | 0.205 m                           |
| 02  | Base Bakelite Plate                          | 0.05 m                            |
| 03  | Test disc diameter                           | 0.44 m                            |
| 04  | Thickness of Test Disc                       | 0.003 m                           |
| 05  | Thermocouple on Hemisphere                   | 4 Nos.                            |
| 06  | Water tank of Capacity with immersion heater | 8 Litre                           |
| 07  | Thermocouple on test disc                    | 1 No.                             |
| 08  | Temperature indicator                        | 0-300 °C                          |
| 09  | Diameter of the test disc (d)                | 0.0195                            |
| 10  | Mass of the test disc (m)                    | 0.0076 kg                         |
| 11  | Specific heat of test disc (Brass) ( $C_p$ ) | 877 J/kg °K                       |
| 12  | Area of Test Disc ( $A_d$ )                  | $2.98 \times 10^{-4} \text{ m}^2$ |

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**8. Observations:**

| Water temperature T 6 | T 1 | T 2 | T 3 | T 4 |
|-----------------------|-----|-----|-----|-----|
|                       |     |     |     |     |

|             |     |     |     |     |     |     |     |     |     |     |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Time in Sec | 10  | 20  | 30  | 40  | 50  | 60  | 70  | 80  | 90  | 100 |
| T5          |     |     |     |     |     |     |     |     |     |     |
| Time in Sec | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
| T5          |     |     |     |     |     |     |     |     |     |     |



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**8. Calculations:**

Where,

$$\sigma = \frac{m C_p (dT_s/dt)_{t=0}}{A_D (T_e^4 - T_s^4)}$$

$m$  = mass of the test specimen = 0.0047Kg

$C_p$  = Specific heat of the specimen = 410 J/Kg °C

$T_e$  = Enclosure temperature, °K

$T_s$  = Initial temperature of the specimen, °K

$(dT_s/dt)$  = calculated from graph.

$A_D$  = Surface area of the test specimen

$$= \pi d^2/4$$

where  $d = 0.015m$

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**9. Precaution:**

1. Use stabilized A. C single-phase supply (preferably).
2. Always keep the dimmer stat at zero position before start.
3. Use the proper voltage range on VOLTMETER.
4. Gradually increase the heater inputs.
5. Operate selector switch of temperature indicator gently.

There is a possibility of getting absurd results if the supply voltage is fluctuating or if the input is not adjusted till the satisfactory steady state condition reached.

**10. Conclusion:**

Stefan Boltzman's constant is \_\_\_\_\_.

**Exercise:**

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1. What does the Stefan-Boltzmann law tell us?
2. How does Stefan's law depend on temperature?
3. What is the significance of the Stefan Boltzmann law when applied to the sun versus the earth atmosphere system?
4. What are black body and white body? Why does black body radiation occur?
5. What is the significance of Stefan's constant?
6. What are applications of the Stefan-Boltzmann law?
7. What is a diffuse gray surface?
8. Why is the Stefan-Boltzmann law so helpful for tracking climate change?
9. Why do all objects emit radiation?
10. Does temperature affect wavelength of light?
11. Does radiation increase temperature?
12. How does temperature affect the radiation emitted by an object?
13. Does wavelength increase or decrease with temperature?
14. Does density affect radiation?
15. How does wavelength affect radiation?



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## Experiment No: 07

**1. Aim:** Study of Pool boiling phenomenon and determination of Critical Heat Flux (CHF).

### 2. Objectives:

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

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

### 3. Apparatus:

Test heater is connected also to mains via a dimmer. An ammeter is connected in series while a voltmeter across it to read the current and voltage. The glass container is kept on a stand, which is fixed on a metallic platform. There is provision of illuminating the test heater wire with the help of a lamp projecting light from back and the heater wire can be viewed through a lens.

This experimental set up is designed to study the pool-boiling phenomenon up to critical heat flux point. The pool boiling over the heater wire can be visualized in the different regions up to the critical heat flux point at which the wire melts. The heat flux from the wire is slowly increased by gradually increasing the applied voltage across the test wire and the change over from natural convection to nucleate boiling can be seen.

The formation of bubbles and their growth in size and number can be visualized followed by the vigorous bubble formation and their immediate carrying over to surface and ending this in the braking of wire indicating the occurrence of critical heat flux point.

### 4. Theory:

The heat flux supplied to the surface is plotted against  $(T_w - T_s)$  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:

1. Natural Convection Region
2. Nucleate Boiling Region
3. Film Boiling Region

The region of natural convection occurs at low temperature differences (of the order of 10 °C or less). Heat transfer from the heated surface to a liquid in its vicinity causes the liquid to be superheated.

The superheated liquid rises to the free liquid surface by natural convection, where vapour is produced by evaporation. As the temperature difference  $(T_w - T_s)$  is increased, nucleate boiling starts. In this region, it is observed that bubbles start to form at certain locations on the heated surface.

Region II consists of two parts. In the first part, II – a, the bubbles formed are very few in number. They condense in the liquid and do not reach the free surface.

In the second part, II – b, the rate of bubbles formation and the number of locations where they are formed increase. Some of the bubbles now rise all the way to the free surface.



With increasing temperature difference, a stage is finally reached when the rate of formation of bubbles is so high, that they start to coalesce and blanket the surface with a vapour film.

This is the beginning of the region III viz film boiling. In the first part of this region III-a, the vapour film is unstable, so that the film boiling may be occurring on a portion of the heated surface area, while nucleate boiling may be occurring on the remaining area. In the second part, III-b, a stable film covers the entire surface. The temperature difference in this region is of the order of  $1000^{\circ}\text{C}$  and consequently radiative heat transfer across the vapour film is also significant.

It will be observed that the heat flux does not increase in a regular manner with the temperature difference. In region I, the heat flux is proportional to  $(T_w - T_s)^n$ , where 'n' is slightly greater than unity. 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. Beyond this, in the region II-A, in spite of increasing temperature difference, the heat flow increases with the formation of a vapour film.

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The heat flux passes through a minimum at the end of region III-a. It starts to increase  $(T_w - T_s)$  only when stable film boiling begins and radiation becomes increasingly important. It is of interest to note how the temperature of the heating surface changes as the heat flux is steadily increased from zero.

Up to point A, natural convection boiling and nucleate boiling occur and the temperature of the heating surface is obtained by reading off the value of  $(T_w - T_s)$  from the boiling curve and adding to it the value of  $T_s$ . If the heat flux is increased even a little beyond the value of A, the temperature of the surface will shoot up to the value corresponding to the point C. it is apparent from figure 1 that the surface temperature corresponding to point C is high.

For most surfaces, it is high enough to cause the material to melt. Thus in most practical situations, it is undesirable to exceed the value of heat flux corresponding to point A. This value is therefore of considerable engineering significance and is called the critical or peak heat flux. The pool-boiling curve as described above is known as Nukiyam pool Boiling Curve.

The discussions so far has been concerned with the various type of boiling which occur in saturated pool boiling. If the liquid is below the saturation temperature we say that sub-cooled pool boiling is taking place. Also in many practical situations, e.g. steam generators; one is interested in boiling in a liquid flowing through tubes. This is called forced convection boiling, may also be saturated or sub-cooled and of the nucleate or film type.

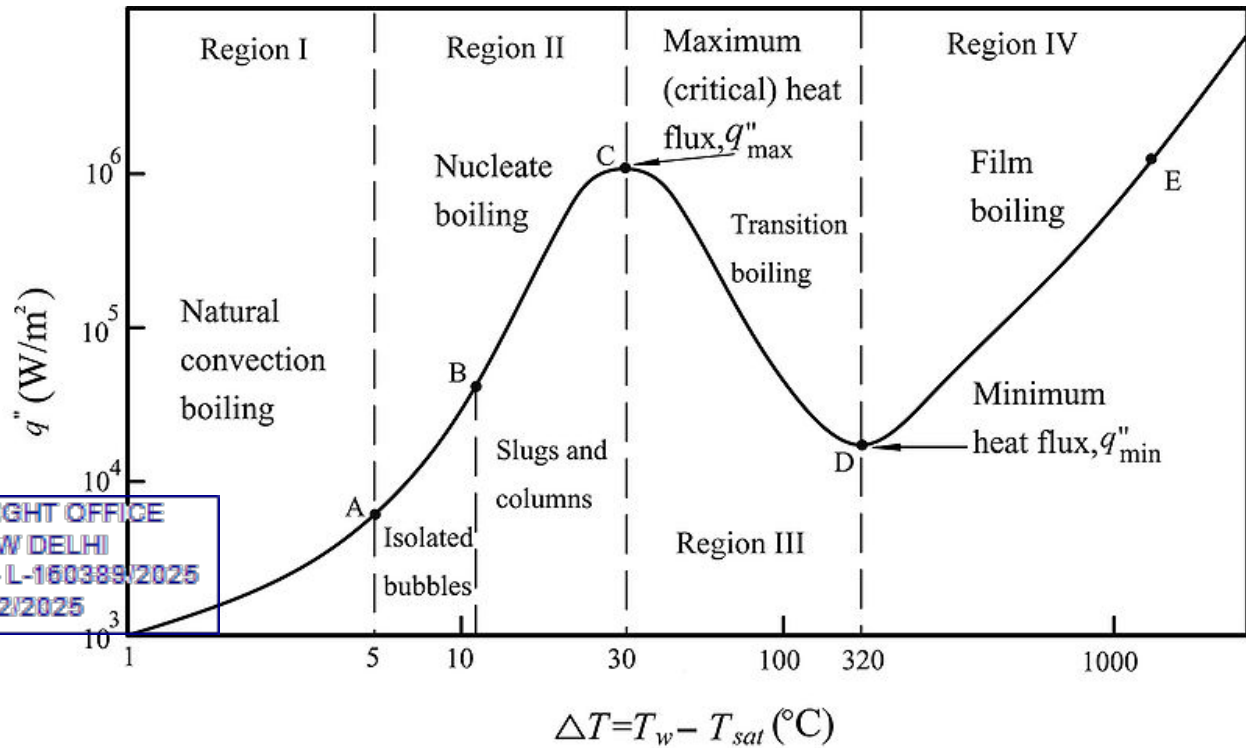
Thus in order to completely specify boiling occurring in any process, one must state.

- i. Whether it is forced convection boiling or pool boiling,
- ii. Whether the liquid is saturated or sub cooled, and
- iii. Whether it is in the natural convection nucleate or film boiling region.



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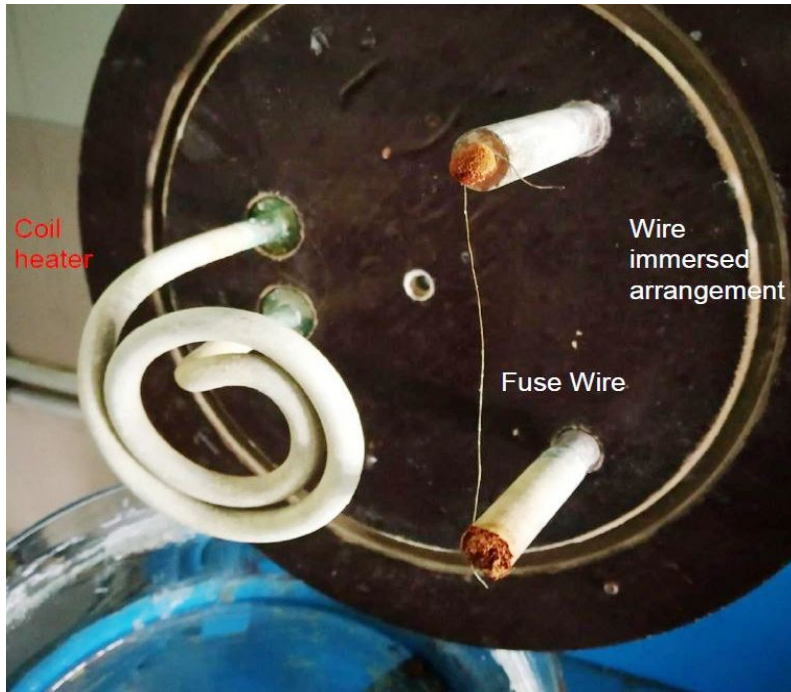
### 5. Diagram (Pool Boiling):



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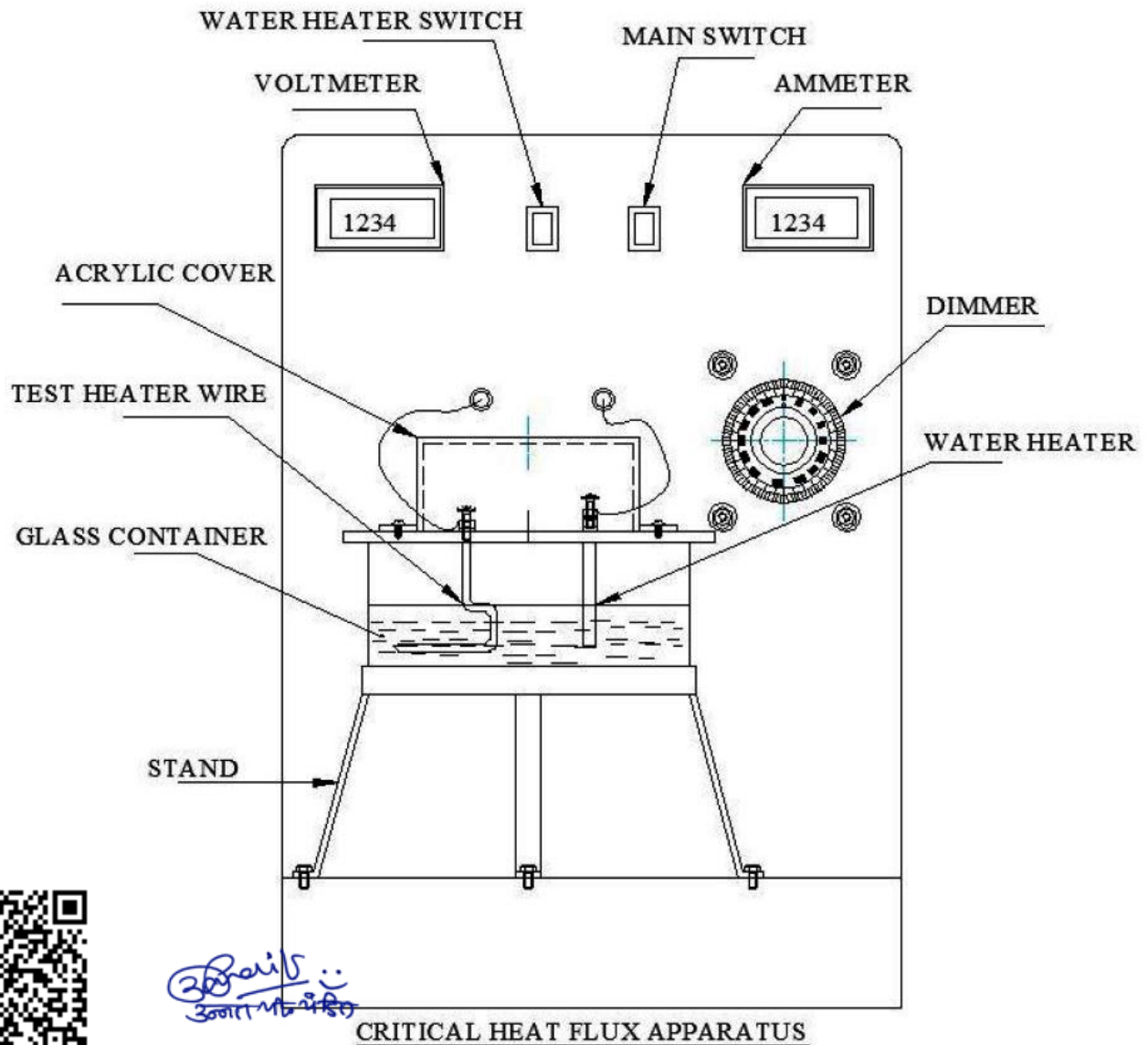
### 5.1 Schematic Diagram (Setup):





Actual Apparatus Image

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**6. Procedure:**

1. Fill the tank with water.
2. Dip the Nichrome wire into the water and make the electrical connections.
3. Note the current reading in steps of 1 amp till a maximum current of 10 ampere.
4. Between each reading the time interval of two min is allowed for steady state to establish.
5. Water temperature is noted with a temperature indicator at the beginning and the end of the experiment.
6. The average of these two is taken as the bulk liquid average temperature.
7. Note down the power and temperatures from the indicators.

**7. Specifications:**

| Sr. | Component                      | Specification                  |
|-----|--------------------------------|--------------------------------|
| 01  | Glass Container                | Diameter 250mm & Height 100 mm |
| 02  | Length of the Test Heater Wire | 100 mm                         |
| 03  | Temperature indicator          | 0-300 °C                       |
| 04  | Ammeter                        | 0-5A                           |
| 05  | Voltmeter                      | 0-300 V                        |
| 06  | Dimmerstat                     | 1000 watt                      |
| 07  | Heater (for Water Heating)     | Coil Nichrome type             |

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**8. Observations:**

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

| Sr. No. | Water / Bulk Temp T in °C | Voltage (V) | Ampere (I) |
|---------|---------------------------|-------------|------------|
| 1       |                           |             |            |
| 2       |                           |             |            |

**9. Calculation:**

Q = Heater power in Watts

$Q = V \times I$  (Watts)



Critical heat flux in  $w / m^2$

$\frac{Q}{A}$

## 10. Conclusion:

Heater wire in different regions up to the critical heat flux point at which the wire melts is found out to be -----

## Exercises:

1. What is the critical heat flux in boiling heat transfer process?
2. Why does critical heat flux increase with pressure?
3. What is critical heat flux apparatus? Why it is flux important?
4. Why is it called critical heat flux?
5. What is beyond the critical heat flux region?
6. What is critical radius of insulation?
7. What is transition boiling & film boiling?
8. What is departure from nucleate boiling?
9. What is the difference between sub cooled and saturated boiling?
10. What is nucleation site in boiling?
11. What are the three types of boiling?
12. What is sub cooled water? Why is sub cooling beneficial?
13. What phase change is the opposite of freezing?
14. Why slow heating is required for sublimation?
15. What is sublimation critical point?

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## Experiment No: 08

**1. Aim:** Determination of heat transfer, overall heat transfer coefficient and effectiveness of Gasketed Plate Heat Exchanger.

**2. Objectives:**

To study following,

- a. Study of Gasketed Plate Heat Exchanger
- b. To Study & verify LMTD method
- c. To find out the Heat transfer Rate, Heat transfer Coefficient

**3. Technical Description:**

Heat exchangers are devices used to transfer heat energy from one fluid to another. A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. In heat exchangers, there are usually no moving parts and work interactions. Heat exchangers are broadly classified on the basis of construction as:-

1. Tubular
2. Plate Type
3. Extended Surface
4. Regenerative

Plate Type Heat Exchangers are broadly classified into PHE, Spiral, Plate Coil and Printed Circuit. The PHE is further classified into Gasketed, Welded and Brazed on the basis of sealing. The corrugations on successive plates contact or cross each other to provide mechanical support to the plate pack through a large number of contact points. The resulting flow passages are narrow, highly interrupted, and tortuous, and enhance the heat transfer rate and decrease fouling resistance by increasing the shear stress, producing secondary flow, and increasing the level of turbulence. The corrugations also improve the rigidity of the plates and form the desired plate spacing. Plates are designated as hard or soft, depending on whether they generate a high or low intensity of turbulence. There are several plate patterns available for PHE as washboard, zigzag, chevron or herringbone, protrusions and depressions, washboard with secondary corrugations and oblique washboard

The set-up consists of a Gasketed Plate Heat Exchanger with hot water and Cold water IN/OUT provision. Temperature tapping are provided in the test Heat Exchanger to measure the temperature change with the help of PT100 temperature sensors. Present set-up is self-contained hot water re-circulating unit & cold water re-circulating unit provided with tank and a centrifugal pump etc. Flow measuring unit (rotameter) are fitted in flow of both side line to conduct the experiment on different flow rates.

**4. Requirement for Operation:**

Electricity Supply: Single Phase, 220V AC, 50Hz.

Water Supply (Initial Fill).

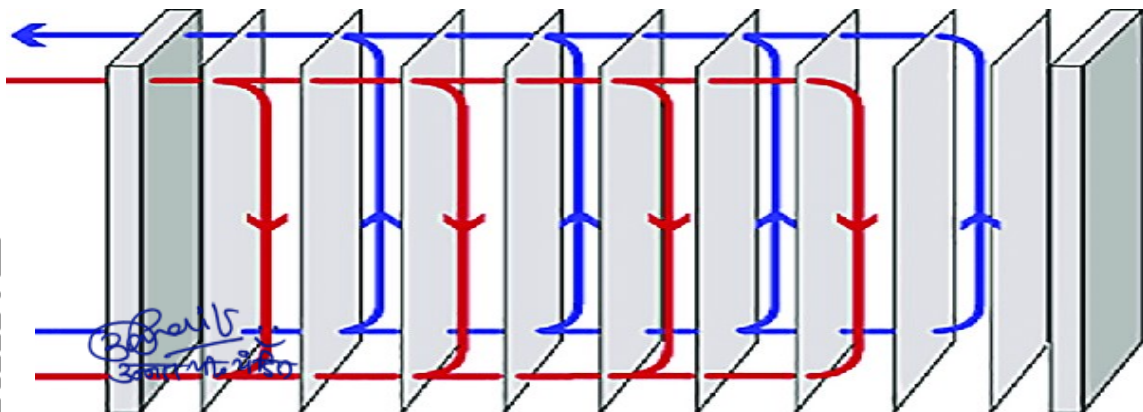
Room Area required: 1.5 m x 0.75 m



### 5. Diagrams



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## 6. Technical Specification:

- Test Section: Gasketed Plate Heat Exchanger with 11 Nos. of Plates inside
- Water Circulation: 0.5 HP FHP Pump, Laxmi make.
- Flow Measurement: Using Rotameter 0-2000LPM
- Hot water Tank: Capacity 50 Ltrs.
- Cold water Tank: Capacity 175 Ltrs.
- Pipe Size for Hot & Cold Water flow =  $\frac{3}{4}$  Inch

### Control Panel Comprises of:

Standard make On/Off Switches Mains Indicator Temperature Scanner, Temperature controller, MCB etc.

**Specifications Table**

| Parameter                         | Specifications     | Parameter                                | Specifications     |
|-----------------------------------|--------------------|--|--------------------|
| Type of Heat Exchanger            | Gasketed Plate HEX | Pipe Size used                           | $\frac{3}{4}$ inch |
| Capacity of HEX                   | 1100LPH            | Type of Fluid                            | Water              |
| Number of Plates & its Material   | 11 & S.S           | Hot Water Tank Capacity in liters        | 50                 |
| Material of Gasket used           | Nitrile            | Colour indication of pipe for Hot Fluid  | Red                |
| Heat transfer Area in $m^2$       | 0.55               | Cold Water Tank Capacity in liters       | 175                |
| Design Pressure in Bar            | 7                  | Colour indication of pipe for Cold Fluid | Blue               |
| Test Pressure in Bar              | 6                  | Cold Water In & Out Temp                 | T1 & T2 Resp.      |
| Design Temperature in $^{\circ}C$ | 90                 | Hot Water In & Out Temp                  | T1 & T2 Resp.      |

## 7. LMTD Method:

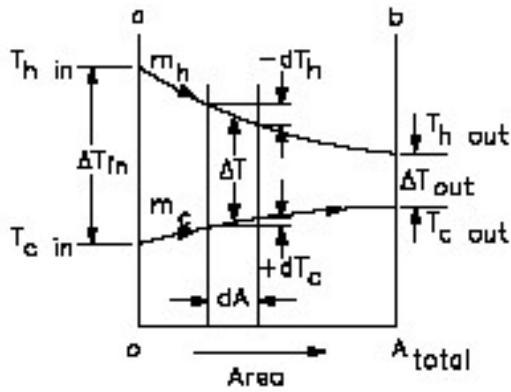
One of the fundamental assumptions adopted in the derivation of the LMTD method is that the fluid specific heats are constant and the fluid temperature variations only result from heat exchange.. It is convenient to use the LMTD method when the fluid inlet and outlet temperatures are known. The logarithmic mean temperature difference (also known as log mean temperature difference, LMTD) is used to determine the temperature driving force for heat transfer in flow systems, most notably in heat exchangers.

The log mean temperature difference is defined as the logarithmic mean of the temperature difference of the inlet and outlet of the heat exchanger.

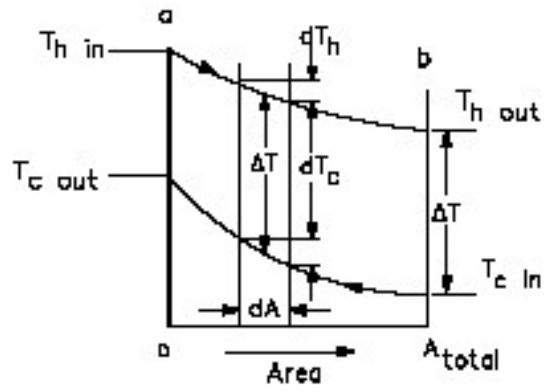
LMTD is used because the temperature profile for the change in temperature across the of the heat exchanger increases or decreases exponentially.



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Temperature Distribution in Parallel Flow Heat Exchanger



Temperature Distribution in Counter-Flow Heat Exchanger

8. Observation Table:

Cold Side Observation Table:

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| Cooling water Inlet Temp, oC | Cooling water Outlet Temp, 0C | Flow rate of cooling water, LPM | Mass flow rate of cooling water, m Kg/S | Specific Heat, Cp, KJ/kgC | Heat Transfer Rate KW |
|------------------------------|-------------------------------|---------------------------------|---|---------------------------|-----------------------|
|                              |                               |                                 |   |                           |                       |
|                              |                               |                                 |   |                           |                       |
|                              |                               |                                 |   |                           |                       |
|                              |                               |                                 |   |                           |                       |

Hot Side Observation Table:

| Hot water Inlet Temp, °C | Hot water Outlet Temp, °C | Flow rate of Hot water, LPM | Mass flow rate of Hot water, m Kg/S | Specific Heat, Cp, KJ/kgC | Heat Transfer Rate, kW |
|--------------------------|---------------------------|-----------------------------|-------------------------------------|---------------------------|------------------------|
|                          |                           |                             |                                     |                           |                        |
|                          |                           |                             |                                     |                           |                        |
|                          |                           |                             |                                     |                           |                        |
|                          |                           |                             |                                     |                           |                        |



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**Calculations: For Reading No.01**

1.  $\Delta T_1 = Th_i - Tc_o =$
2.  $\Delta T_2 = Th_o - Tc_i =$
3.  $LMTD = \Delta T_1 - \Delta T_2 / \ln (\Delta T_1 / \Delta T_2) =$
4. Surface Area A,  $m^2 =$
5. Q, Heat Transfer KW =  $(Q_{cold} + Q_{Hot}) / 2 * 1000 =$  \_\_\_\_\_ KW
6. Overall Heat Transfer Rate,  $U = Q / (A * LMTD) =$  \_\_\_\_\_  $W/m^2K$

**Calculations: For Reading No.02**

1.  $\Delta T_1 = Th_i - Tc_o =$
2.  $\Delta T_2 = Th_o - Tc_i =$
3.  $LMTD = \Delta T_1 - \Delta T_2 / \ln (\Delta T_1 / \Delta T_2) =$
4. Surface Area A,  $m^2 =$
5. Q, Heat Transfer KW =  $(Q_{cold} + Q_{Hot}) / 2 * 1000 =$  \_\_\_\_\_ KW
6. Overall Heat Transfer Rate,  $U = Q / (A * LMTD) =$  \_\_\_\_\_  $W/m^2K$

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**Calculations: For Reading No.03**

1.  $\Delta T_1 = Th_i - Tc_o =$
2.  $\Delta T_2 = Th_o - Tc_i =$
3.  $LMTD = \Delta T_1 - \Delta T_2 / \ln (\Delta T_1 / \Delta T_2) =$
4. Surface Area A,  $m^2 =$
5. Q, Heat Transfer KW =  $(Q_{cold} + Q_{Hot}) / 2 * 1000 =$  \_\_\_\_\_ KW
6. Overall Heat Transfer Rate,  $U = Q / (A * LMTD) =$  \_\_\_\_\_  $W/m^2K$

**Prepare Result Table:**

**Result Table**

| $\Delta T_1$ | $\Delta T_2$ | LMTD | Surface Area A, $m^2$ | Q, Heat Transfer KW | Overall Heat Transfer Rate, U |
|--------------|--------------|------|-----------------------|---------------------|-------------------------------|
|              |              |      |                       |                     |                               |
|              |              |      |                       |                     |                               |
|              |              |      |                       |                     |                               |
|              |              |      |                       |                     |                               |



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## 9. Conclusion:

Hence we calculated overall heat transfer rate by using LMTD method for Gasketed Plate type Heat Exchanger.

### Exercise:

1. What is the driving force for heat transfer in a heat exchanger?
2. Why does pressure drop in heat exchanger?
3. How does pressure drop affect heat exchangers?
4. What causes pressure drop in heat exchanger?
5. How does flow rate affect heat exchanger? Does pressure affect heat exchanger performance?
6. What is fouling factor?

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