# HEAT TRANSFER AND SOLAR ENERGY LABORATORY

**Class:** A3MA **Section:** A **S. No.** 05

**Course Title** : **Heat and Mass Transfer Laboratory**

**Course Number** : **MEC 3910**

**Experiment (Brief Title):** Calibration

Date of Experiment Performed : 14/08/24
Due date of Submission : 21/08/24
Late Submission date :

Teachers' Remark :

Marks Awarded :

| Rubric No. | I | II | III | IV | V | Total |
|---|---|---|---|---|---|---|
| Maximum Marks | 1 | 1 | 2 | 3 | 3 | 10 |
| Marks awarded | 1 | 1 | 2 | 2.5 | 1.5 | 8.0 |

Rubrics for laboratory courses

I. Object of the experiment and specifications of the equipment/instruments used.
II. Brief theory and related equations used
III. Observation Sheets, Sample calculations (student should explain at the time of evaluation)
IV. Results mathematical/graphical (student should explain at the time of evaluation)
V. Discussions (should be different from other students)

Name : Nikhil Singh
Class : A3MA
S. No. : 05
Faculty No. : 22MEB173
En. Roll. No. : GL6695

# HEAT TRANSFER AND SOLAR ENERGY LABORATORY
# DEPARTMENT OF MECHANICAL ENGINEERING, AMU, ALIGARH

## CALIBRATION

***Object:*** Calibration of temperature indicator and thermocouples

***Introduction:***

Thermocouple, a transducer based on Seebeck effect is the most common and widely used device for temperature measurement. It is a self generating transducer and is basically a pair of dissimilar metallic conductors joined to produce an e.m.f. when the two junctions are kept at different temperature. The magnitude of e.m.f. depends upon the magnitude of the temperature difference and the material combination.

Thermocouples are low in cost, reliable in service, are easily used over a wide range of temperature measurement and have very good response characteristics.

The apparatus consists of a temperature indicator (digital type, least count of 1mV with dial range 0-10/0-30 mV), an ice bath, hot bath and a panel for connecting thermocouple etc.

***Procedure:***

1. Connect the copper metal wire to common binding post '+C' and the constant metal wire to binding post No. 1 or No. 2.
2. Keep the channel selector switch $SW_4$ on 1st position or second position depending upon the couple connection.
3. Now switch on ($SW_1$ and $SW_2$) heater and temperature indicator supply and keep it on for about 10-15 minutes in order to allow warming up time for the circuit.
4. Keep the ice-bath and boiling water ready for use.
5. Immerse the thermocouple in ice-bath at 0°C by proper stirring and check it by thermometer. Get zero reading on digital temperature indicator by means of potentiometer marked minimum.
6. Now the same thermocouple bead should be immersed in the boiling water. Note that the thermocouple should not touch the water container. Adjust the corresponding boiling water temperature by means of potentiometer marked max. This finishes rough calibration.
7. Repeat steps 5 and 6 until you get consistent results as per thermometer.
8. After completing this procedure switch over to other channels and see that the same response is obtained.
9. Check that you are getting steady indication for all these procedures. Any loose connection will give unsteady and violent deflections. When you check for channel selectors, switch on $SW_4$ also.
10. Follow the same procedure for calibration of the thermocouple.

***Precautions:***

1. Operate all the switches gently.
2. Connect the thermocouple wires properly at binding posts.
3. Do not switch on supply to the millivoltmeter or temperature indicator without connecting the thermocouple.
4. The ice in the bath should be in small crystal form

***Basic Elements of a Thermoelectric Circuitry:***

The usual thermocouple circuit, however, includes measuring junctions, thermocouple extension wires, reference junctions, copper connecting wires, a selector switch and a potentiometer.

***Thermopile:***

More than one thermocouple is used in series for sensing small temperature differences. It magnifies thermoelectric power by the number of thermocouples in series, enabling the deflection of small changes in temperature level, one observation gives, by calibration, the arithmetic means of temperatures sensed by N individual measuring junctions, when total e.m.f. is divided by N.

***Different sets of thermocouples:***

Some of the thermocouple pairs are as follows:

| *S. No.* | *Thermocouple pairs* | *Type* | *Temperature ranges (°C)* |
|---|---|---|---|
| *1* | *Chromel-Constantan* | *Type-E* | *-10 to 980* |
| *2* | *Iron-Constantan* | *Type-J* | *-180 to 760* |
| *3* | *Chromel-Alumel* | *Type-K* | *-10 to 1370* |
| *4* | *Copper-Constantan* | *Type-T* | *-180 to 390* |
| *5* | *Platinum-13% Rhodium & Platinum* | *Type-R* | *-0 to 1640* |
| *6* | *Platinum – 15% Rhodium & Platinum* | *Type-S* | *-0 to 1640* |

Name..Nikhil Singh.....Class..A3MA.....S.No.....05.....Date:..14/08/24

***Observation Table:***

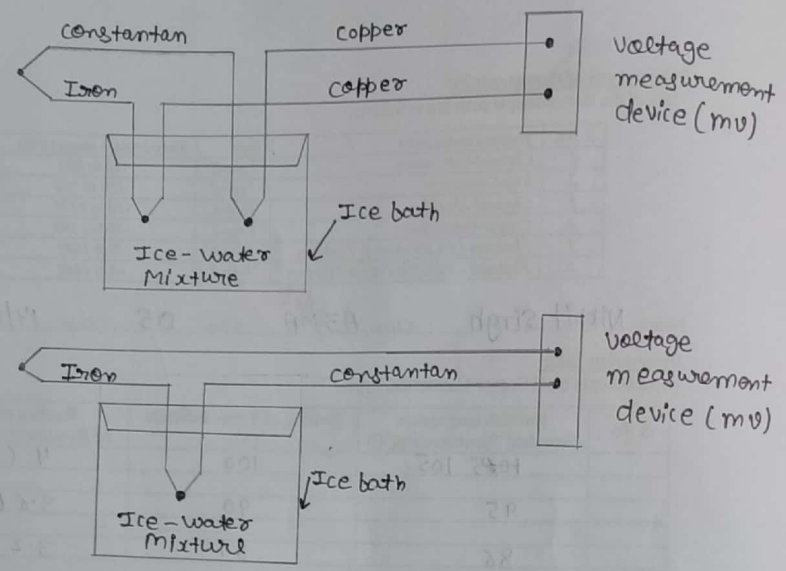
Thermocouple type: Copper-Constantan, Type – T

| S.No. | Hot bath temperature (Standard Thermometer) (°C) | Reading of Temp. Indicator (°C) | Reading of Millivoltmeter (mV) |
|---|---|---|---|
| | ~~105~~ 105 | 100 | 4 (95°c) |
| | 95 | 90 | 3.6 (86°c) |
| | 86 | 80 | 3.2 (77°c) |
| | 76 | 70 | 3.0 (72°c) |
| | 66 | 60 | 2.8 (68°c) |
| | 55 | 50 | 2.4 (59°c) |
| | 45 | 40 | 2.0 (49°c) |
| | 36 | 30 | 1.6 (40°c) |
| | ~~25~~ | ~~20~~ | |

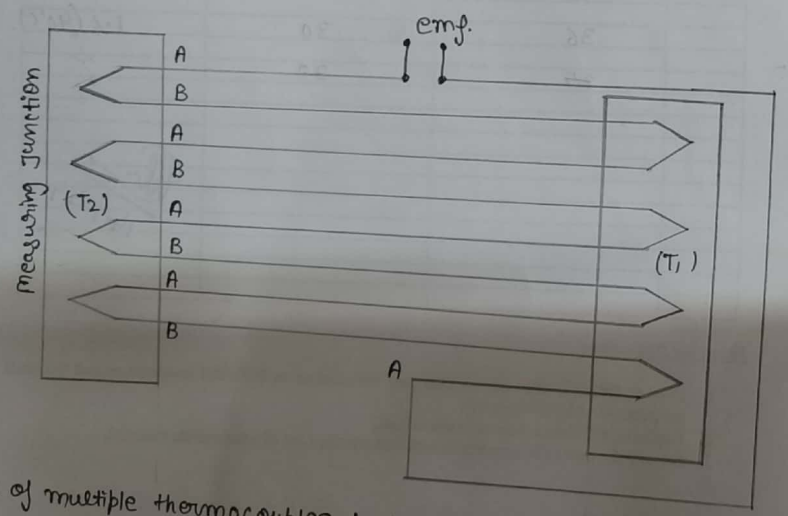
14.8.24

***Points for Discussion:***

1. Discuss the calibration curves (Standard temperature vs Indicated temperature and Standard temperature vs Millivoltmeter).
2. Explain the different thermoelectric effects.
3. Explain the Law of homogeneous materials and the Law of intermediate material.




Conventional methods for establishing reference temperature in thermocouple circuit



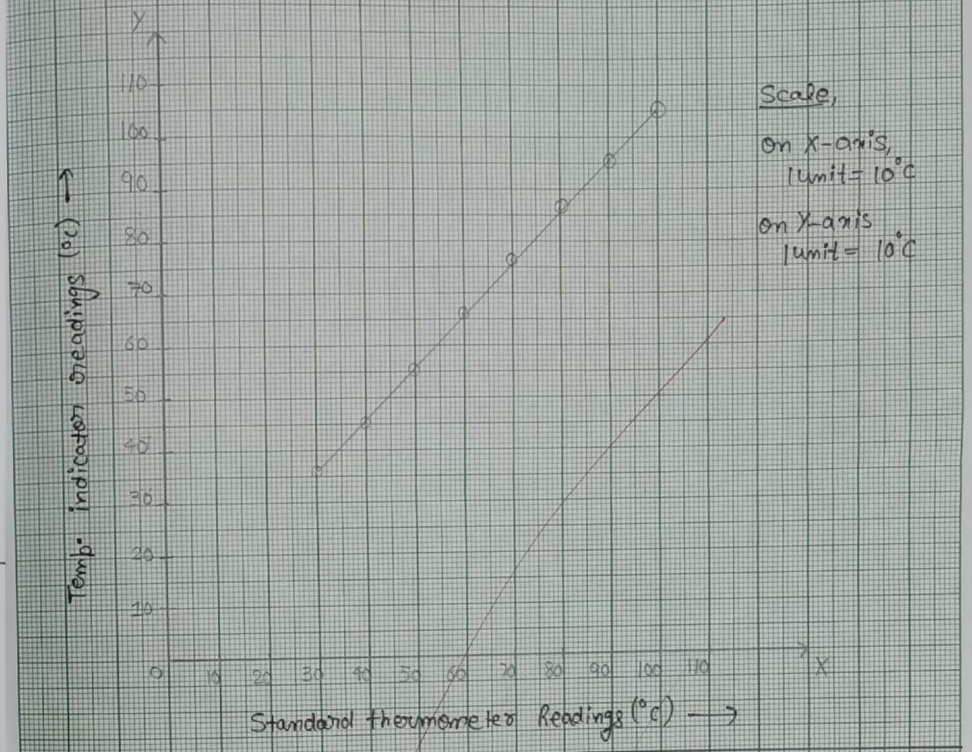

use of multiple thermocouples to increase the emf signal for small temperature differential measurements or to obtain average temperature.

Discussion:- 22MEB173 A3MA-05 GL6695

22MEB173 GL6695 A3MA-05

Q=1 Discuss the calibration curves.

(a) Standard Temp. V/s Indicated temperature




(b) Standard Temp. V/s millivoltmeter

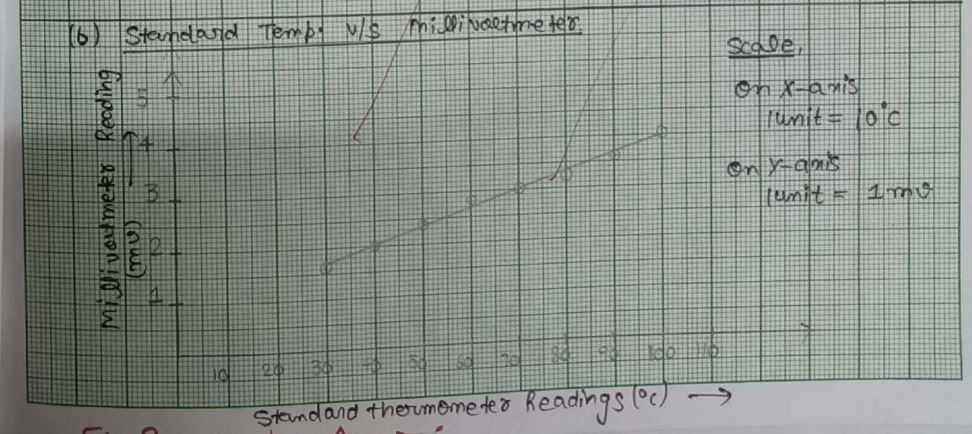



Fig. 2 Variation of ...

Discussion:- 22MEB173 A3MA-05 GL6695

2) Explain the different thermoelectric effects.

Thermoelectric effects involve the direct conversion of temperature differences to electric voltages & vice versa.

(i) Seebeck effect :- It occurs when a temperature gradient is applied across a material, causing a voltage diffence b/w two ends.

(ii) Peltier effect :- This is basically the reverse of seebeck effect, when an electric current flows through a junction of two different materials, it causes heat to be absorbed at one junction and released at other.

(iii) Thomson effect :- It occurs when an electric current flows through a single homogeneous material that has a temperature gradient.

Summary :-

Seebeck effect :- Temperature difference ⟶ Voltage

Peltier effect :- electric current ⟶ Heating or cooling

Thomson effect :- electric current in a temp. gradient ⟶ Heat absorption or emission

3) Explain the Law of homogeneous materials & Law of intermediate material.

⇒ <u>Law of Homogeneous materials</u>

"A thermoelectric effect cannot be produced in a circuit made entirely of a single homogeneous material, even if there is a temp. gradient present".

- Its principle related to the behaviour of thermo electric effects in materials
- This law highlights the need for material diversity in designing thermo electric devices.

⇒ <u>Law of Intermediate materials.</u>

It states that - "The insertion of an intermediate material into a thermoelectric circuit doesn't affect the overall thermo electric voltage or current, provided that the intermediate material is at a uniform temperature and doesn't generate an emf. on its own.

- This Law helps in understanding how different material can be incorporated into thermo electric devices without inadvertently altering their performance.

# HEAT TRANSFER AND SOLAR ENERGY LABORATORY

**Class:** A3MA **Section:** A **S. No.** 05

**Course Title** : **Heat and Mass Transfer Laboratory**

**Course Number** : **MEC 3910**

**Experiment (Brief Title):** Thermal conductivity

Date of Experiment Performed : 21/08/24
Due date of Submission : 28/08/24
Late Submission date :

Teachers' Remark :

Marks Awarded :

| Rubric No. | I | II | III | IV | V | Total |
|---|---|---|---|---|---|---|
| Maximum Marks | 1 | 1 | 2 | 3 | 3 | 10 |
| Marks awarded | 1 | 1 | 2 | 2 | 2 | 8.0 |

Rubrics for laboratory courses

I. Object of the experiment and specifications of the equipment/instruments used.
II. Brief theory and related equations used
III. Observation Sheets, Sample calculations (student should explain at the time of evaluation)
IV. Results mathematical/graphical (student should explain at the time of evaluation)
V. Discussions (should be different from other students)

Name : Nikhil Singh
Class : A3MA
S. No. : ~~03~~ 05
Faculty No. : 22MEB173
En. Roll. No. : GL6695

# HEAT TRANSFER AND SOLAR ENERGY LABORATORY
# DEPARTMENT OF MECHANICAL ENGINEERING, AMU, ALIGARH

## THERMAL CONDUCTIVITY

***Object:*** To determine the thermal conductivity of an Insulating material by two slabs guarded hot plate method.

***Principle of Guarded Hot Plate Method:***
Guarded hot plate method is the most accurate method to find the thermal conductivity of solids having low conductivity.
The essential parts - the hot plate, the cold plates, the heater assembly, thermocouples and the specimens in position are shown in Fig. 1. It is required to have a one-dimensional heat flow through the flat specimen, and arrangement for maintaining its faces at constant temperature and some metering methods to measure the heat flow through a known area. To eliminate the distortion caused by edge losses in unidirectional heat flow, the central plate is surrounded by a guard ring, which is separately heated; temperatures are measured by calibrated thermocouples either attached to the plates or to the specimens at the hot and cold faces. Two specimens are used to ensure that all the heat comes out through the specimen only. Knowing the heat input to the central plate heater, the temperature difference across the specimen, its thickness and the metering area, one can calculate the value of k for the specimen:

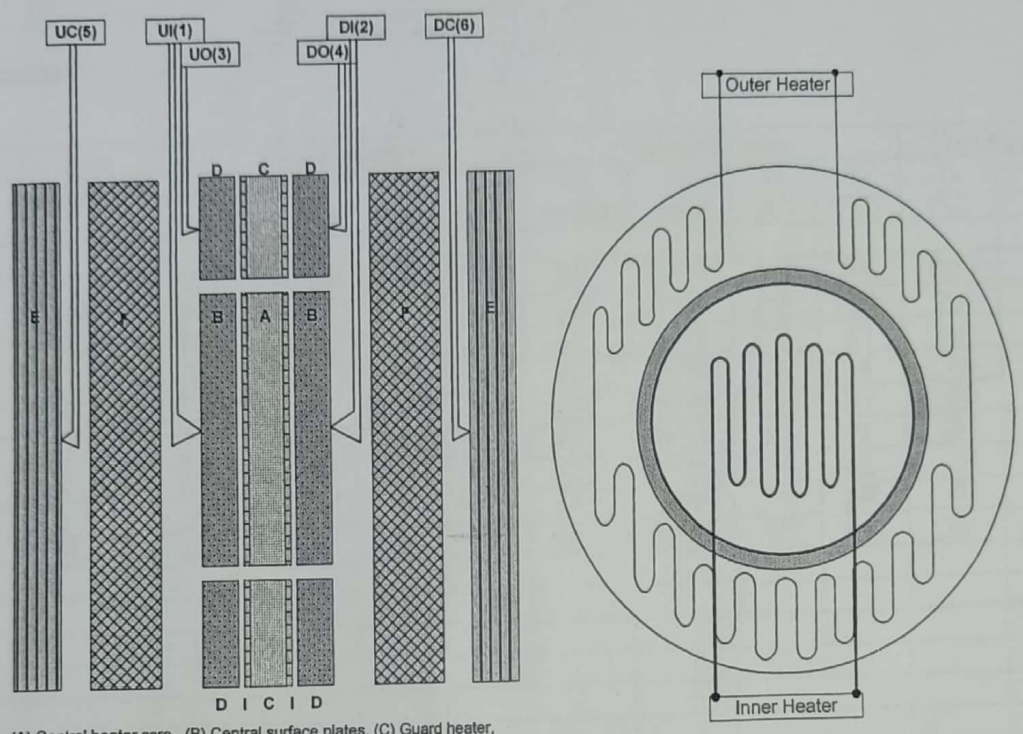
$$k = \frac{q\,L}{2\,A\,(T_h - T_c)}$$

| | | |
|---|---|---|
| Where $k$ | = | Thermal conductivity of the specimen, W/m°C |
| $A$ | = | Metering area of the specimen, $m^2$ |
| $T_c$ and $T_h$ | = | Average temperature of cold plate and hot plate respectively. |
| $L$ | = | Thickness of specimen, m |

***Description:***
The heater plate is surrounded by a heating ring for stabilizing the temperature of the primary heater and prevents heat loss radially around its edges. The primary and guard heaters are made up of mica sheets in which is wound closely spaced Nichrome wire and packed with upper and lower mica sheets. These heaters together form a plate which along with upper and lower copper plates and rings form the heater plate assembly.
Two thermocouples are used to measure the hot face temperature at the upper and lower central heater assembly copper plates. Two more thermocouples are used to check balance in both the heater input (Fig.1).
Specimens are held between the heater and cooling unit on each side of the apparatus, thermocouple No. 5 and No. 6 measure the temperature of the upper cooling plate and lower cooling plate, respectively. The cooling chamber is a composite assembly of spiral grooved Aluminium casting and Aluminium cover with entry and exit adaptors for water inlet and outlet.

***Test Procedure:***
The cooling circuit is started, and then calculated input is given to the central and guard heaters through separate single phase supply lines with dimerstat in each line and it is adjusted to maintain the desired temperatures. The guard heater input is adjusted such that there is no radial heat flow which is checked to the central heater (I and V) and the thermocouple readings are recorded every 10 minutes till a reasonably steady state condition is reached. To ensure no radial heat transfer, the outer heater input is about 2.5 to 3 times more than the central heater input.

***Precautions:***
1. Start the cooling circuit before switching on the heaters and adjust the flow rate of water so that practically there is no temperature rise in the circulation fluid.
2. Keep dimmerstats to zero voltage position before start. Increase the voltage gradually.




(A) Central heater core, (B) Central surface plates, (C) Guard heater,
(D) Guard surface plates, (E) Cooling unit with surface plates,
(F) Test specimens, (I) Insulation sheet, UC,UI,UO,DC,DI,DO Thermocouples

TWO SLAB GUARDED HOT PLATE SCHEMATIC ASSEMBLY

CENTRAL AND GUARD HEATERS

**Fig. 1 Two slab guarded hot plate schematic assembly central section**

***Discussion:***

1. Plot the temperatures recorded by each thermocouple against time on the same graph paper showing steady state conditions.
2. Find the value of k for last reading when steady state has been attained and compare it with the standard tabulated results. Discuss on the results.
3. Write a note on thermal conductivity of materials.
4. Thermal conductivity of a given material depends upon its state and varies with the structure, humidity, pressure and temperature: Explain.
5. Why is the thermal conductivity of metals higher than that of fluid?
6. Why is the thermal conductivity of insulating material lower than that of metals and alloys?
7. Discuss the various methods of determining thermal conductivity.
8. Define thermal conductance and thermal resistance.
9. Write a note on super-conducting materials.

Name: Nikhil Singh Class: A3MA S. No: 05 Date: 21/08/24

***Observations:***

| S.No. | Time (minutes) | Central Heater | | | | Guarded heater | | | | Cooling plate | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $V_1$ (volts) | $I_1$ (amp) | $T_1$ (°C) | $T_2$ (°C) | $V_2$ (volts) | $I_2$ (amp) | $T_3$ (°C) | $T_4$ (°C) | $T_5$ (°C) | $T_6$ (°C) |
| 1. | 0 | 68 | 0·25 | 44 | 46 | 66 | 0·75 | 48 | 50 | 30 | 31 |
| 2. | 10 | 68 | 0·25 | 54 | 55 | 66 | 0·75 | 58 | 59 | 31 | 31 |
| 3. | 20 | 68 | 0·25 | 59 | 60 | 66 | 0·75 | 63 | 61 | 31 | 31 |
| 4. | 30 | 68 | 0·25 | 63 | 64 | 66 | 0·75 | 67 | 66 | 30 | 31 |
| 5. | 40 | 68 | 0·25 | 67 | 68 | 66 | 0·75 | 71 | 71 | 30 | 31 |
| 6. | 50 | 68 | 0·25 | 69 | 70 | 66 | 0·75 | 73 | 71 | 31 | 31 |
| 7. | 60 | 68 | 0·25 | 71 | 71 | 66 | 0·75 | 74 | 73 | 31 | 31 |
| 8. | 70 | 68 | 0·25 | 73 | 74 | 66 | 0·75 | 75 | 75 | 31 | 31 |
| 9. | 80 | 68 | 0·25 | 73 | 74 | 66 | 0·75 | 75 | 75 | 31 | 31 |

21/8/24

$T_h = (T_1+T_2)/2$, °C
$T_c = (T_5+T_6)/2$, °C
$k = (V_1 . I_1 . L)/2A\ (T_h - T_c)$, W / m - °C
$A = \pi/4\ (0.1+x)^2$, $m^2$
x = Width of gap between the heater plates, $2.5 \times 10^{-3}$ m
L = $12.5 \times 10^{-3}$, m

2) Find the value of K for last reading when steady state has

22MEB173 GL6695 A3MA-05

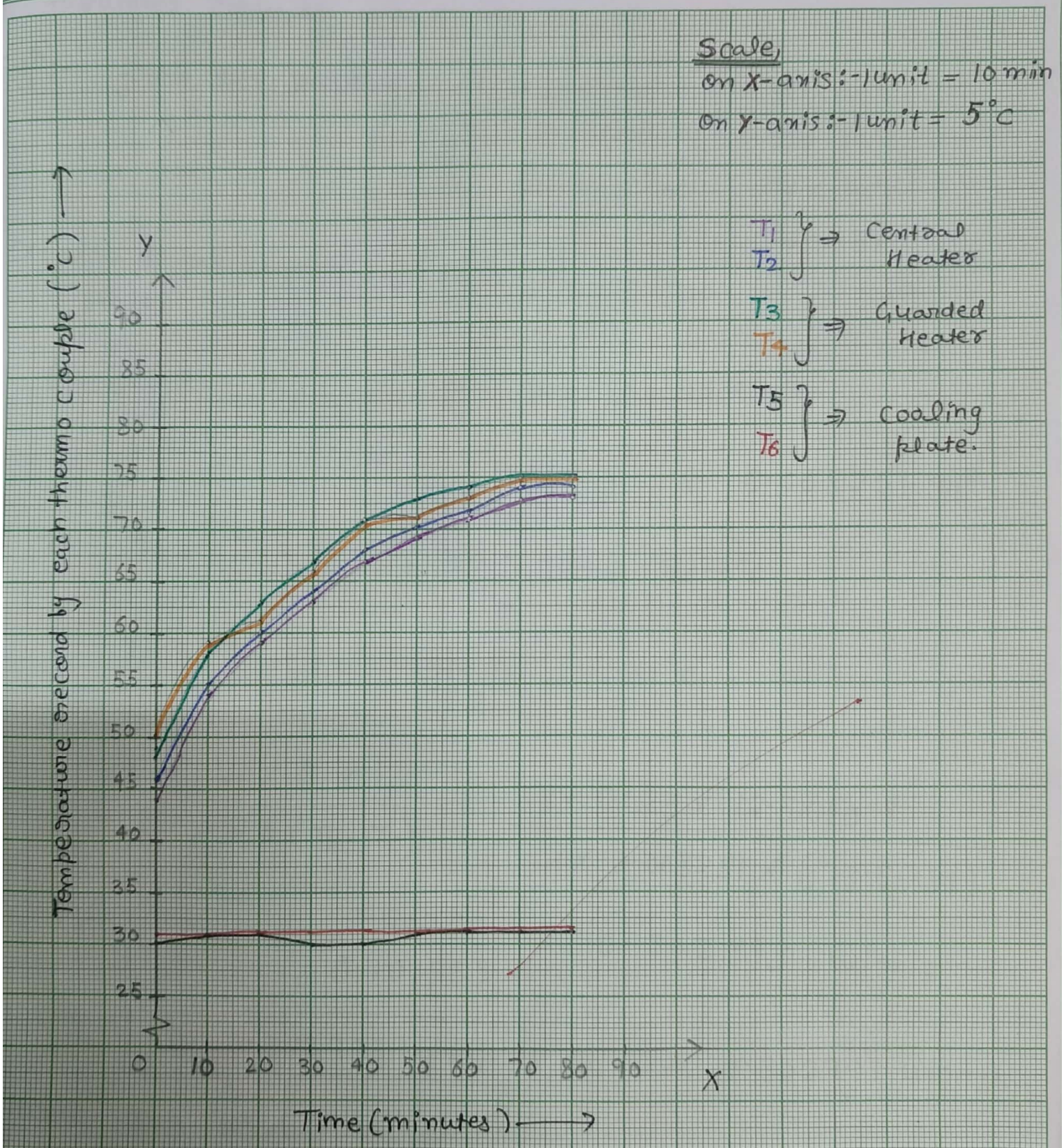



Fig. 1

⇒ fig. 1 Shows the Variation of temp. recorded by each thermo couple against time on the graph showing steady state condition.

2) Find the value of K for last reading when steady state has been attained and compare it with the standard tabulated results. discuss the results.

Sol$^n$:- from last reading, $V_1 = 68$ volts, $I_1 = 0.25$ amp., $L = 12.5 \times 10^{-3}$ m

$T_1 = 73°C$, $T_2 = 74°C$, $T_5 = 31°C$, $T_6 = 31°C$

$x$ (width of gap b/w the heater plates) $= 2.5 \times 10^{-3}$ m

$$A = \frac{\pi}{4}[0.1 + x]^2 \Rightarrow \frac{\pi}{4}[0.1 + 2.5 \times 10^{-3}]^2$$

$$\Rightarrow \frac{\pi}{4}(0.1025)^2 = 0.008251 \text{ m}^2$$

$$T_h = \frac{T_1 + T_2}{2} = \frac{73 + 74}{2} = 73.5°C$$

$$T_c = \frac{T_5 + T_6}{2} = \frac{31 + 31}{2} = 31°C$$

$$K = \frac{V_1 \times I_1 \times L}{2A(T_h - T_c)} \Rightarrow \frac{68 \times 0.25 \times 12.5 \times 10^{-3}}{2 \times 0.008251 \times (73.5 - 31)}$$

$$K = \frac{0.2125}{0.701335} = 0.302993 \text{ W/m°C}$$

$\boxed{K = 0.302993 \text{ W/m°C}}$ or $\boxed{K = 0.302993 \text{ W/m-K}}$

Hence, The thermal conductivity of specimen is found out to be 0.302993 W/m°C or 0.302993 W/m-K

The standard tabulated value of thermal conductivity for given metal is given by 0.2 W/m-K,

now from the experiment,

$$K = 0.302993 \ W/mK$$

On comparison,

$$\% \text{ error} = \left(\frac{0.302993 - 0.2}{0.2}\right) \times 100$$

$$\boxed{\% \text{ error} = 51.49 \%}$$

Discussion, The result obtained by this experiment consist about 51.49 % error, which is basically the effect of several error's mentioned as,

- → Human error
- → Observation error
- → Apparatus error
- → Machine error
- → environmental affect.

and may have several other cause too.



3) write a short note on thermal conductivity of materials.

⇒ Thermal conductivity measures a material's ability to transfer heat. metals like copper have high thermal conductivity, making them effective heat conductors, while materials like wood and insulation have low thermal conductivity, acting as insulators. This property is crucial in applications involving heat management, such as in electronics and Building materials.

4) Thermal conductivity of a given material depends upon its state and varies with the structures, humidity, pressure and temperature, explain?

- State of the material → Solids typically have higher thermal conductivity than liquids and gases due to tightly packed particles, which facilitate more efficient heat transfer compared to the more dispersed particles in fluids.

- Structure:→ crystalline materials, with their orderly atomic arrangement, conduct heat better than amorphous materials, because the regular structures allows easier transfer of vibrational energy, essential for thermal conduction.

- **Humidity** ⇒ In porous materials, higher humidity increases thermal conductivity because water having higher conductivity than air, fills the pores.

- **Pressure** ⇒ In gases higher pressure enhance thermal conductivity by bringing particles close together improving heat transfer, In solids and liquids, pressure has minimal impact unless the material is highly compressible.

- **Temperature**:- Thermal conductivity decreases with rising in temperature in solids due to increased atomic vibrations that scatter heat.

5) why is thermal conductivity of metals higher than that of fluids.

⇒ This is due to the presence of free electrons that rapidly transfer heat and their densely packed atomic structure, allowing efficient energy transfer.

6) why is thermal conductivity of insulating material lower than that of metals & alloys.

⇒ Insulating materials have lower thermal conductivity than metals and alloys because they lack free electrons for efficient heat transfer and have a less dense atomic structure. Their loosely bounded atoms and air filled pores further hinder the transfer of thermal energy.



7) Discuss the various methods of determining thermal conductivity.

⇒ Thermal conductivity can be determined using several methods, each suited to different materials and conditions. The most common method include,

① **Steady state method**:- This method measure thermal conductivity under constant temperature conditions, where heat flow is steady.

② **Transient ~~to~~ method**:- These techiques measure thermal conductivity under changing temperature conditions, which are quicker and often more adaptable to different sample types.

8) Define thermal conductance & thermal resistance.

① **Thermal conductance** → Heat conduction also kn as thermal conduction, it is the process where heat is transfered with in a body due to the collision of neighbouring particles.

e.g:-

② **Thermal Resistance** → It is a heat property as a measurement of a temp-difference by which an object or material resist a heat flow

→ Just the reciprocal of Thermal conductance.

9) write a short note on super conducting materials

⇒ Super conducting materials exhibit zero electrical resistance and expel magnetic field when cooled below a cricital temperature. This allows current to flow without energy loss, making them ideal for applications like MRI m/c and maglev trains.

Super conductors are classified into 2 types

→ Type I (pure metals)

→ Type II (complex compounds)

e.g → lead, Niobium Titanium (Nb Ti), Yttrium barium copper oxide (YBCO) etc.

# HEAT TRANSFER AND SOLAR ENERGY LABORATORY

**Class:** A3MA **Section:** A **S. No.** 05

**Course Title** : **Heat and Mass Transfer Laboratory**

**Course Number** : **MEC 3910**

**Experiment (Brief Title):** Heat Pipe

Date of Experiment Performed : 28/8/24
Due date of Submission : 04/09/24
Late Submission date :

Teachers' Remark :

Marks Awarded :

| Rubric No. | I | II | III | IV | V | Total |
|---|---|---|---|---|---|---|
| Maximum Marks | 1 | 1 | 2 | 3 | 3 | 10 |
| Marks awarded | 1 | 1 | 2 | 2 | 2 | 8 |

Rubrics for laboratory courses

I. Object of the experiment and specifications of the equipment/instruments used.
II. Brief theory and related equations used
III. Observation Sheets, Sample calculations (student should explain at the time of evaluation)
IV. Results mathematical/graphical (student should explain at the time of evaluation)
V. Discussions (should be different from other students)

Repeat graph

Name : Nikhil Singh
Class : A3MA
S. No. : 05
Faculty No. : 22MEB173
En. Roll. No. : GL6695

Name: Nikhil Singh Class: A3MA S. No. 07 Date: 28/08/24

## OBSERVATIONS

***Observation Table 1***

| Unit | Time after start (in minutes) | Temperature at thermocouple location, °C | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| **Heat pipe** V = 60 (V) I = 1.85 (A) | 40 | 38.6 | 37.3 | 36.6 | 34 | 31.8 |
| | 50 | 39.2 | 38 | 37.3 | 34.8 | 32.5 |
| | 60 | 39.7 | 38.4 | 37.7 | 35.2 | 32.9 |
| **Stainless steel pipe** V = 60 (V) I = 1.85 (A) | | 6 | 7 | 8 | 9 | 10 |
| | 40 | 51.1 | 38.2 | 33.1 | 29.8 | 28.9 |
| | 50 | 51.9 | 38.4 | 33.2 | 29.9 | 29.0 |
| | 60 | 54 | 39.9 | 34.2 | 30 | 29.2 |
| **Copper pipe** V = 60 (V) I = 1.85 (A) | | 11 | 12 | 13 | 14 | 15 |
| | 40 | 46.5 | 40.2 | 36.7 | 31.4 | 31.3 |
| | 50 | 47.1 | 40.7 | 37.1 | 31.7 | 31.8 |
| | 60 | 47.6 | 41.2 | 37.5 | 32.1 | 32.3 |

28.9.24

***Observation Table 2***

| | Unit | Time Interval (Minutes) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 | 50 | 60 |
| Temperature of water in the condenser tank, °C | Heat pipe | 29.3 | 30.2 | 31.0 | 31.8 | 32.5 | 32.9 |
| | S. Steel pipe | 28.5 | 28.6 | 28.8 | 28.9 | 29.0 | 29.2 |
| | Copper Pipe | 29.1 | 29.9 | 30.6 | 31.3 | 31.8 | 32.3 |

***Tabulated results***

| Conductance in W/°C of the three pipes | | | | |
|---|---|---|---|---|
| S. No. | Time (Minutes) | Heat pipe | Stainless steel pipe | Copper pipe |
| 1. | 40 | 41.11 | 10.67 | 15.85 |
| 2. | 50 | 74 | 6.37 | 14.41 |
| 3. | 60 | 65.29 | 7.11 | 9.40 |

22MEB173 GL6695 A3MA-05

Topic _____ Date _____

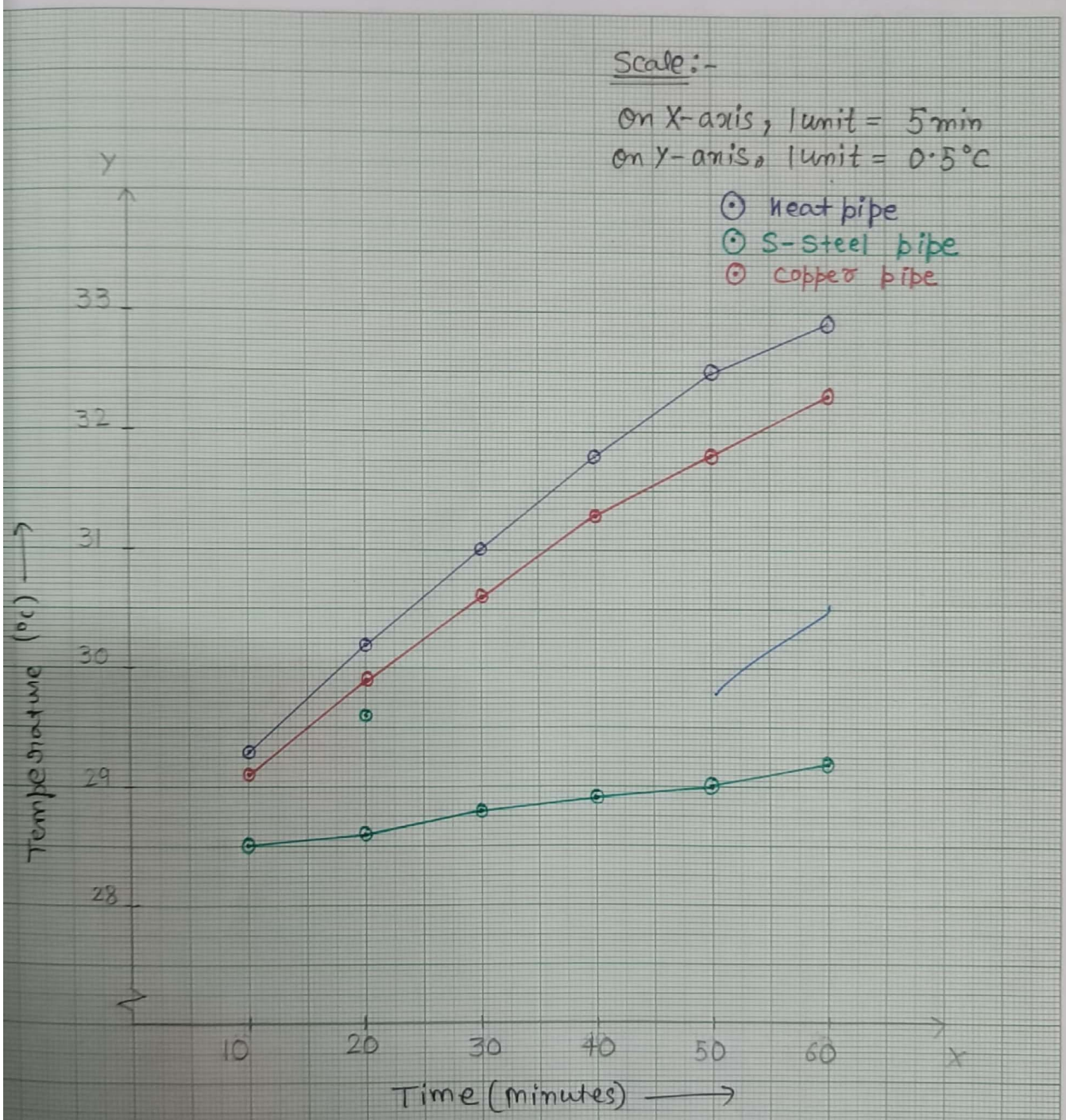



Fig-1 Rise in temperature of the heat sink due to heat transfer for different pipes.

22MEB173 GL6695

22MEB173 | GL 6695
A3MA-05

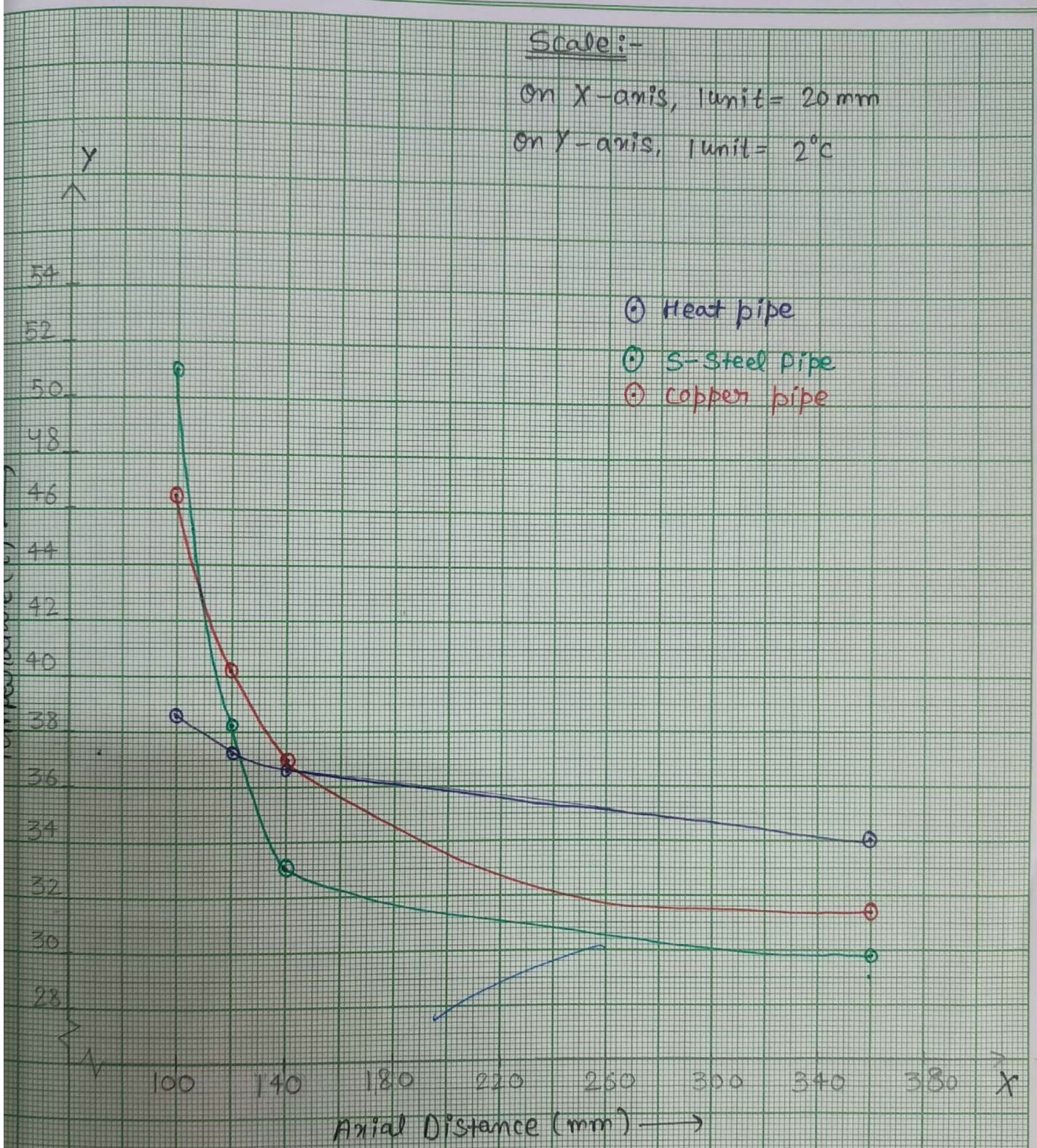



Fig 2, Temperature distribution along the length at 40mm

22MEB173 GL 6695

22MEB173 | GL 6695
A3MA-05

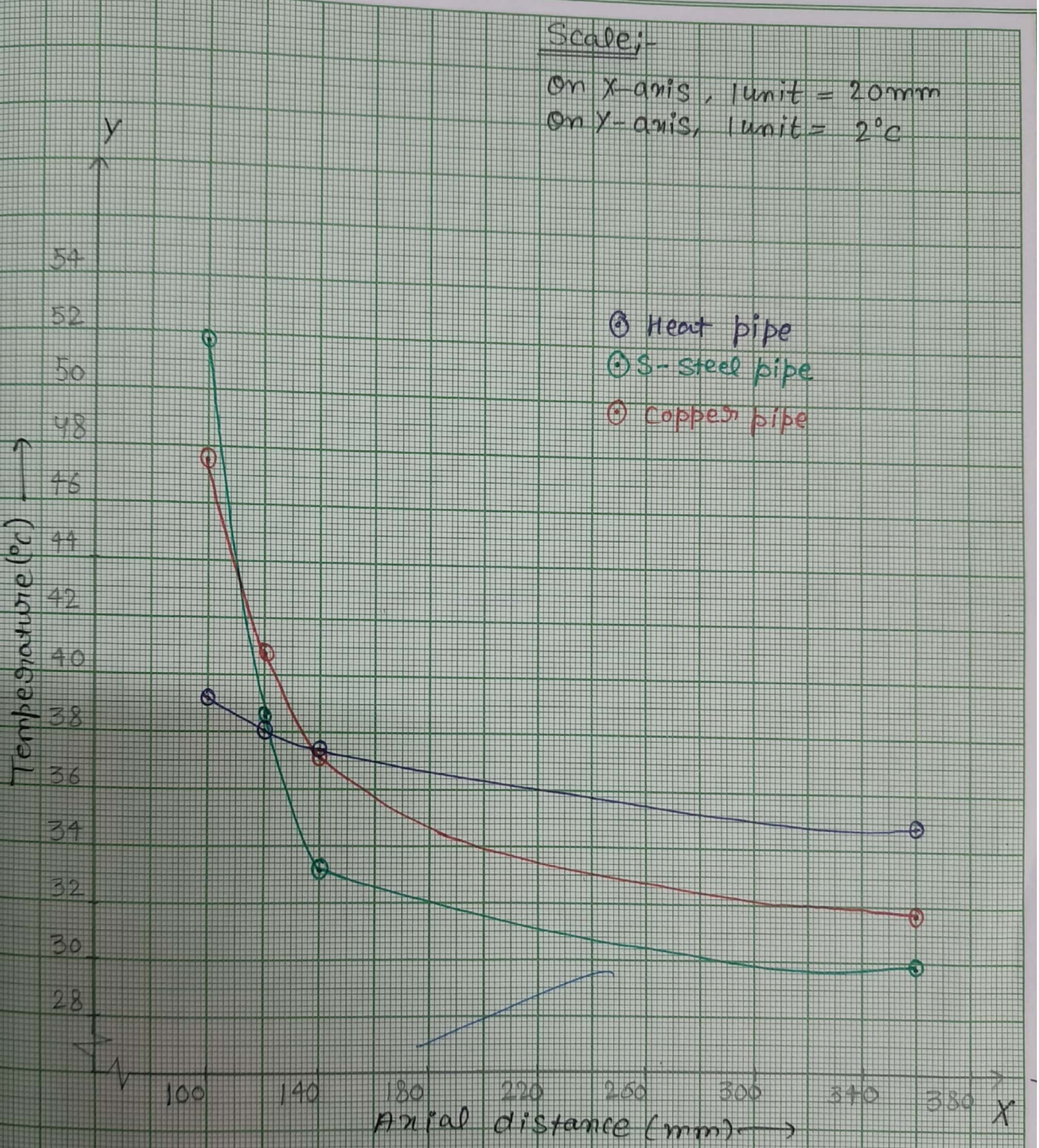



Fig 3, Temperature Distribution along the length at 50 mm

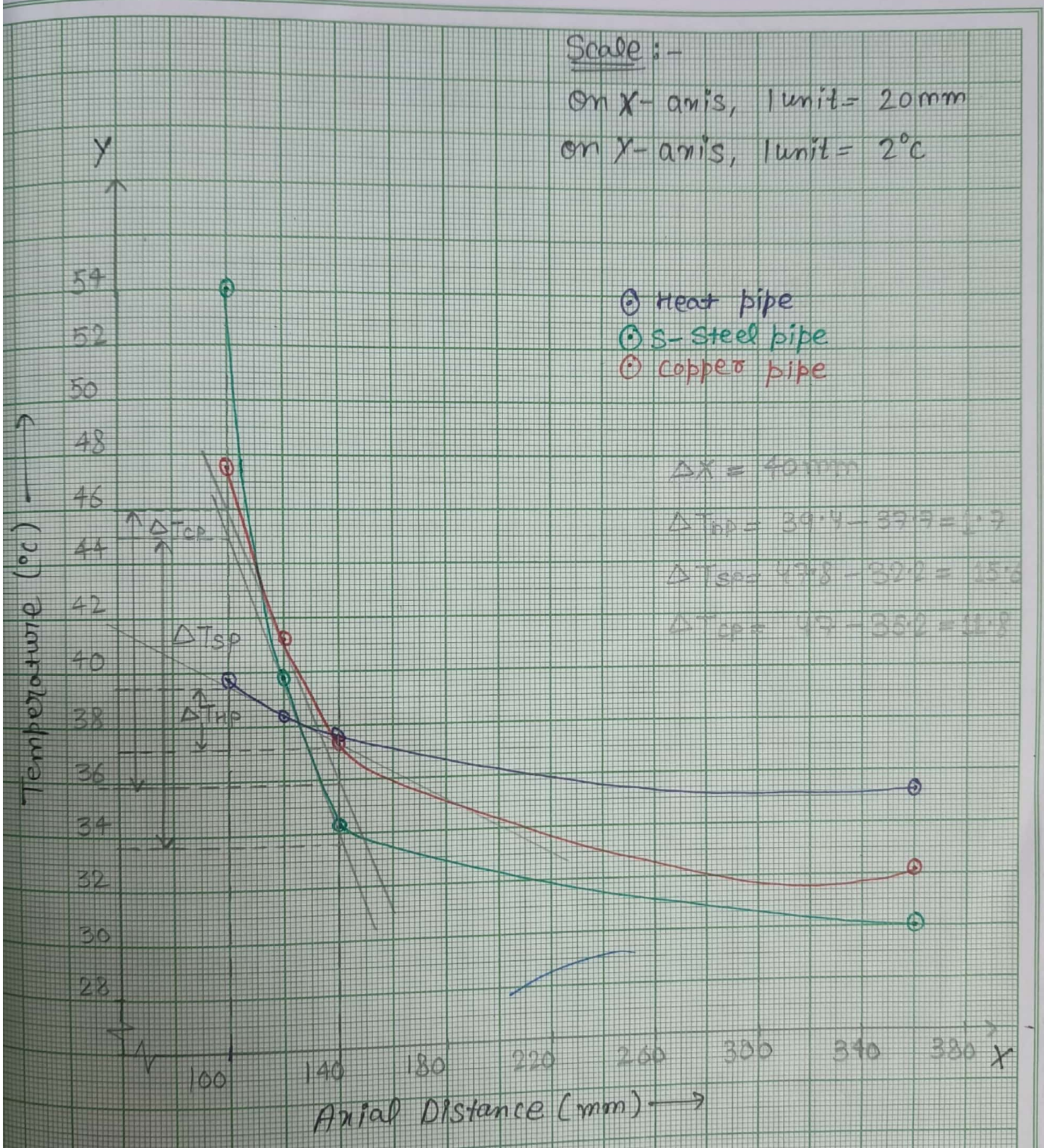



Fig 4, Temperature Distribution along the length at 60mm

## Discussion

22MEB173 | GL 6695

Plot condenser temperature v/s time for three pipes on a single graph paper:-

Shown in fig. 1.

3 Select any location in adiabatic region of the pipe length (x) and mark it on temp. curves of three. then draw tangents on these points with same value of $\Delta x$. find $\Delta T$ for each of the curves. Hence find the conductance of three pipes. using Fourier's Law of Heat conduction ie, $C = q/\Delta T$

where $q$ = heat supplied in W to pipe and

$C = KA/L$ (w/°c) of pipe.

$1^n$:-

$V = 60$ volts

$I = 1.85$ A

for time interval $t = 60$ min.

$q = V \times I$

$q = 60 \times 1.85 = 111$ W

$\Delta T_{HP} = 1.7°C$

$\Delta T_{SP} = 15.6°C$

$\Delta T_{CP} = 11.8°C$

$\therefore \quad C_{HP} = \frac{Q}{\Delta T_{HP}} = \frac{111}{1.7} = 65.29 \ W/°C$

$C_{SP} = \frac{Q}{\Delta T_{SP}} = \frac{111}{15.6} = 7.11 \ W/°C$

$C_{CP} = \frac{Q}{\Delta T_{CP}} = \frac{111}{11.8} = 9.40 \ W/°C$

Q=4 compare the values of C obtained for each pipe and at different times.

Solⁿ:- for $t = 40 min$ $\quad C_{HP} > C_{CP} > C_{SP}$

$t = 50 min$ $\quad C_{HP} > C_{CP} > C_{SP}$

$t = 60 min$ $\quad C_{HP} > C_{CP} > C_{SP}$

Q=5 what conclusions can you draw from the graphs plotted,

Solⁿ:- Temperature gradients along heat pipes is least due to most thermal conductivity among all.

Heat pipe being most conductive, water's temperature will be highest in heat pipe in water- temperature V/s time (fig 1) graph.

# HEAT TRANSFER AND SOLAR ENERGY LABORATORY

**Class:** A3MA **Section:** A **S. No.** 05

**Course Title** : **Heat and Mass Transfer Laboratory**

**Course Number** : **MEC 3910**

**Experiment (Brief Title):** Extended Surface

Date of Experiment Performed : 04/09/24
Due date of Submission : 25/09/24
Late Submission date :

Teachers' Remark :

Marks Awarded :

| Rubric No. | I | II | III | IV | V | Total |
|---|---|---|---|---|---|---|
| Maximum Marks | 1 | 1 | 2 | 3 | 3 | 10 |
| Marks awarded | 1 | 1 | 2 | 1½ | 1½ | 7 |

Rubrics for laboratory courses

I. Object of the experiment and specifications of the equipment/instruments used
II. Brief theory and related equations used
III. Observation Sheets, Sample calculations (student should explain at the time of evaluation)
IV. Results mathematical/graphical (student should explain at the time of evaluation)
V. Discussions (should be different from other students)

Name : Nikhil Singh

Class : A3MA

S. No. : 05

Faculty No. : 22MEB173

En. Roll. No. : GL6695

Name Nikhil Singh Class A3MA S.No. 05 Date: 04/9/24

## OBSERVATIONS

### Forced Convection

Velocity of air, $V_f$ = 1.35 m/s ;
Heat supplied, q = 100 W
→ 25×4

| S.No. | Time (Minutes) | Surface temperature (°C) | | | | | | | | Air Temperature(°C) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | 5 | 49 | 41 | 51 | 45 | 42 | 41 | 50 | 41 | 31 | 31 |
| | 10 | 59 | 49 | 61 | 54 | 50 | 47 | 60 | 49 | 31 | 31 |
| | 15 | 64 | 53 | 67 | 58 | 54 | 51 | 65 | 53 | 31 | 31 |
| | 20 | 67 | 55 | 69 | 60 | 56 | 52 | 67 | 55 | 31 | 31 |
| | 25 | 69 | 56 | 71 | 62 | 57 | 53 | 69 | 56 | 31 | 31 |
| | 30 | 70 | 57 | 72 | 63 | 58 | 54 | 71 | 57 | 31 | 31 |
| | 35 | 71 | 57 | 73 | 64 | 59 | 55 | 72 | 58 | 31 | 31 |
| | 40 | 71 | 57 | 73 | 65 | 59 | 56 | 72 | 58 | 31 | 31 |

4.9.24

### Free convection

Heat supplied, q = 100 W

| S.No. | Time (Minutes) | Surface temperature (°C) | | | | | | | | Air Temperature(°C) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 5 | 52 | 45 | 54 | 50 | 48 | 46 | 55 | 47 | 30 | 30 |
| 2 | 10 | 68 | 60 | 71 | 65 | 61 | 58 | 69 | 60 | 30 | 30 |
| 3 | 15 | 82 | 73 | 84 | 78 | 74 | 70 | 83 | 73 | 32 | 31 |
| 4 | 20 | 89 | 80 | 91 | 85 | 81 | 76 | 90 | 79 | 32 | 32 |
| 5 | 25 | 94 | 84 | 96 | 89 | 85 | 80 | 94 | 83 | 33 | 31 |
| 6 | 30 | 98 | 87 | 100 | 93 | 89 | 84 | 98 | 87 | 34 | 32 |
| 7 | 35 | 100 | 90 | 102 | 95 | 91 | 86 | 101 | 89 | 34 | 32 |
| 8 | 40 | 103 | 92 | 105 | 97 | 93 | 87 | 103 | 91 | 34 | 32 |
| 9 | 45 | 105 | 94 | 107 | 99 | 96 | 90 | 105 | 94 | 34 | 32 |
| 10 | 50 | 107 | 95 | 108 | 100 | 97 | 91 | 107 | 95 | 34 | 32 |

***Calculations:***

1. Plot T Vs t (t = time) for every thermocouple point on the same graph paper; this will show steady state conditions.
2. Using the boundary condition: $T = T_{tip}$ at $x = L_C$ and the observed values of $T_o$ and $T_a$ under the steady condition, determine 'm' from the equation (3) and then find the heat transfer coefficient, h.
3. Using the equation (2), plot the observed temperatures with x. This will show a straight line; the slope of which will also give the value of 'm' and hence, calculate 'h'.

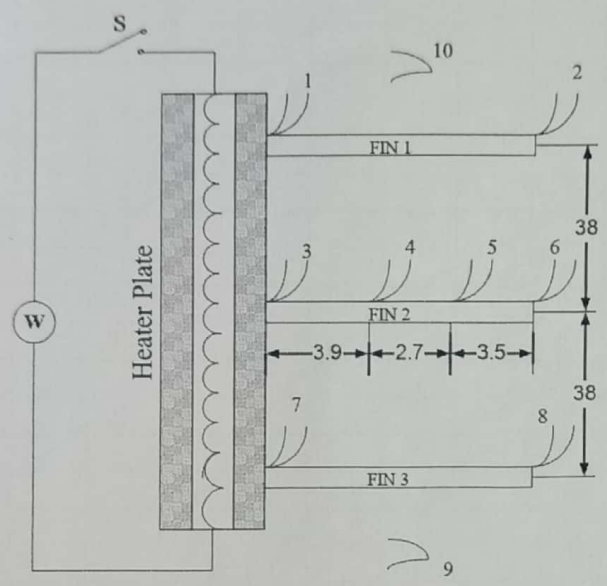



Fig.1 Arrangement of Thermocouples

***Results and Discussion:***

1. Discuss the results obtained under the forced and free convections.
2. Calculate the rate of heat transfer for a single fin and for the total number of the fins (if any) and hence, find the heat lost from the unfinned portion of the plate. Also find the fin efficiency and effectiveness.
3. Show that,

$$\frac{q_{max}}{q_{wf}} = \sqrt{\frac{1}{Bi}}$$

and indicate the significance of Biot number in your experiment.

4. Define the various dimensionless numbers related to the convective heat transfer.
5. ***Tabulated Results:***

| S.No. | Condition | h (eq. 2) ($W/m^2$-°C) | h (eq.3) ($W/m^2$-°C) | Q (W) | $q_{max}$ (W) | $q_{wf}$ (W) | η | ϕ |
|---|---|---|---|---|---|---|---|---|
| 1. | Forced | | 77.24 | 34.55 | 14.77 | 0.559 | 76.66 | 26.40 |
| 2. | Free | | 20.949 | 19.76 | 13.14 | 0.259 | 91.17 | 58.70 |

1) Forced convection

22MEB173 GL6695 A3MA-05

2) Free Convection

Scale :- On X-axis, 1 unit = 2.5 min
On Y-axis, 1 unit = 5°C

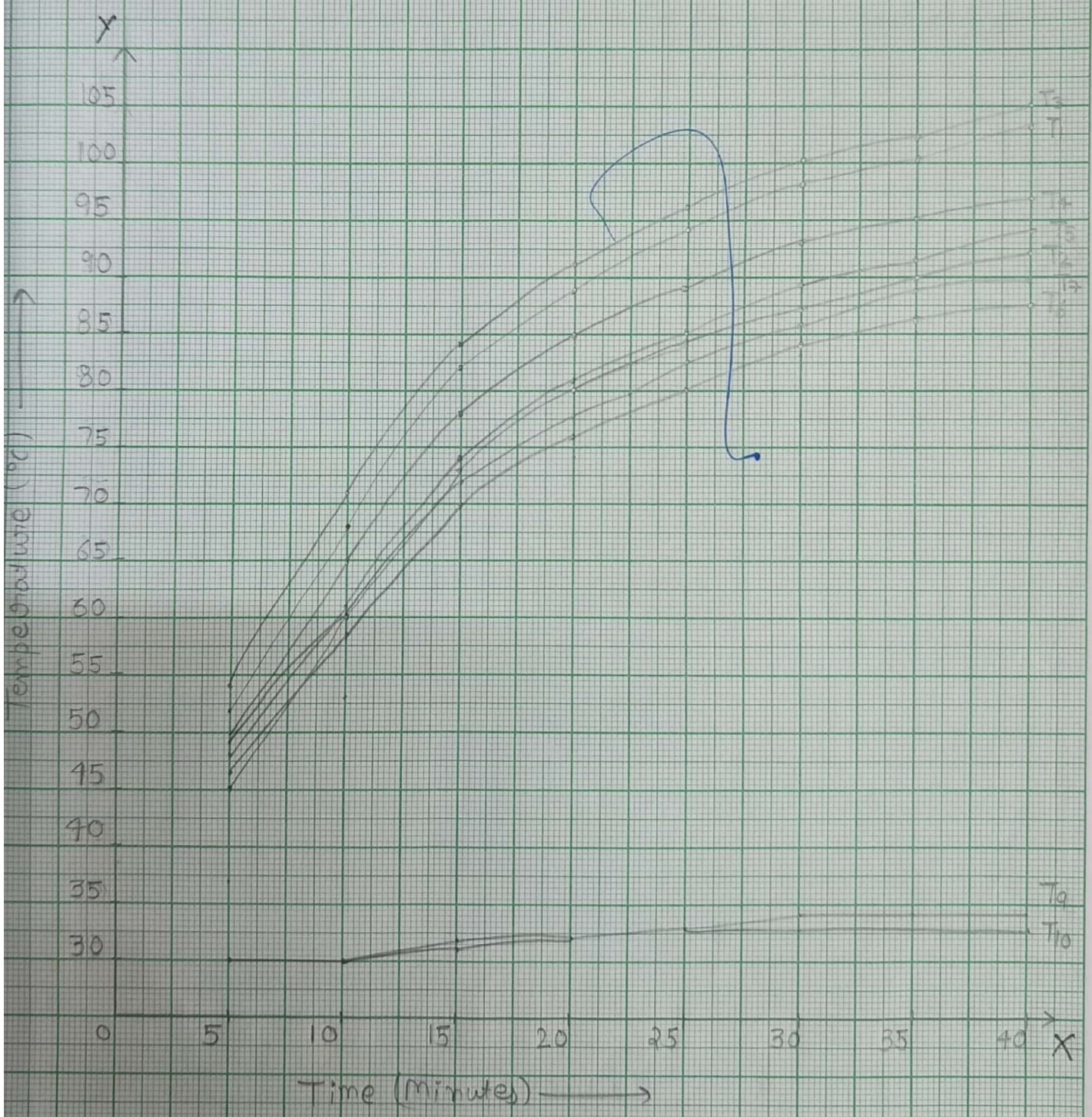



Fig. Shows the Temperature of thermo couple V/S Time.

1) Forced convection

22MEB173 GL6695 A3MA-05

① Forced convection

Scale:-

On X-axis → 1unit = 2.5 min

On Y-axis → 1unit = 5 °C

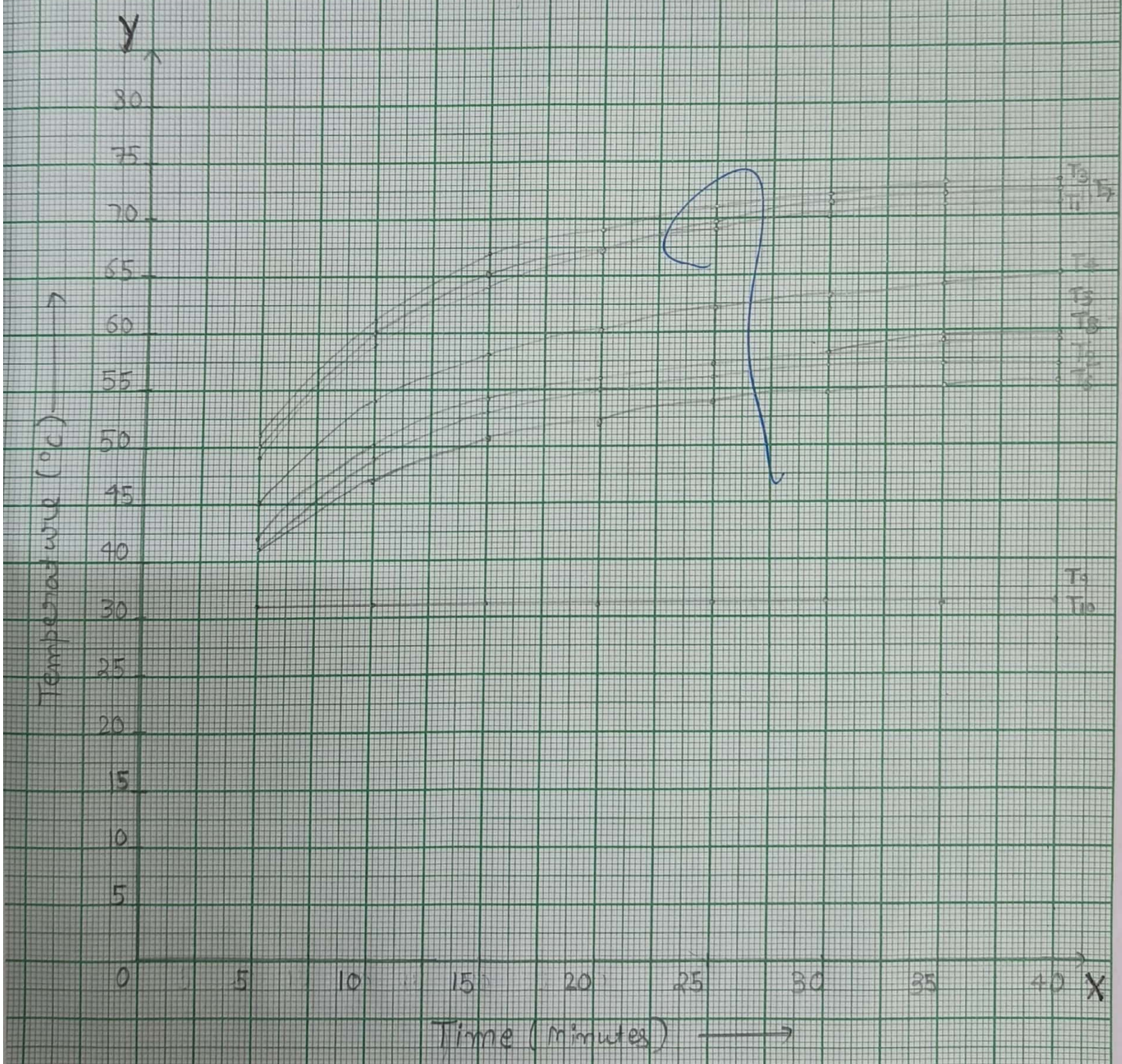



Fig. Shows the Temperature of thermocouple V/S Time.

## 1) Forced convection

$$h = \frac{m^2 k A}{P} = \frac{m^2 k \times \pi d^2}{4\pi d} = \frac{m^2 k d}{4}$$

from eqn (3) $\frac{T - T_a}{T_o - T_a} = \frac{\cosh\{m(L-x)\}}{\cosh(mL)}$

taking $x = L_c$

$$\therefore mL = \cosh^{-1}\left[\frac{T_o - T_a}{T - T_a}\right]$$

$$\therefore m = \frac{\cosh^{-1}\left[\frac{T_o - T_a}{T - T_a}\right]}{L_c}$$

**Corrected length**

$$L_c = L + \frac{d}{4}$$

$$= 0.1 + \frac{0.015}{4}$$

$$L = 0.10375\,m$$

**for fin 1**

$T = 57°C$, $T_a = 31°C$, $T_o = 71°C$

$$m = \frac{\cosh^{-1}\left[\frac{71-31}{57-31}\right]}{L_c} = 9.600$$

$$m = \left(\frac{hP}{kA}\right)^{1/2}$$

$P = \pi d = \pi \times 0.015$

$P = 0.0471\,m$

$k = 202\ W/m°C$

$$A = \frac{\pi}{4} d^2 = \frac{\pi}{4}(0.015)^2 = 1.767 \times 10^{-4}\,m^2$$

$$m = \sqrt{\frac{hP}{KA}} \Rightarrow h_1 = \frac{m^2 KA}{P}$$

$$h_1 = \frac{(9.6)^2 \times (202) \times (0.0001767)}{0.04712}$$

$$h_1 = 69.81 \ W/m^2\,°C$$

heat transfer from fin1 :-

$$Q_{fin} = \sqrt{hPKA} \cdot (T_0 - T_a) \tanh(mL_c)$$

$$= \sqrt{69.81 \times 0.0471 \times 202 \times 1.76 \times 10^{-4}} \ (40) \tanh(9.6 \times 0.10375)$$

$$Q = 10.417 \ W$$

fin efficiency,

$$\eta_1 = \frac{\tanh(mL_c)}{mL_c} \times 100$$

$$= \frac{\tanh(9.600 \times 0.10375)}{9.600 \times 0.10375} \times 100$$

$$\boxed{\eta_1 = 76.29\%}$$

Now

for fin2

$m_2 = 11.169$

$h_2 = 94.499 \ W/m^2\,°C$

$Q_2 = 13.742 \ W$

$\eta_2 = 70.81\%$

for fin 3

$m_3 = 9.434$

$h_3 = 67.421 \ W/m^2\,°C$

$Q_3 = 10.390 \ W$

$\eta_3 = 76.884\%$

$$h_{avg} = \frac{h_1 + h_2 + h_3}{3}$$

$$\Rightarrow \frac{69.81 + 94.49 + 67.42}{3}$$

$$h_{avg} = 77.247 \ W/m^2\,°C$$

maxm heat transfer by fins :-

$$Q_{max} = (h_{avg} PKA)^{1/2} (T_0 - T)_{mean}$$

$$Q_{max} = 14.779 \ W$$

Average efficiency.

$$\eta = \frac{76.29 + 70.81 + 76.884}{3}$$

$$\boxed{\eta_{avg} = 76.65\%}$$

Total heat Transfer by fins :-

$$Q = Q_{fin1} + Q_{fin2} + Q_{fin3} \quad \therefore \boxed{Q = 34.550 \ W}$$

Heat transfer without fin ($Q_{wf}$)

$$Q_{wf} = h_{avg} \times A \times (T_0 - T_a)_{mean}$$

$$Q_{wf} = 77.247 \times 1.767 \times 10^{-4} \times 41$$

$$\boxed{Q_{wf} = 0.5596}$$

Fin efficiency.

$$\phi = \frac{Q_{max}}{Q_{wf}} = \frac{14.779}{0.5596} \quad \boxed{\therefore \phi = 26.40}$$

## 2) For Free convection

for fin 1:-

$T_a = 32°c$

$T = 94°c$

$T_0 = 105°c$

$$\frac{T - T_a}{T_0 - T_a} = \frac{\cosh\{m(L-x)\}}{\cosh(mL)}$$

at $x = L_c$

$$m = \frac{\cosh^{-1}\left(\frac{105-32}{94-32}\right)}{0.10375}$$

$m = 5.659\ m^{-1}$

now. $m = \left(\frac{hP}{KA}\right)^{1/2}$

$$\therefore h_1 = \frac{m^2 KA}{P}$$

$$h_1 = \frac{(5.659)^2 \times 202 \times 1.767 \times 10^{-4}}{0.0471}$$

$$\boxed{h_1 = 24.26\ w/m^2\,°c}$$

Heat transfer from fin 1,

$$q_1 = \sqrt{hPKA}\,(T_0 - T_a)\tanh(mL_c)$$

$$= \sqrt{24.26 \times 0.0471 \times 202 \times 1.767 \times 10^{-4}} \times 73 \times \tanh[5.659 \times 0.10375]$$

$$\boxed{q_1 = 7.785\ w}$$



for fin efficiency:-

$$\eta_1 = \frac{\tanh(mL_c)}{mL_c} \times 100 = \frac{\tanh[5.659 \times 0.10375]}{5.659 \times 0.10375} \times 100$$

$$\boxed{\eta_1 = 89.89\ \%}$$

For fin 2

$m_2 = 4.347\ m^{-1}$

$h_2 = 14.3156\ w/m^2\,°c$

$q_2 = 4.1984\ w$

$\eta_2 = 93.72\ \%$

for fin 3

$m_3 = 5.659\ m^{-1}$

$h_3 = 24.265\ w/m^2\,°c$

$q_3 = 7.785\ w$

$\eta_3 = 89.89\ \%$

- $$h_{avg} = \frac{h_1 + h_2 + h_3}{3}$$

$$\therefore h_{avg} = \frac{24.265 + 14.315 + 24.265}{3}$$

$h_{avg} = 20.949\ w/m^2\,°c$

- Max$^m$ heat Transfer by fin:

$$q_{max} = \sqrt{h_{avg} \times P \times K \times A}\,(T_0 - T_a)_{mean}$$

$$= \sqrt{20.949 \times 0.0471 \times 220 \times 1.767 \times 10^{-4}} \times 70$$

$q_{max} = 13.140\ w/m^2\,°c.$

- Average efficiency.

$$\eta_{avg} = \frac{\eta_1 + \eta_2 + \eta_3}{3} = \frac{89.89 + 93.72 + 89.89}{3}$$

$$\boxed{\eta_{avg} = 91.74\ \%}$$

- **Total heat transfer by fins (Q)**

$$Q = q_{fin1} + q_{fin2} + q_{fin3}$$

$$Q = 7.785 + 4.198 + 7.785$$

$$\boxed{Q = 19.769\,w}$$

- **Heat Transfer without fin ($q_{wf}$)**

$$q_{wf} = h_{avg} \times A \times (T_o - T_a)_{mean}$$

$$= 20.94 \times 1.767 \times 10^{-4} \times 70$$

$$\boxed{q_{wf} = 0.2591}$$

- **fin efficiency**

$$\phi = \frac{q_{max}}{q_{wf}} = \frac{13.140}{0.2591}$$

$$\boxed{\phi = 50.70}$$



# Discussion

Q=1 Discuss the result obtained under the forced and free convection.

⇒ It is observed that the heat transfer rate is higher in forced convection.

The fin efficiency also came out higher in case of forced convection.

Q=2 Show that, $\frac{q_{max}}{q_{wf}} = \sqrt{\frac{1}{Bi}}$

Solⁿ:- $Bi = \frac{h \cdot l}{K} = \frac{\text{Conduction resistance}}{\text{convection resistance}}$

$$\frac{q_{max}}{q_{wf}} = \frac{\sqrt{hPKA}\,(T_o - T_a)}{hA(T_o - T_a)} = \sqrt{\frac{PK}{hA}}$$

$$Bi = \frac{hd}{2t} \times \frac{l}{l} = \frac{hA}{KP}$$

$$Bi = \left(\frac{q_{wf}}{q_{max}}\right)^2$$

$$(Bi)^2 = \frac{q_{wf}}{q_{max}} \Rightarrow \frac{q_{max}}{q_{wf}} = \frac{1}{\sqrt{Bi}}$$

Q=3 Define the various dimensionless numbers related to convective heat transfer.

① Reynold's Number (Re) = It is ratio of inertial force to the viscous force.

$$Re = \frac{\rho V D}{\mu}$$

② Prandtl Number :- It is the ratio of momentum diffusivity to thermal diffusivity

$$Pr = \frac{\mu C_p}{K}$$

③ Grashaff's Number :- It is the ratio of Boundary force to viscous force.

$$Gr = \frac{Bg(\Delta T) L^3}{V^2}$$

④ Nusselt Number :- It is the ratio of convection to conduction Heat transfer across a Boundary.

$$Nu = \frac{hL}{K_f}$$

# HEAT TRANSFER AND SOLAR ENERGY LABORATORY

**Class:** A3MA **Section:** ~~05~~ A **S. No.** 05

**Course Title** : **Heat and Mass Transfer Laboratory**

**Course Number** : **MEC 3910**

**Experiment (Brief Title):** Solar cooker

Date of Experiment Performed : 09/10/24
Due date of Submission : 16/10/24
Late Submission date : 18/10/24

Teachers' Remark :

Marks Awarded :

| Rubric No. | I | II | III | IV | V | Total |
|---|---|---|---|---|---|---|
| Maximum Marks | 1 | 1 | 2 | 3 | 3 | 10 |
| Marks awarded | 1 | 1 | 2 | 2 | 2 | 8.0 |

Rubrics for laboratory courses

I. Object of the experiment and specifications of the equipment/instruments used.
II. Brief theory and related equations used
III. Observation Sheets, Sample calculations (student should explain at the time of evaluation)
IV. Results mathematical/graphical (student should explain at the time of evaluation)
V. Discussions (should be different from other students)

Name : Nikhil Singh
Class : A3MA
S. No. : 05
Faculty No. : 22MEB173
En. Roll. No. : GL6695

Name Nikhil Singh ..... Class A3MA ... S.No. 05 ..... Date: 09/10/24

***Observation Tables:***

| | | | | Ambient Air | Temperature of the material into the Pot. (°C) | | | | | Cooking pot cover temperatures. (°C) | | | | | Air velocity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. N. | Time (min) | Solar flux (mV) | Solar Flux (W/m²) | $T_a$ (°C) | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | m/s | $T_c$ | $T_w$ |
| 1. | 0 | 5·2 | 642·2 | 38 | 19 | 19 | 18·8 | 18·7 | 22·7 | 37 | 41·3 | 41·6 | | 41·8 | 0·4 | 40·4 | 19·6 |
| 2. | 5 | 4·9 | 605·15 | 38 | 26·9 | 26·4 | 27·2 | 29·6 | 35 | 53·8 | 57·4 | 57·3 | | 57·2 | 1·3 | 56·4 | 29 |
| 3. | 10 | 4·5 | 555·75 | 38 | 34·3 | 34·7 | 45·8 | 36·2 | 40·8 | 58·1 | 60 | 59·8 | | 60·3 | 1·3 | 59·5 | 38·3 |
| 4. | 15 | 4·6 | 568·1 | 37 | 36·7 | 36·5 | 37·1 | 38·1 | 43·2 | 61·7 | 64·4 | 64·3 | | 64·5 | 0·9 | 63·7 | 38·3 |
| 5. | 20 | 4·9 | 605·15 | 37 | 37·3 | 37·5 | 38·9 | 40·9 | 45·1 | 62·8 | 65·6 | 65·9 | | 66·2 | 1·1 | 65·1 | 39·9 |
| 6. | 25 | 5·1 | 629·85 | 38 | 44 | 45 | 45·5 | 45·2 | 49·6 | 67·8 | 71·1 | 71·5 | | 72·6 | 0·93 | 70·7 | 45·8 |
| 7. | 30 | 4·9 | 605·15 | 41 | 47·6 | 52·4 | 52·3 | 53·2 | 56·7 | 74·0 | 77·4 | 77·5 | | 80·8 | 1·7 | 77·4 | 52·4 |
| 8. | 35 | 4·5 | 555·75 | 37 | 53·2 | 54 | 55·2 | 63 | 61 | 76·5 | 79·1 | 79·2 | | 80·4 | 1·85 | 78·8 | 57·2 |
| 9. | 40 | 4·6 | 568·1 | 38 | 58·3 | 59·3 | 60 | 66 | 64 | 79 | 80·6 | 80·5 | | 80·5 | 0·33 | 80·1 | 61·5 |
| 10. | 45 | 4·4 | 543·4 | 37 | 62·5 | 63·6 | 63·9 | 77·1 | 67·8 | 81·4 | 83·7 | 83·8 | | 84·8 | 1·65 | 75·9 | 66·9 |
| 11. | 50 | 4·2 | 518·7 | 37 | 65·3 | 66 | 65·8 | 71·8 | 69·1 | 81·6 | 83·3 | 83·3 | | 84·8 | 0·73 | 83 | 67·6 |
| 12. | 60 | 4·3 | 531·05 | 38 | 68·1 | 69·7 | 70·3 | 75·4 | 73·4 | 86·2 | 86·9 | 86·9 | | 87·5 | 2·9 | | |
| 13. | 65 | 4·1 | 506·35 | 37 | 68 | 74·4 | 74 | 80·3 | 76·2 | 87·8 | 88·2 | 88·6 | | 88·1 | 1·4 | | |

9.10.24

For Solar flux, conversion factor from mV to W/m² is mV x 123.5= W/m²
Assume Transmissivity-Absorptivity factor (τα) =0.95

***Tabulated Results:***

| Material in the pot | Slopes 'b' | Intercept $\ln\left(\frac{I(\tau\alpha)A}{MC}\right)$ | Time constant 1/b (minutes) | Actual time constant $\left(\frac{3}{b}\right)$ (minutes) | Average I(τα) W/m² | I(τα)/$U_l$ (°C) | $U_l$ (W/m²K) |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Water | 0·029 | −0·4 | 34·48 | 103·44 | 571·80 | 60·03 | 11·46 |
| | | | | | | | High |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

22MEB173 GL6695 A3MA-05

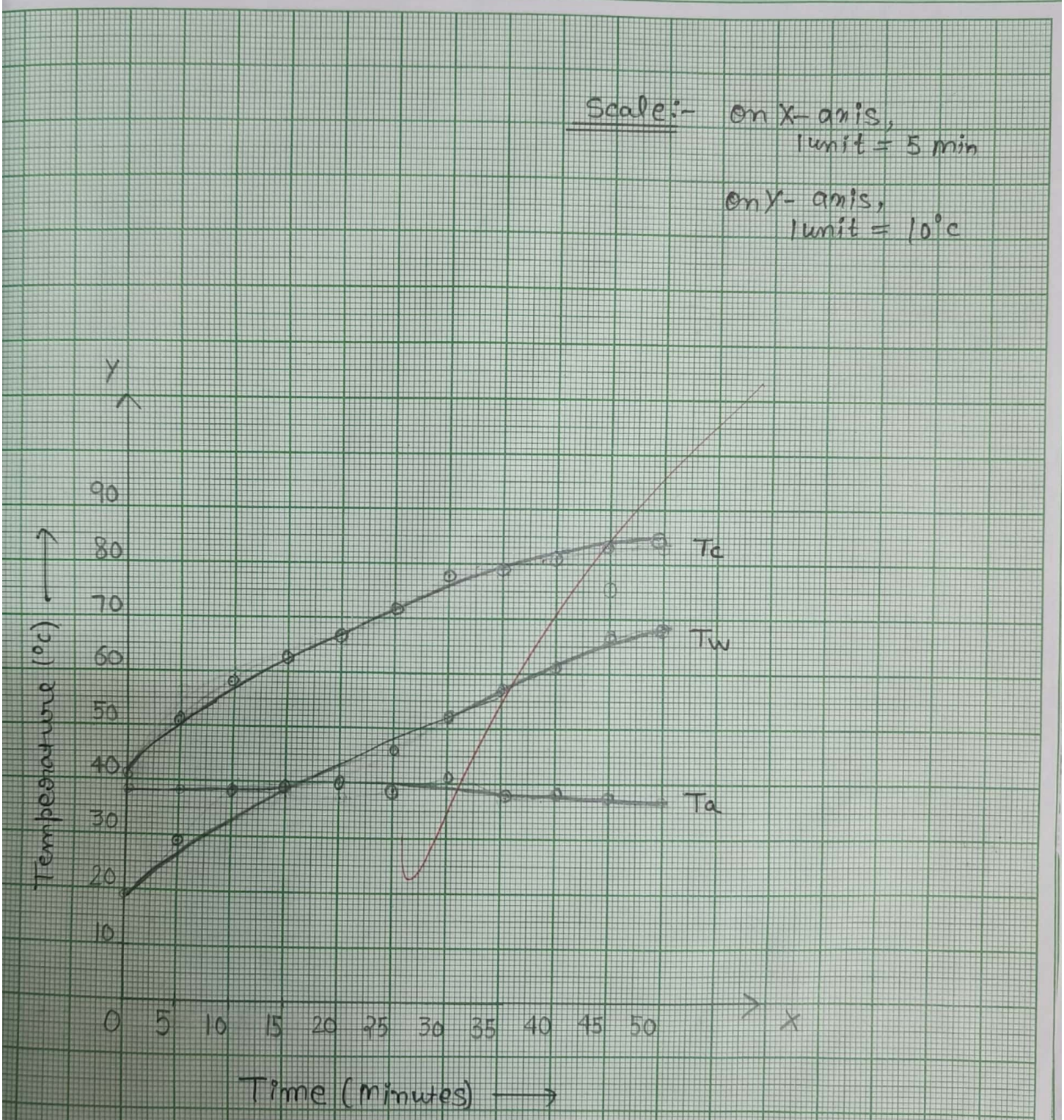
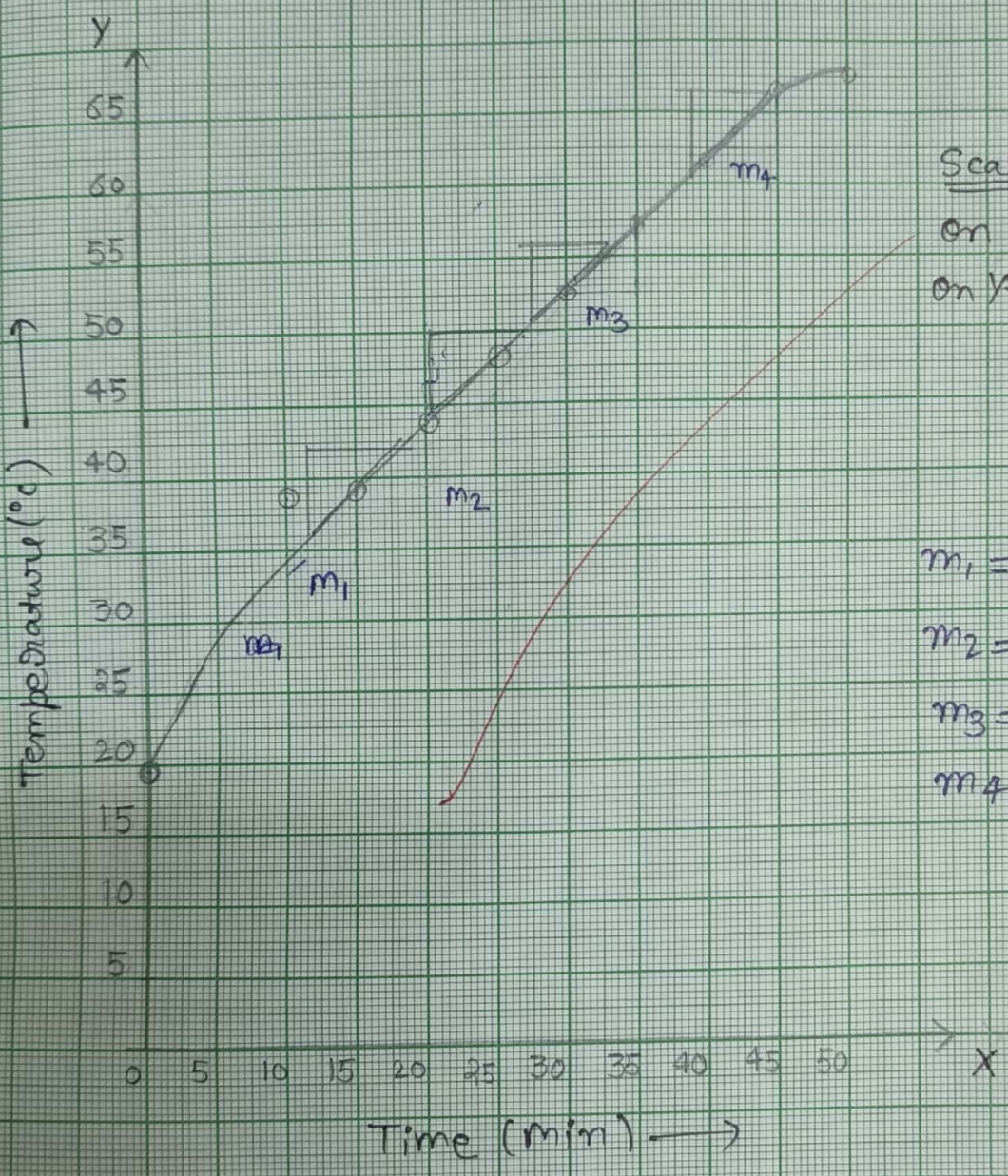



Fig. 1 Shows the temperature (°c) v/s Time (min) for Tc, Tw & Ta

22MEB173 GL6095 A3MA-05




Scale,

On X-axis, 1 unit = 5 min

On Y-axis 1 unit = 5 °C

$m_1 = 0.69$

$m_2 = 0.61$

$m_3 = 0.55$

$m_4 = 0.42$

Fig (2) Shows Tw V/S Time.

## Sample calculations :-

22MEB173 GL6695 A3MA.

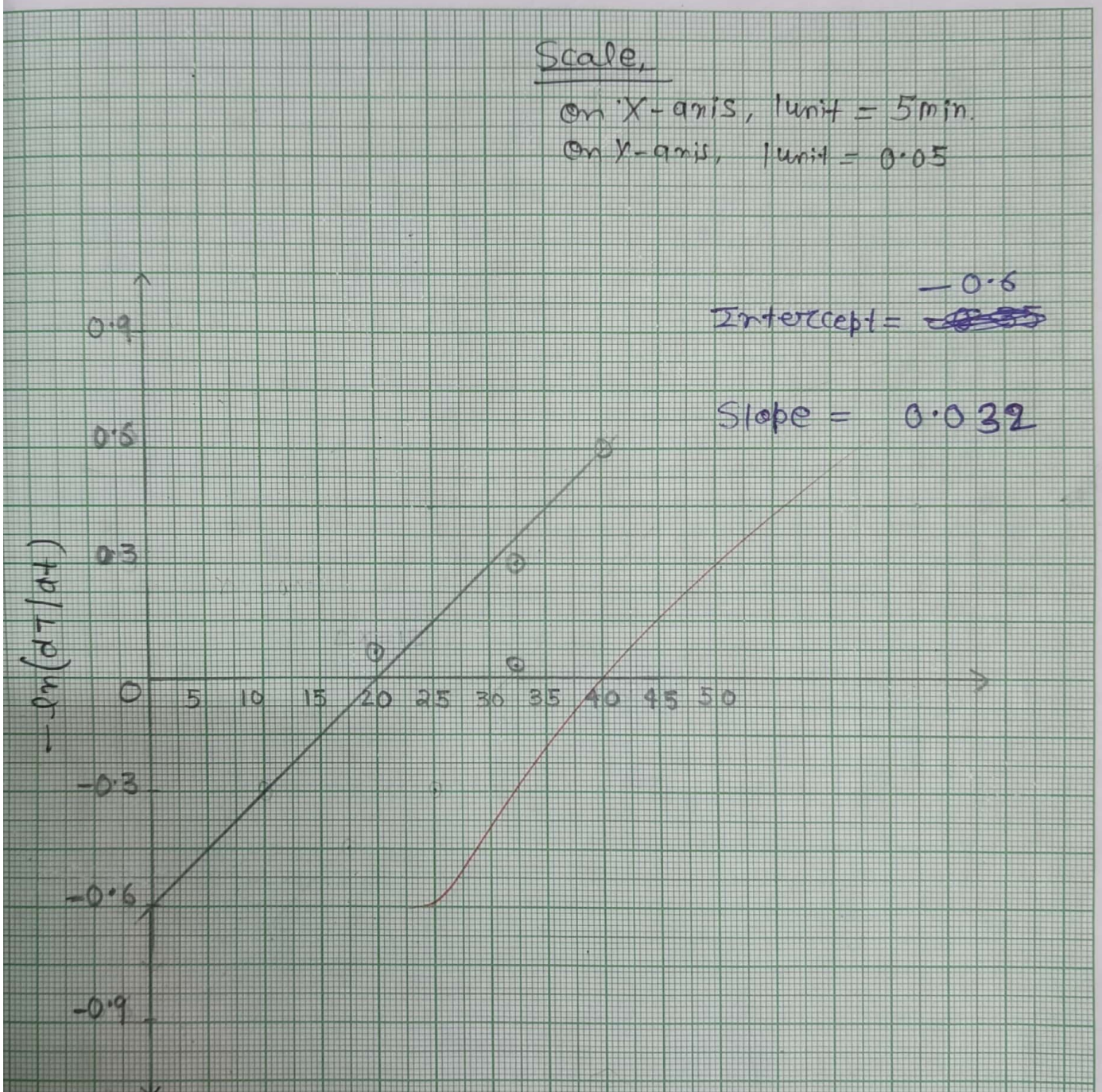



Fig. 3 Variation of $-\ln(dT/dt)$ with time (min)

## Sample calculations :-

Average temperature of material into the pot (°c)

for Reading NO. 3,

$$T_w = \frac{34.3 + 34.7 + 45.8 + 36.2 + \cancel{48.} \; 40.8}{5}$$

$$\boxed{T_w = 38.3\,°c}$$

Average temperature of cooking pot cover (°c)

$$T_c = \frac{58.1 + 60 + 59.8 + 60.3}{4}$$

$$\boxed{T_c = 59.5\,°c}$$

Similarly for other readings. we plot them on graph.

Now, finding slope on 4 equally spaced point $T_w$ Curve

$m_1 = 0.69$

$m_2 = 0.61$

$m_3 = 0.55$

$m_4 = 0.42$

taking $-\ln$ of the slope.

$-\ln(m_1) =$ 0.371

$-\ln(m_2) =$ 0.494

$-\ln(m_3) =$ 0.597

$-\ln(m_4) =$ 0.867

On plot the above values on graph and find slope and intercept of line,

1) slope of line $= \frac{\Delta y}{\Delta x} = 0.029$

2) Intercept $= -0.35$

• Time constant $(t) = \frac{m \times c}{U_1 A} = \frac{1}{0.029} = 34.48$

• Intercept $= +\ln\left(\frac{I \times \tau \times d \times A}{m \times c}\right)$

$= \frac{I \times \tau \times d \times A}{m \times c} = e^{0.4} = 1.49$

$$I = \frac{5.2 + 4.9 + 4.5 + 4.6 + 4.9 + 5.1 + 4.9 + 4.5 + 4.6 + 4.4 + 4.2 + 4.3 + 4.1}{13}$$

$\boxed{I = 4.63\ mV}$

$\Rightarrow 4.63 \times 123.5 \times 60 \Rightarrow 3.43 \times 10^4\ J/m^2 min$

$\frac{I(\tau \alpha A)}{MC} \Rightarrow 1.49$

$\frac{A}{MC} \Rightarrow \frac{1.49}{3.43 \times 104 \times 0.95} \Rightarrow 4.88 \times 10^{-5}\ m^2 min/J$

$U_1^* = \frac{0.029}{4.88 \times 10^{-5}} \Rightarrow 688$

$U_1 = \frac{688}{60} \Rightarrow 11.46\ W/m^2K$

## Discussion,

from the observation we can observe that as the time increases temp. in water goes on increasing and after some time it attains steady state, This is very little change in the value of temp. of pot cover and point very from the curve due to experimetal error and surrounding disturbances.

# HEAT TRANSFER AND SOLAR ENERGY LABORATORY

**Class:** A3MA **Section:** A **S. No.** 05

**Course Title** : **Heat and Mass Transfer Laboratory**

**Course Number** : **MEC 3910**

**Experiment (Brief Title):** Emissivity & Stefan Baltzman constant

Date of Experiment Performed : 16/10/24
Due date of Submission :
Late Submission date : 06/11/24

Teachers' Remark :

Marks Awarded :

| Rubric No. | I | II | III | IV | V | Total |
|---|---|---|---|---|---|---|
| Maximum Marks | 1 | 1 | 2 | 3 | 3 | 10 |
| Marks awarded | 1 | 1 | 2 | 2 | 2 | 8.0 |

Rubrics for laboratory courses

I. Object of the experiment and specifications of the equipment/instruments used.
II. Brief theory and related equations used
III. Observation Sheets, Sample calculations (student should explain at the time of evaluation)
IV. Results mathematical/graphical (student should explain at the time of evaluation)
V. Discussions (should be different from other students)

Name : Nikhil Singh
Class : A3MA
S. No. : 05
Faculty No. : 22MEB173
En. Roll. No. : GL6695

| | |
|---|---|
| Test Plate, diameter =160mm | Temperature Indicator: 0 300 °C with compensation for room temperature |
| Black Plate, diameter =160 mm | Enclosure size: 58cm x 30 cm x 30 cm approximately with one side of Perspex sheet |
| Voltmeter: 0-100-200 V, Ammeter: 0-2 Ampere | Heaters for Plate 1 & 2 : Nichrome strip wound on mica sheet and sand witched between two mica sheets. |
| Thermocouples – Chromel Alumel – (3Nos.) | |
| Dimmerstats for Plate 1&2 : 0- 2A, 0.260 V. | D.P.S.T. Switch. |

Name: Nikhil Singh Class: A3MA S.No: 05 Date: 16/10/24

**Observation Table:**

| S. No. | Time | Black plate | | | | Test plate | | | | Ambient Temperature |
|---|---|---|---|---|---|---|---|---|---|---|
| | | V | I | $q_1$ | Temperature | V | I | $q_2$ | Temperature | |
| 1) | 60 | 50 | 0.65 | | 66 | 40 | 0.52 | | 66 | 35 |
| 2) | 75 | 60 | 0.75 | | 74 | 50 | 0.65 | | 74 | 35 |
| 3) | 90 | 70 | 0.85 | | 89 | 60 | 0.75 | | 89 | 36 |

16/10/24

**Note**: The emissivity of the test plate can be calculated at various temperatures of the plates. With increase in temperature, the test surface becomes somewhat dull and therefore its emissivity increases with increase of surface temperature. This fact could be verified by performing the experiments at various values of $T_S$ and can be plotted in a graph as shown in Fig. 3.

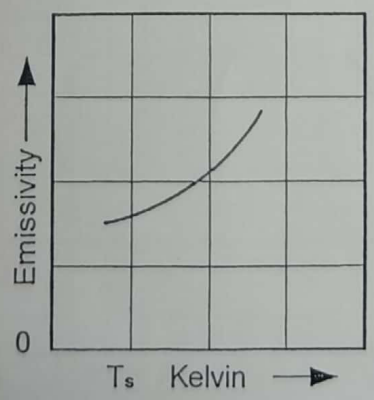



Fig.3 Variation of Emissivity with surface temperature

| $T_S$(K) | $\varepsilon$ |
|---|---|
| 339 | 0.64 |
| 347 | 0.72 |
| 362 | 0.75 |

**REFEREFNCE:**


1- A text book on Heat Transfer By Dr. S.P. Sukhatme
2- Experimental methods for Engineering By J.P. Holman

# Sample calculations.

Nikhil Singh 22MEB173 GL6695 A3MA-05

Scale,

On X-axis :- 1 unit = 5 K

On Y-axis :- 1 unit = 0.1

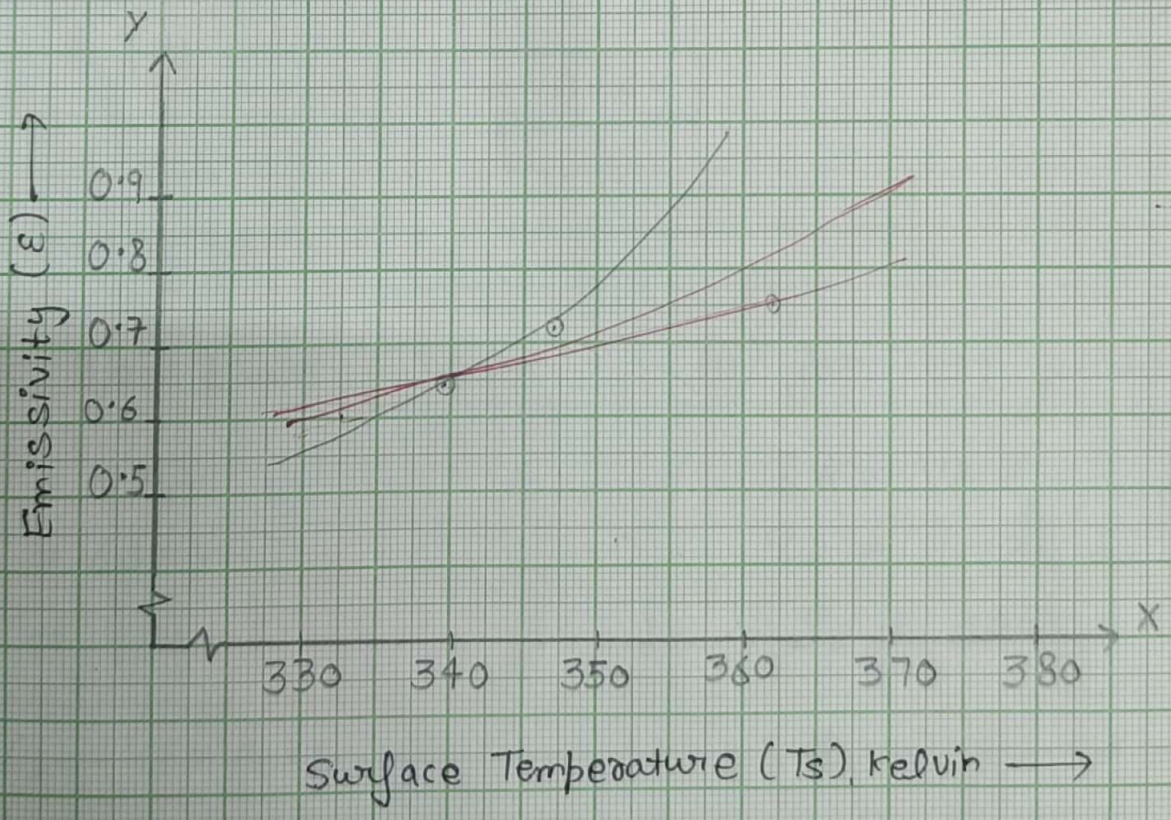



Fig. 1 shows variation of Emissivity (ε) with Surface Temp. (Ts)

# Sample calculations.

## For Reading NO. 1

(i) for Black plate

$q_1 = V \times I$

$q_1 = 50 \times 0.65$

$q_1 = 32.5\ w$

$\therefore q_b = q_1 \times 0.86$

$q_b = 27.95\ w$

(ii) for Test plate

$q_2 = V \times I$

$q_2 = 40 \times 0.52$

$q_2 = 20.8\ w$

$q_s = q_2 \times 0.86$

$q_s = 17.88\ w$

Now, Emissivity $(\varepsilon) = \dfrac{q_s}{q_b} = \dfrac{17.88}{27.95} = 0.64$

$$\boxed{\varepsilon = 0.64}$$

## For Reading NO. 2

) For Black plate

$q_1 = V \times I$

$q_1 = 60 \times 0.75$

$q_1 = 45\ w$

$\therefore q_b = 45 \times 0.86$

$q_b = 38.7\ w$

(ii) for Test plate

$q_2 = V \times I$

$q_2 = 50 \times 0.65$

$q_2 = 32.5\ w$

$\therefore q_s = 32.5 \times 0.86$

$q_s = 27.95\ w$

Now Emissivity $(\varepsilon) = \dfrac{q_s}{q_b} = \dfrac{27.95}{38.7} = 0.722$

$$\boxed{\varepsilon = 0.72}$$

- For Reading No. 3

(i) for ~~test~~ Black plate

$q_1 = V \times I$

$= 70 \times 0.85$

$q_1 = 59.5\,W$

$\therefore q_b = q_1 \times 0.86$

$q_b = 51.17\,W$

(ii) for test plate

$q_2 = V \times I$

$= 50 \times 0.75$

$q_2 = 45\,W$

$q_s = 45 \times 0.86$

$q_s = 38.7\,W$

Now Emissivity $(\varepsilon) = \frac{q_s}{q_b} = \frac{38.7}{51.17} = 0.756$

$$\boxed{\varepsilon = 0.75}$$

Graph Discussion:-

From the graph between emissivity and surface Temp. We ~~observe~~ observe that as the temperature is increasing the emissivity also increases and there is a non-linear relationship b/w these quantities.

# HEAT TRANSFER AND SOLAR ENERGY LABORATORY
# DEPARTMENT OF MECHANICAL ENGINEERING, AMU, ALIGARH

## STEFAN BOLTZMAN CONSTANT

**Object:** To determine Stefan Boltzmann constant

**Introduction:** 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 $\frac{q}{A} = \sigma T^4$ , $W/m^2$. The constant of proportionality, $\sigma$ is called the Stefan Boltzmann constant and has the value of $\sigma = 5.67 \times 10^{-8}$ , $W/m^2 K^4$ [$4.876 \times 10^{-8}$, $kcal/hm^2 K^4$

The Stefan Boltzmann Law can be derived by integrating the Planck's Law over the entire spectrum of wave lengths from 0 to $\infty$, though historically it is worth noting that the Stefan Boltzmann Law was independently developed before Planck's Law. The object of this experimental sat up is to measure the value of this constant fairly close, by an easy arrangement.

**Apparatus:** The apparatus as illustrated in Fig. 1 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 C used to heat B to some suitable constant temperature. The hemispherical shape of B is chosen solely on the grounds that it simplifies the task of draining the water between B and C. Four Chromel- Alumel thermocouples are attached to various points on surface of B to measure its mean temperature to be read by a Temperature Indicator.

The disk D, which is mounted in an insulated Bakelite sleeve S, is fitted in a hole drilled in the centre of base plate A. The base of S is conveniently supported from under side of A. A Chromel- Alumel thermocouple is used to measure the temperature of D ($T_5$). The 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 temperature change of disk with time is used to calculated the Stefan Boltzmann constant.

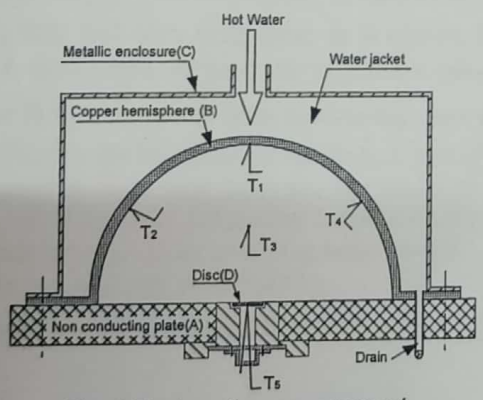



Fig. 1 Test section arrangement

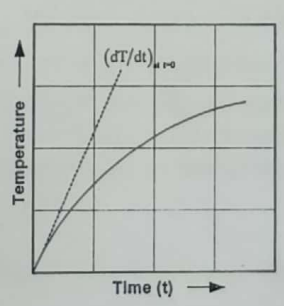



Fig. 2 Variation of Disc temperature with time

**Specifications:**

1. Hemispherical enclosure diameter = 200mm.
2. Base Plate , Bakelite diameter = 240mm.
3. Sleeve size , diameter = 44mm.
4. Test Disc diameter 20mm.
5. Mass of test disc. 7.7 gm
6. Specific heat , S of the test disc (copper) = 0.41868 kJ/kg°C (0.1 kcal/kg m°C).
7. No. of Thermocouples mounted on B = 4
8. No. of Thermocouples mounted on D =1

9. Temperature Indicator Digital (0.1°C Least count): 0-200°C with built in cold junction compensation.
10. And a timer set for 5 s to display temperature rise of the disc.
11. Immersion water heater of suitable capacity, tank for hot water, suitable size water jacket for hemisphere, fixing arrangement for sleeve (Fig.1)

*The surface of B and A forming the enclosure are blackened by using lamp black to make their absorptivity, approximately unity. The copper surface of the disc D is also blackened.*

**Experimental Procedure:**

1. Heat the water in the tank by the immersion heater up to a temperature of about 90°C.
2. The disk D is removed before pouring the hot water in the jacket.
3. The hot water is poured in the water jacket. The hemispherical enclosure B and A will come to some uniform temperature T in short time after filling the hot water in the jacket. The thermal inertia of hot water is quit adequate to prevent significant cooling in the time required to conduct the experiment.
4. The enclosure will soon come to thermal equilibrium conditions.
5. The disk D is now inserted in A at a time when its temperature is say, $T_5$ (To be sensed by a separate thermocouple).

The radiant energy falling on D from the enclosure is given by $E=\sigma A_D T^4$ , W (1)

Where, $A_D$ = area of the disc D and T = average temperature of the enclosure recorded by the thermocouples.

The emissivity of the disc D is assumed to be unity (Black Disc).

The radiant energy emitted by the disc D into the enclosure will be $E_1=\sigma A_D T_5^4$ (2)

Net heat input to the disc D per unit time is given by $E-E_1=\sigma A_D\left(T^4-T_5^4\right)$ (3)

If the disc D has mass m and specific heat $C_p$ then, in a short time after D is inserted in A,

$$m C_p \left(dT/dt\right)_{at\ t=0}=\sigma A_D\left(T^4-T_5^4\right) \text{, therefore,} \qquad \sigma=\frac{m C_p \left(dT/dt\right)_{at\ t=0}}{A_D\left(T^4-T_5^4\right)} \qquad (4)$$

In this equation, $\left(dT/dt\right)_{at\ t=0}$ denotes the rate of temperature rise of the disc D at the instant when its temperature is $T_5$ that will vary with time. It is clearly best measured at time t = 0 before heat conduction from A to D begins to have any significant effect. $\left(dT/dt\right)_{at\ t=0}$ is obtained from the plot of temperature rise of D with respect to time, by drawing slope at t = 0 when temperature = $T_5$ (see Fig. 2). Note that the disc D with its insulating sleeve S, is placed quickly in position and start the timer and record the temperature at fixed time intervals. The whole process is completed in about 30 seconds of time. Longer D is left in position, the greater is the probability of errors due to heat conduction from A to D. The experiment is repeated for obtaining better results.

1- Mass of the test disc (m) = 0.0077 kg
2- Specific heat (S) of disc material (Copper) = 0.41868 kJ/kg°C (0.1 kcal/ kg m °C)

Name: Nikhil Singh Class: A3MA S.No: 05 Date: 16/10/24

| OBSERVATIONS | | | |
|---|---|---|---|
| Temperature of disc D before insertion 27.7 (°C) | | Temperature of disc D when it is inserted | |
| Thermocouple No. | Temperature (°C) | Time (s) t | Temperature ($T_5$) °C |
| $T_1$ | 88.3 | 0 | 27.7 |
| $T_2$ | 88.0 | 5 | 28.4 |
| $T_3$ | 88.9 | 10 | 30.5 |
| $T_4$ | 89.7 | 15 | 31.3 |
| | | 20 | 31.7 |
| | | 25 | 31.9 |

16/10/24

3- Average temperature in °C = $\frac{T1 + T2 + T3 + T4}{4}$ = 88·7 °C = 361·7 K

4- Temperature of disc D at the instant when it is inserted ($T_5$), $T_5$ = 27·7 in °C = ~~29~~ 300·7 in K

5- Temperature time response of the disc.

Use the Disc Thermocouple on Temperature Indicator and note down $T_5$ at the time interval of 5 s. Plot the graph of T against t as shown in Fig. 2.

6- Obtain slope from the graph: $(dT/dt)_{at\ t=0}$ = 0·36 °C/s

7- Valve of σ can be obtained by using equation (4)

8- Discuss on the result obtained.

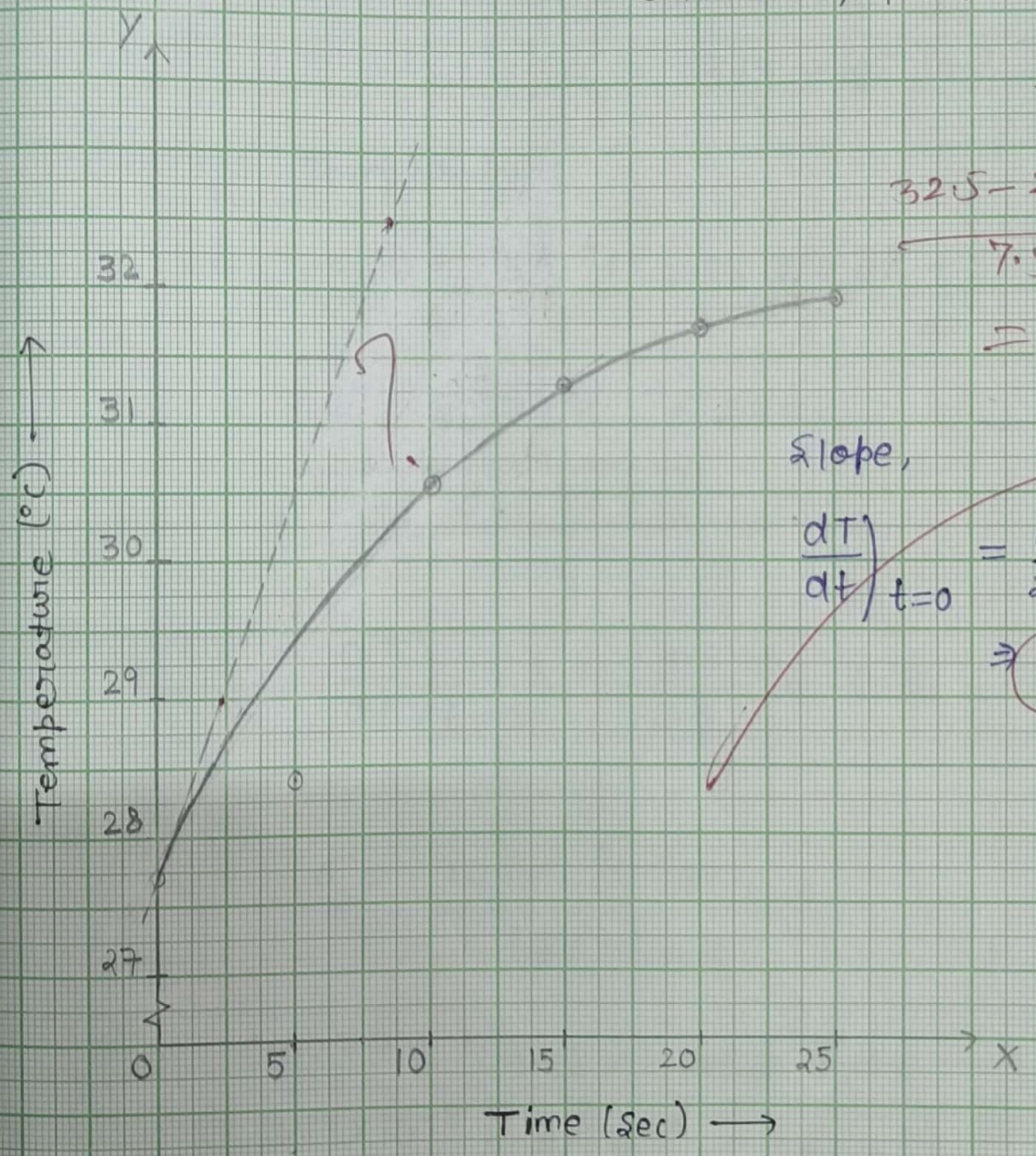
ample calculations,

Nikhil Singh 22MEB173 GL6695 A3MA-05

Scale:-

On X-axis, 1 unit = 2.5 sec

On Y-axis, 1 unit = 0.5 °C




$$\frac{32.5 - 29.0}{7.5} = 0.46$$

Slope,

$$\left.\frac{dT}{dt}\right)_{t=0} = \frac{0.9}{2.5} \Rightarrow 0.36\ °C/s$$

Fig. 2 Shows Temperature V/s Time.

8 °C

7

4

## Sample calculations,

given that,

- Mass of the flat disc (m) = 0.0077 kg.
- Specific heat ($C_p$) of the disc material (copper) = 0.41868 kJ/kg°C
- Test disc diameter = 20 mm

$$\therefore \text{area} = \pi (0.1 \times 10^{-3})^2$$

$$A_0 = 3.14 \times 10^{-4} m^2$$

- Average Temperature

$$T = \frac{T_1 + T_2 + T_3 + T_4}{4} = \frac{88.3 + 88 + 88.9 + 89.7}{4}$$

$$T = 88.72°C + 273 K$$

$$\boxed{T = 361.72 K}$$

from graph, $\left.\frac{dT}{dt}\right)_{t=0} = \frac{0.9}{2.5} = 0.36$ °c/s

from eqn ①

$$\sigma = \frac{m C_p (dT/dt)_{t=0}}{A_0 (T^4 - T_5^4)}$$

$$\sigma = \frac{0.0077 \times 418.68 \times 0.46}{3.14 \times 10^{-4} [361.72^4 - 300.7^4]} = 5.359 \times 10^{-7} \ W/m^2K^4$$

$$\boxed{\cancel{\sigma = 4.196 \times 10^{-7} \ W/m^2K^4}}$$

~~% error = $\left[\frac{5.67\times10^{-8} - 4.19\times10^{-7}}{5.67\times10^{-8}}\right]\times100$~~

~~% error = 0.261 × 100~~

~~⇒ 26.1% error,~~

# Discussion on graph,

- from the graph b/w disc temp. and time we observe that the temperature will increase w.r.t time. and non-linear in nature,

- The value of Stefen-Boltzmann constant obtained is ~~$4.19\times10^{-7}$ W/m² K⁴~~. $5.359\times10^{-7}$ W/m² K⁴

- whereas standard value is $5.67\times10^{-8}$ W/m² K⁴

- ~~Therefore percentage error will be about 26.1% that is due to observations, apparatus.~~

# HEAT TRANSFER AND SOLAR ENERGY LABORATORY

**Class:** A3MA **Section:** A **S. No.** 05

**Course Title** : **Heat and Mass Transfer Laboratory**

**Course Number** : **MEC 3910**

**Experiment (Brief Title):** Transient Heat conduction

Date of Experiment Performed : 06/11/24
Due date of Submission :
Late Submission date : 13/11/24

Teachers' Remark :

Marks Awarded :

| Rubric No. | I | II | III | IV | V | Total |
|---|---|---|---|---|---|---|
| Maximum Marks | 1 | 1 | 2 | 3 | 3 | 10 |
| Marks awarded | 1 | 1 | 2 | 2½ | 2 | 8½ |

Rubrics for laboratory courses

I. Object of the experiment and specifications of the equipment/instruments used
II. Brief theory and related equations used
III. Observation Sheets, Sample calculations (student should explain at the time of evaluation)
IV. Results mathematical/graphical (student should explain at the time of evaluation)
V. Discussions (should be different from other students)

Name : Nikhil Singh

Class : A3MA

S. No. : 05

Faculty No. : 22MEB173

En. Roll. No. : GL6695

Name: Nikhil Singh S.N. 05 Class: A3MA Date 06/11/24

**Observation Table:**

| ***Forced convection*** | | | | ***Free convection*** | | | |
|---|---|---|---|---|---|---|---|
| Heat supplied to the heater = 400 W | | | | Heat supplied to the heater = 400 W | | | |
| Velocity of air = 2.7 m/s | | | | Velocity of air = m/s | | | |
| Temperature of air in the duct, $T_f$ = 30 °C | | | | Temperature of air in the duct, $T_f$ = 28 °C | | | |
| Time for heat supply = s | | | | Time for heat supply = s | | | |
| Time in sec. | Temperature (°C) | Time in sec. | Temperature (°C) | Time in sec. | Temperature (°C) | Time in sec. | Temperature (°C) |
| 0 | 180 | 450 | 80 | 0 | 180 | 960 | 85 |
| 15 | 173 | 465 | 78 | 30 | 172 | 1020 | 83 |
| 30 | 168 | 480 | 77 | 60 | 166 | 1080 | 80 |
| 45 | 163 | 495 | 75 | 90 | 160 | 1140 | 78 |
| 60 | 158 | 510 | 73 | 120 | 155 | 1200 | 75 |
| 75 | 154 | 525 | 72 | 150 | 150 | 1260 | 73 |
| 90 | 149 | 540 | 70 | 180 | 146 | 1320 | 71 |
| 105 | 145 | 555 | 69 | 210 | 143 | 1380 | 69 |
| 120 | 141 | 570 | 68 | 240 | 138 | 1440 | 67 |
| 135 | 137 | 585 | 66 | 270 | 136 | 1500 | 66 |
| 150 | 133 | 600 | 65 | 300 | 132 | 1590 | 63 |
| 165 | 129 | 630 | 63 | 330 | 129 | 1680 | 61 |
| 180 | 126 | 660 | 61 | 360 | 126 | 1770 | 59 |
| 195 | 122 | 690 | 59 | 390 | 123 | | |
| 210 | 119 | 720 | 57 | 420 | 120 | | |
| 225 | 116 | 750 | 55 | 450 | 117 | | |
| 240 | 113 | 780 | 53 | 480 | 116 | | |
| 255 | 110 | 810 | 52 | 510 | 113 | | |
| 270 | 107 | 840 | 50 | 540 | 110 | | |
| 280 | 104 | 870 | 49 | 570 | 108 | | |
| 300 | 101 | 900 | 47 | 600 | 106 | | |
| 315 | 98 | 930 | 46 | 630 | 105 | | |
| 330 | 96 | 960 | 45 | 660 | 103 | | |
| 345 | 94 | 990 | 44 | 690 | 99 | | |
| 360 | 92 | 1020 | 43 | 720 | 98 | | |
| 375 | 90 | 1050 | 42 | 750 | 96 | | |
| 390 | 88 | 1080 | 41 | 780 | 94 | | |
| 405 | 86 | 1110 | 40 | 810 | 93 | | |
| 420 | 84 | | | 840 | 92 | | |
| 435 | 82 | | | 900 | 89 | | |

6.11.24

***Results obtained***

| Mode | $h_a$ from T~t plot | $h_a$ from log plot | Bi | Q (J) | Time constant τ from T~t plot | Time constant τ from log plot |
|---|---|---|---|---|---|---|
| Forced | 64.59 | 49.319 | 0.00259 | -5899 | 427.65 | 428.55 |
| Free | 21.033 | 13.399 | 0.000723 | -2041.2 | 977.80 | 1158.23 |

22MEB173
GL6695
A3MA-05

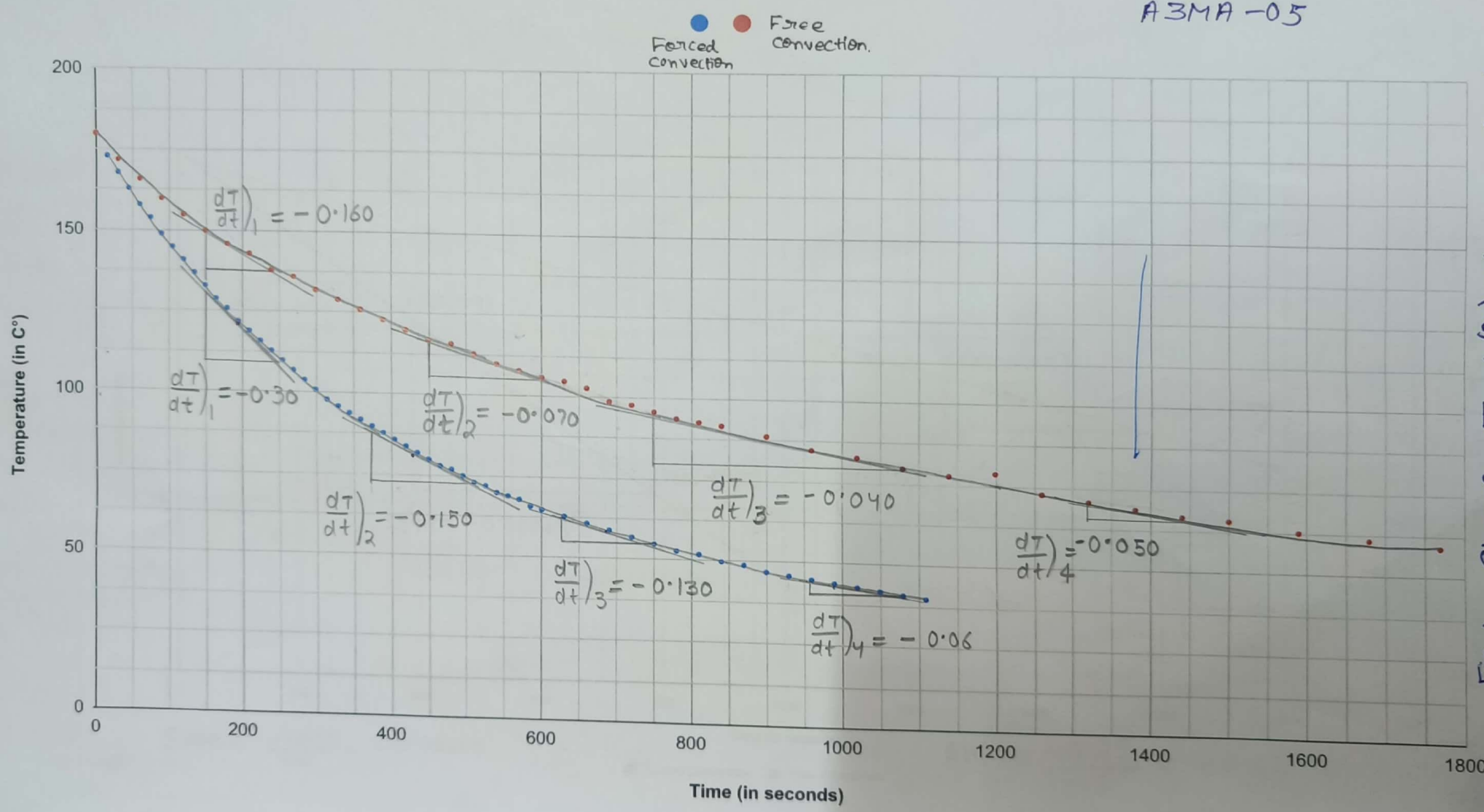
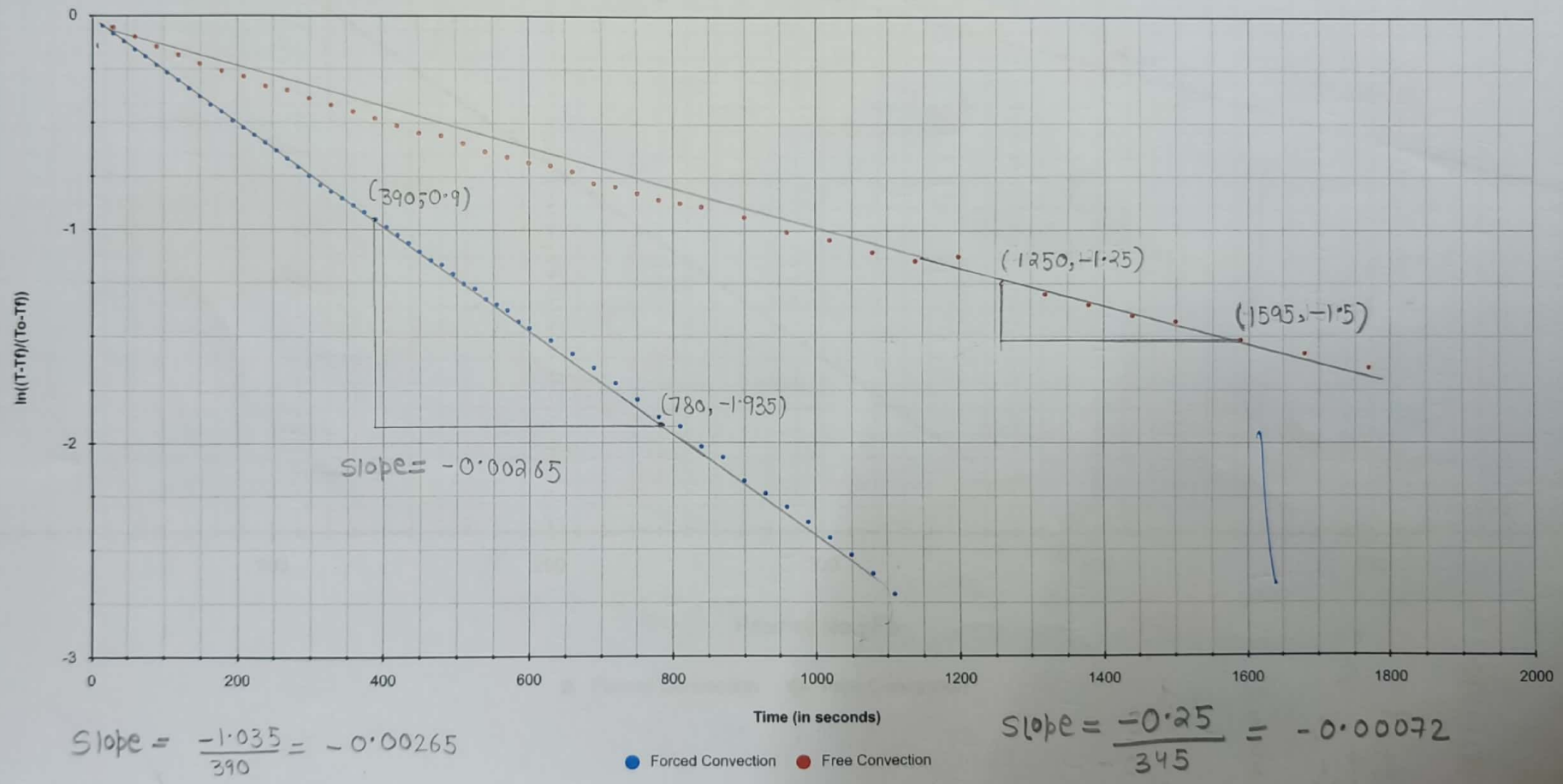



Fig 1 Shows Temp.(°C) V/S Time (sec).

22MEB173 GL6695 A3MA-05




Slope = $\frac{-1.035}{390}$ = -0·00265

Slope = $\frac{-0.25}{345}$ = -0·00072

Fig.2 Shows ln $\left(\frac{T-T_f}{T_o-T_f}\right)$ v/s Time (sec)

22MEB173 GL6695 A3MA-05

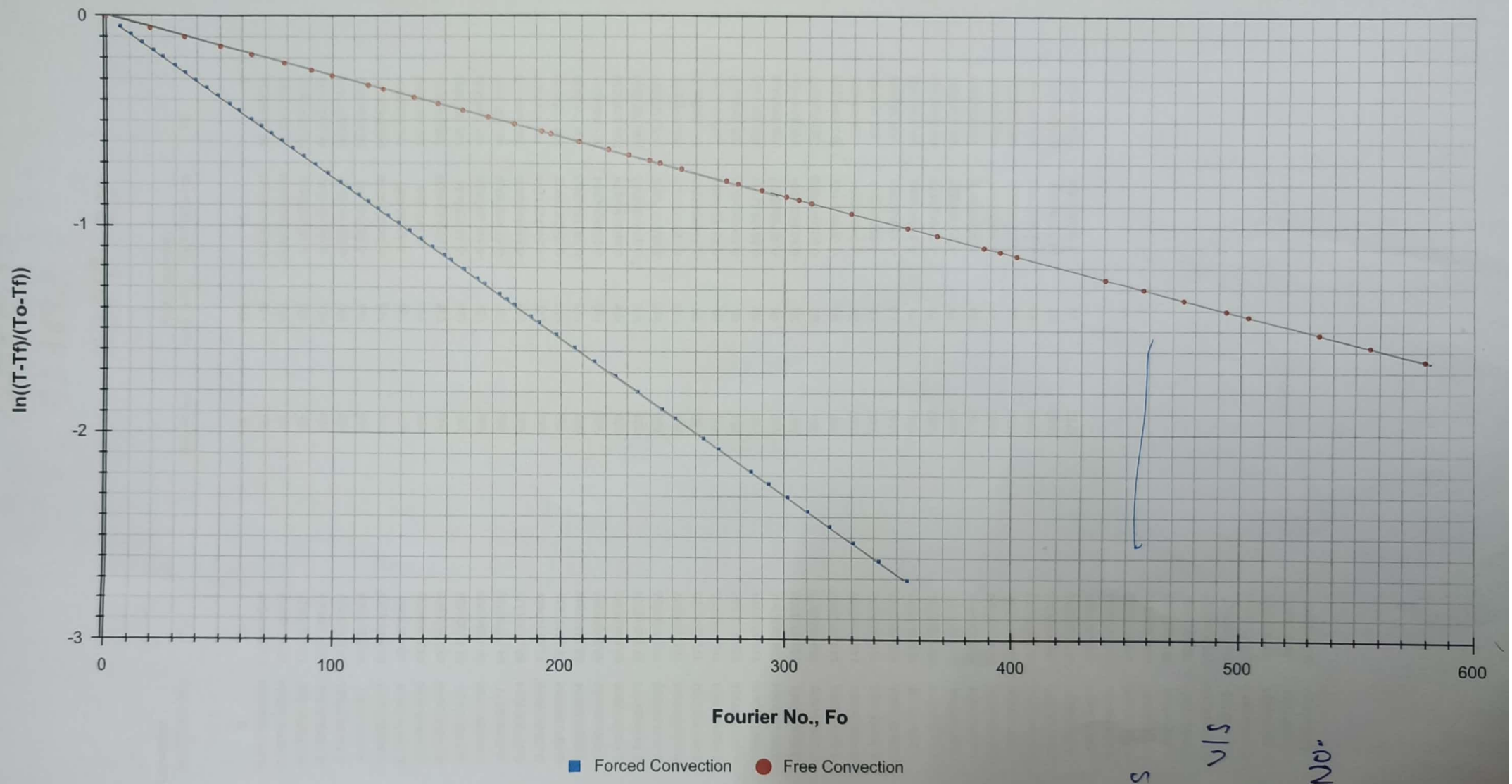



Fig. 3 shows $\ln \frac{T-T_f}{T_o-T_f}$ v/s Fourier No.

## Sample calculations

### 1) Forced convection

$$A = \pi d l$$
$$= \pi \times \frac{25.41}{1000} \times \frac{229}{1000}$$
$$A = 0.08128\ m^2$$

Temperature V/S Time

$\left.\frac{dT}{dt}\right)_1 = -0.30$, at $120°C$.

$\left.\frac{dT}{dt}\right)_2 = -0.150$ at $80°C$

$\left.\frac{dT}{dt}\right)_3 = -0.130$ at $60°C$

$\left.\frac{dT}{dt}\right)_4 = -0.06$ at $40°C$

$$h_1 = \frac{-MC\,(dT/dt)_1}{A(T-T_f)} = \frac{-0.7 \times 486 \times -0.30}{0.018\,(120-30)} = 62.96\ W/m^2\,°C$$

$$h_2 = \frac{-MC\,(dT/dt)_2}{A(T-T_f)} = \frac{-0.7 \times 486 \times -0.150}{0.018 \times (80-30)} = 60.162\ W/m^2\,°C$$

$$h_3 = \frac{-0.7 \times 486 \times -0.130}{0.018 \times (60-30)} = 64.36\ W/m^2\,°C$$

$$h_4 = \frac{-0.7 \times 486 \times -0.06}{0.018 \times (40-30)} = 70.903\ W/m^2\,°C$$

$$h_a = \frac{h_1 + h_2 + h_3 + h_4}{4} = \frac{62.96 + 60.162 + 64.36 + 70.903}{4}$$

$$h_a = 64.59\ W/m^2\,°C$$

2) for free convection :-

$$\left.\frac{dT}{dt}\right)_1 = -0.160 \quad \text{at } 142^\circ c$$

$$\left.\frac{dT}{dt}\right)_2 = -0.070 \quad \text{at } 112^\circ c$$

$$\left.\frac{dT}{dt}\right)_3 = -0.040 \quad \text{at } 83^\circ c$$

$$\left.\frac{dT}{dt}\right)_4 = -0.050 \quad \text{at } 68^\circ c$$

$$h_1 = \frac{-0.7 \times 486 \times -0.160}{0.01828(142-30)} = 26.58 \ w/m^2 {}^\circ c$$

$$h_2 = \frac{-0.7 \times 486 \times -0.070}{0.01828(112-30)} = 18.9 \ w/m^2 {}^\circ c$$

$$h_3 = \frac{-0.7 \times 486 \times -0.040}{0.01828 \times (83-30)} = 14.07 \ w/m^2 {}^\circ c$$

$$h_4 = \frac{-0.7 \times 486 \times -0.050}{0.01828 \times (68-30)} = 24.48 \ w/m^2 {}^\circ c$$

$$h_a = \frac{26.58 + 18.9 + 14.07 + 24.48}{4} = 21.033 \ w$$

Q=4 Ensure that the values of Bi are less than 0.1 in order to justify using the lumped heat capacity method.

⇒ Clearly Bi for forced convection & free convection are 0.00259 & 0.00723. which is clearly less than 1

=5 Show that instantaneous rate of heat transfer 'q' and total heat loss 'Q' from rod during cooling are,

$q = hA(T_f - T_0)\, e^{-Bi\,Fo}$ &

$Q = \rho C V (T_0 - T_f)\left[e^{-Bi\,Fo} - 1\right] J$

$$\frac{T - T_f}{T_0 - T_f} = e^{-hA/\rho C V t}$$

$$T = T_f + (T_0 - T_f)\, e^{-hA/\rho C V t}$$

$$q = \rho C V \cdot \frac{dT}{dt}$$

$$q = (T_0 - T_f)\, hA\, e^{-Bi\,Fo}$$

Total heat Loss, $Q = \rho C V (T_0 - T_f)\left[e^{-Bi\,Fo} - 1\right]$

$\therefore Q_{forced} = 0.7 \times 486 \times (170 - 119)\left[e^{-0.0283 \times 54.423} - 1\right]$

$= -5.688\ kJ$

$Q_{free} = 0.7 \times 486 \times (180 - 160)\left[e^{-0.00723 \times 78.698} - 1\right]$

$= -2.032\ kJ$

(ii) from graph, $\ln \frac{T - T_f}{T_0 - T_f}$ v/s Time

- Forced convection, Slope = $-0.00265$

$$h = \frac{0.000265 \times 0.7 \times 486}{0.01828} = 49.317$$

$$\boxed{h = 49.317 \ W/m^2 {}^\circ C}$$

- Free convection, Slope = $-0.00072$

$$h = \frac{0.00072 \times 0.7 \times 486}{0.01828}$$

$$\boxed{h = 13.399 \ W/m^2 {}^\circ C}$$

forced convection ;-Slope = $Bi = 0.00259$

free convection ;-Slope = $Bi = 0.000723$

Q=6

$$\tau = \frac{\rho C V}{hA} = \frac{MC}{hA} \quad : \quad A = \pi D L$$

for forced convection, $\tau = \frac{0.7 \times 486}{64.59 \times 0.01828} = 288.13 \text{ sec}$

for free convection, $\tau = \frac{0.7 \times 486}{21.033 \times 0.01828} = 884.95 \text{ sec}$

Q=7 Discuss the various parameters obtained :

1) Heat Transfer coefficient:- It is used to find the amount of heat transfered from a body through convection.

$$\boxed{Q = hA\Delta T}$$

2) Biot Number:- It gives a simplen index of the ratio of Internal Resistance due to conduction to surface resistance for conduction.

$$B_T = \frac{hV}{KA}$$

3) Fourier Number:- This Number relates the heat Loss temperature change with time.

$$F_o = \frac{\alpha t}{L^2}$$

4) Time constant(T):- "It is time taken by the system to reach its steady state or heat loss capacity reaches 63.2%

$$\tau = \frac{MC}{hA}$$

# HEAT TRANSFER AND SOLAR ENERGY LABORATORY

**Class:** A3MA **Section:** A **S. No.** 05

**Course Title** : **Heat and Mass Transfer Laboratory**

**Course Number** : **MEC 3910**

**Experiment (Brief Title):** Critical Heat flux

Date of Experiment Performed : 13/11/24
Due date of Submission : 21/11/24
Late Submission date :

Teachers' Remark :

Marks Awarded :

| Rubric No. | I | II | III | IV | V | Total |
|---|---|---|---|---|---|---|
| Maximum Marks | 1 | 1 | 2 | 3 | 3 | 10 |
| Marks awarded | 1 | 1 | 2 | $2\frac{1}{2}$ | 2 | $8\frac{1}{2}$ |

Rubrics for laboratory courses

I. Object of the experiment and specifications of the equipment/instruments used
II. Brief theory and related equations used
III. Observation Sheets, Sample calculations (student should explain at the time of evaluation)
IV. Results mathematical/graphical (student should explain at the time of evaluation)
V. Discussions (should be different from other students)

Name : Nikhil Singh
Class : A3MA
S. No. : 05
Faculty No. : 22MEB173
En. Roll. No. : GL6695

Name: Nikhil Singh S.N. 05 Class: A3MA Date: 13/11/24

*Observations:* 1. Diameter of test heater wire: d = 40 SWG = 0.111 mm
2. Length of test heater : L = 100 mm
3. Surface Area, A = πdL : A = $3.48 \times 10^{-5}$ m²

| S.No. | Temperature of water (°C) | Ammeter Reading I (amp) | Voltmeter Reading V (volt) | Critical Heat Flux (W/m²) | $(T_w - T_{sat})$ (°C) |
|---|---|---|---|---|---|
| 1. | 50 | 4.4 | 50 | $6.31 \times 10^6$ | |
| 2. | 60 | 4.0 | 48 | $5.57 \times 10^6$ | |
| 3. | 70 | 3.6 | 44 | $4.54 \times 10^6$ | |
| 4. | 80 | 3.2 | 38 | $3.49 \times 10^6$ | |
| 5. | 90 | 2.8 | 32 | $2.57 \times 10^6$ | |
| 6. | 100 (Saturation) | | | | |
| | (i) | 1.0 | 10 | $2.87 \times 10^5$ | 9.92 |
| | (ii) | 1.2 | 12 | $4.13 \times 10^5$ | 11.20 |
| | (iii) | 1.4 | 14 | $5.62 \times 10^5$ | 12.42 |
| | (iv) | 1.6 | 16 | $7.34 \times 10^5$ | 13.57 |
| | (v) | 1.8 | 18 | $9.29 \times 10^5$ | 14.68 |
| | (vi) | 2.0 | 20 | $1.15 \times 10^6$ | 15.75 |
| | (vii) | 2.2 | 22 | $1.39 \times 10^6$ | 16.78 |
| | (viii) | 2.4 | 24 | $1.65 \times 10^6$ | 17.79 |

(i) The Ammeter, Voltmeter readings below the saturation temperatures are noted when the wire melts.
(ii) For the saturation temperature, ammeter and voltmeter readings are to be recorded at each step, while increasing the supply, until the wire melts. (*The supply should be given very slowly so that near about 4 to 5 steps may be recorded*).

13.11.24

*Calculations:*
(i) Calculate the heat fluxes for the readings taken and tabulate in the observation sheet.
(ii) Plot critical heat flux versus bulk temperature
(iii) For the readings at saturation condition calculate the wire temperatures for different heat fluxes using the following relation:

$$(T_w - T_{sat}) = \frac{h_{fg}}{C_{pl}} Pr_l C_{sf} \left[ \frac{q/A}{\mu_l h_{fg}} \left( \frac{\sigma}{g(\rho_l - \rho_v)} \right)^{1/2} \right]^{1/3}$$

The properties of water are to be evaluated at the saturation temperature and one atmospheric pressure. Assume: $C_{sf} = 0.01$. Thus, temperature excess, $\Delta T = T_w - T_{stat}$ are known for some values of (q/A) upto the critical point.

*Results:*
a) Plot the calculated value of (q/A) with the excess temperature.
b) Calculate the critical heat flux using

$$q/A = 0.149 h_{fg} \left[ \sigma g \rho_v^2 (\rho_l - \rho_v) \right]^{1/4} \quad \text{W/m}^2$$

c) Compare your results with the experimental values and the boiling curve supplied in the class.

*Discussion:*
a) Discuss on your results and predict melting temp. of the Nichrome wire used.
b) The critical heat flux value decreases as the bulk temp. approaches the saturation. Why? Explain.
c) Differentiate between subcooled and saturated boiling.
d) Discuss the phenomenon of nucleate boiling and film boiling.
e) Discuss the various regimes of saturated pool boiling.
f) Discuss the bubble shape and size.
g) Risk of burning foods with silicon coated pans is less than with ordinary pan. Explain.

*Reference:*
Heat transfer by J.P. Holman: (pp. 415 – 425) and Heat transfer by A. Bejan: (pp. 419 – 433)

# Sample calculations,

diameter of wire (d) = 0.111 mm

length of test heater L = 100 mm

Surface area, $A = \pi d L$

$= \pi \times 0.111 \times 100$

$= 3.48 \times 10^{-5} \, m^2$

## For Reading 5.

$T_w = 90°C$

$V = 32 V$

$I = 2.8 A$

experimental heat flux,

→ critical heat flux $= \frac{Q}{A} = \frac{V \times I}{A}$

$$\frac{Q}{A} = \frac{2.8 \times 32}{3.48 \times 10^{-5}} = 2.57 \times 10^{6} \, W/m^2$$

## Theoretical heat flux,

at 90°C

$h_{fg} =$ ~~2382.9~~ 2283.2 kJ/kg K

$\sigma = 0.0686$ N/m

$\rho_L = 965.25$ kg/m³

$\rho_v = 0.423$ kg/m³

$$\therefore \frac{Q}{A} = 0.149 \, h_{fg} \left[ \sigma g \rho_v^2 (\rho_L - \rho_v) \right]^{1/4}$$

$$\frac{q}{A} = 0.149 \times 2283.2 \left[ \frac{0.0686 \times 9.81 \times (0.423)^2 \times}{[965.25 - 0.423]} \right]^{1/3}$$

$$\frac{q}{A} = 1116.826 \text{ kw/m}^2$$

$$= 1116826.4 \text{ w/m}^2$$

Similarly,

$q_1 = 6.31 \times 10^6$ w/m²

$q_2 = 5.51 \times 10^6$ w/m²

$q_3 = 4.54 \times 10^6$ w/m²

$q_4 = 3.49 \times 10^6$ w/m²

$q_5 = 2.57 \times 10^6$ w/m²

Consider reading No. 6 :-

$V = 20$ volt

$I = 2$ amp.

for excess temperature

$h_{fg} = 2256.9$ kJ/kg

$Pr_L = 1.75$

$C_{sf} = 0.01$

$\mu_L = 0.282 \times 10^{-3}$

$C_{PL} = 4.18 \times 10^3$ J/kg K

$\sigma = 0.0588$ N/m

$\rho_L = 957.85$ kg/m³

$\rho_v = 0.5977$ kg/m³

$\frac{q}{A} = 1.14 \times 10^6$ w/m²

$$T_w - T_{sat} = \frac{h_{fg}}{C_{PL}} Pr_L C_{sf} \left[ \frac{q/A}{\mu_L h_{fg}} \left( \frac{\sigma}{g(\rho_L - \rho_v)} \right)^{1/2} \right]^{1/3}$$

$$T_w - T_{sat} = \frac{2256.9 \times 10^3 \times 1.75 \times 0.01}{4.18 \times 10^3} \left[ \frac{1.14 \times 10^6}{0.282 \times 2256.9 \times 10^{-3}} \times \left( \frac{0.0588}{9.81(957.8 - 0.5977)} \right)^{1/2} \right]^{1/3}$$

$\Delta T = T_w - T_{sat}$

$= 15.75°C$

Similarly.

$\Delta T_1 = 9.9°C$

$\Delta T_2 = 11.20°C$

$\Delta T_3 = 12.42°C$

$\Delta T_4 = 13.57°C$

$\Delta T_5 = 14.68°C$

$\Delta T_6 = 15.75°C$

$\Delta T_7 = 16.78°C$

$\Delta T_8 = 17.79°C$

# Discussion.

Q=1 Discuss on your results and predict melting temperatu of the nichrome wire used ?

Critical heat flux for 100°C

$I = 2.4 A, \quad V = 24 volt$

$T_w - T_{sat} = 17.79 °C$

$T_{sat} = 100°C$

∴ ~~Most~~ melting temp. of nichrome wire is

$= 100°C + 17.79°C$

$$\boxed{T_{Melting} = 117.79°C}$$

from graph 1 The critical heat flux decreases as the Bulk temp. increases.

from graph 2 The critical heat flux increases as the excess temp. increases.

Q=2 The critical heat flux values decreases as the Bulk temp. approaches the saturation why ??

As the bulk temp. approaches to saturation temp. bubbles around the heating surface starts forming. after some time they form a blanket around it. and it prevent water coming in its contact.

This resistance cause the reduction in critical hea flux as temperature approaches to saturation temp.

22MEB173 GL6695 A3MA-05

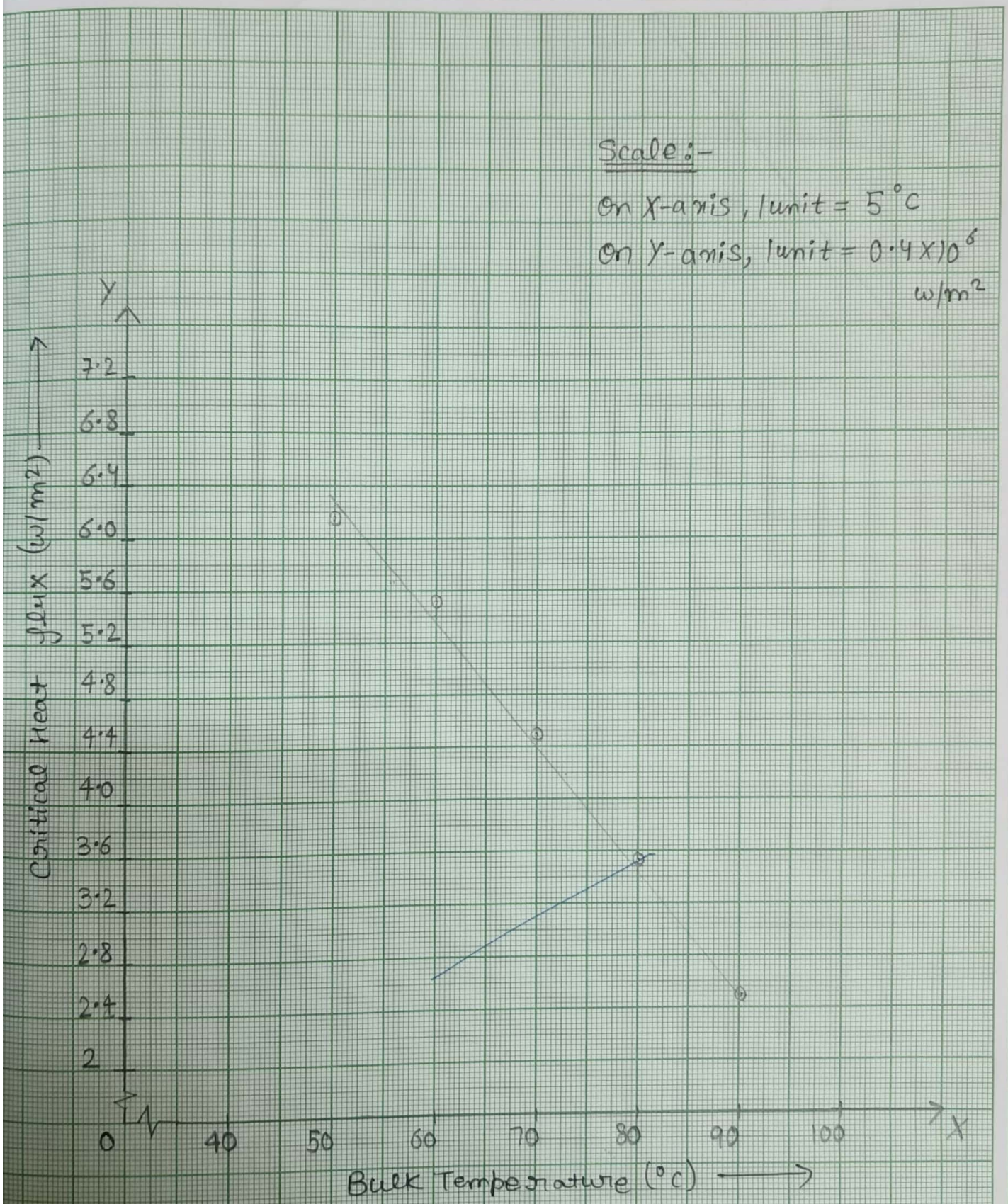



Fig.1 Variation of critical Heat flux with ~~wit~~ Bulk Temp.

22MEB173 GL6695 A3MA-05

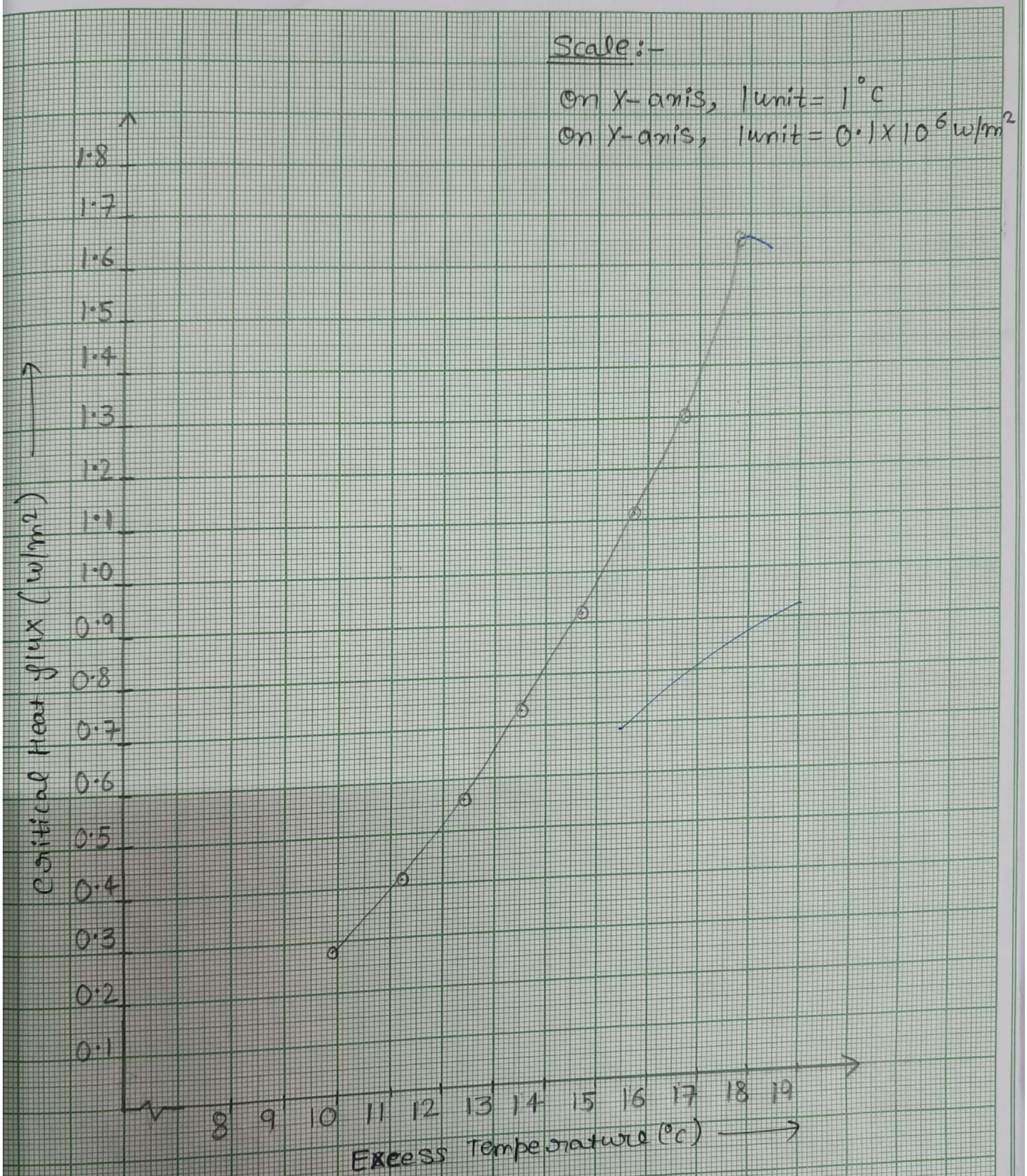



Fig-2 Shows variation of Critical Heat flux with excess Temp.

R.C.H. ALIGARH

=3 Differentiate between sub-coaled and Saturated Boiling.

| Sub-coaled Boiling | Saturated Boiling |
|---|---|
| ub-coaled boiling is a heat ansfer phenomenon that ccurs when a Liquid is eated below its saturation emperature. | Boiling occurs when a Liquid is heated at its Saturation temperature and pressure, resulting in vigorous Boiling with continuous vapor generation. |

=4 Discuss the Phenomenon of nucleate boiling and film boiling.

In Nucleate Boiling heat transfer phenomenon where Liquid vaporizes from a heated surface, forming discrete bubbles that detach and rise to the surface. This process enhances heat transfer, making it crucial mechanism in various applications.

In film boiling heat transfer phenomenon where a thin layer of vapor forms between a heated surface and a Liquid, insulating the surface and reducing heat transfer.

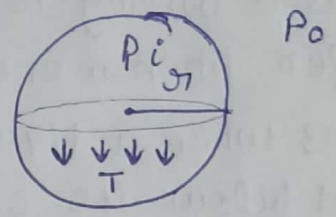
=5 Discuss the various regimes of saturated pool Boiling?

- Natural convection
- Nucleate Boiling
- Transition Boiling
- Film Boiling

Q=6 Discuss the Bubble shape and sizes.

⇒ Bubbles are generally of spherical shape because of the surface tension. It tends to occupy min$^m$ surface area due to surface tension.

$$P_i - P_o = \frac{4T}{r}$$




Q=7 Risk of burning foods with silicon coated pans is less than with ordinary pan why? explain.

⇒ Silicon coated pan reduces burning risk with their non stick surface, even heat distribution, and thermal shock resistance. This prevents food sticking, minimizes hotspots and promotes healthier cooking making cleaning easier and making cooking more efficient & safe.

X——X——X