Project presentation

GROUP 10

GROUP MEMBERS

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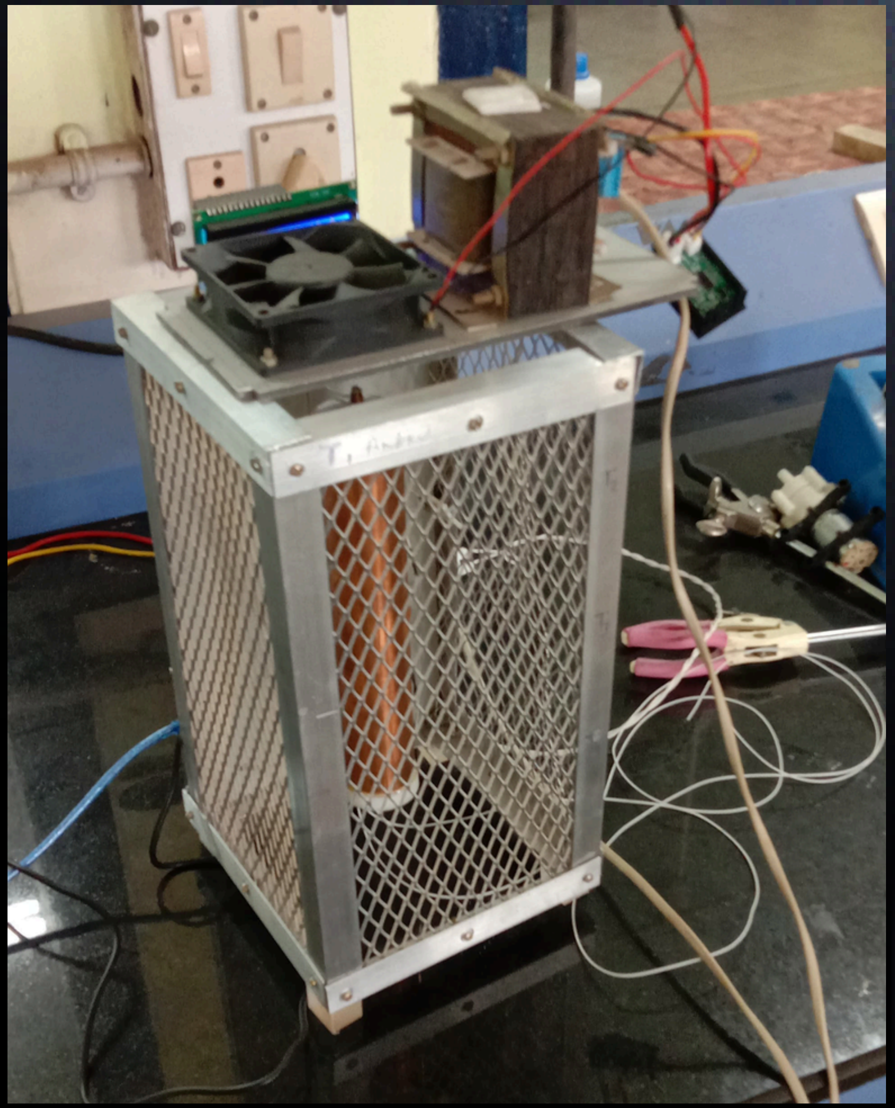
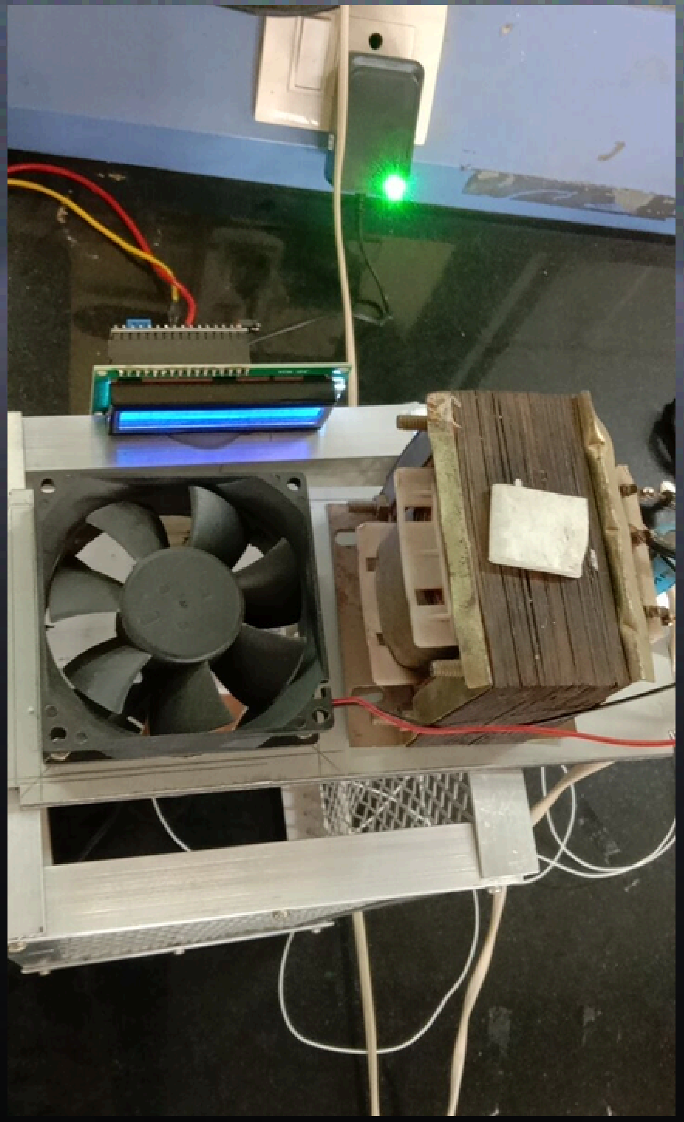
• INTRODUCTION OF THE PROBLEM

Title - Understanding Convection: Natural vs Mixed Cooling

Objective - Compare experimental and theoretical heat transfer coefficients h for natural convection and mixed convection (where forced convection opposes natural convection).





Experimental setup

- <u>Components:</u>
  - Vertical hollow copper rod (OD: 39.86 mm, ID: 34.26 mm, length: 200 mm).
  - Internal heater + 3 temperature sensors (T2, T3, T4) along the rod.
  - Ambient sensor (T1) + Data acquisition system.
  - Fan for forced convection.

• INNOVATIVE ASPECTS

- Combines experimental data processing with theoretical correlations (e.g., Churchill–Bernstein) to cross-validate convective heat transfer coefficients.
- Enables a deep comparison between lumped capacitance model results and external flow correlation predictions, showing the limitations of theoretical models under real conditions.
- Cooling phase studied for comprehensive understanding of transient and steady-state convection.
- Simulates real-world applications (e.g., vertical hollow pipes in heat exchangers or chimneys).

• Methodology:

Steps

1. Heat the rod to a steady-state temperature.
2. Set Voltage=42V and current=0.26 A
3. Cool under natural convection (no fan) and record T(t).
4. Repeat cooling under mixed convection (with fan). In this scenario forced convection is acting opposite to natural convection
5. Average sensor temperatures (Tavg=T2+T3+T4/3).
6. Use laptop to keep data of temperature with time

• Theory:-

Theoretical Background

- **Lumped Capacitance Validity :**

  ° Bi = hLc / K < 0.1 (validated for copper rod)

- **Key Formulas :**

  ° Ra = Gr . Pr, Re = ρVD/μ

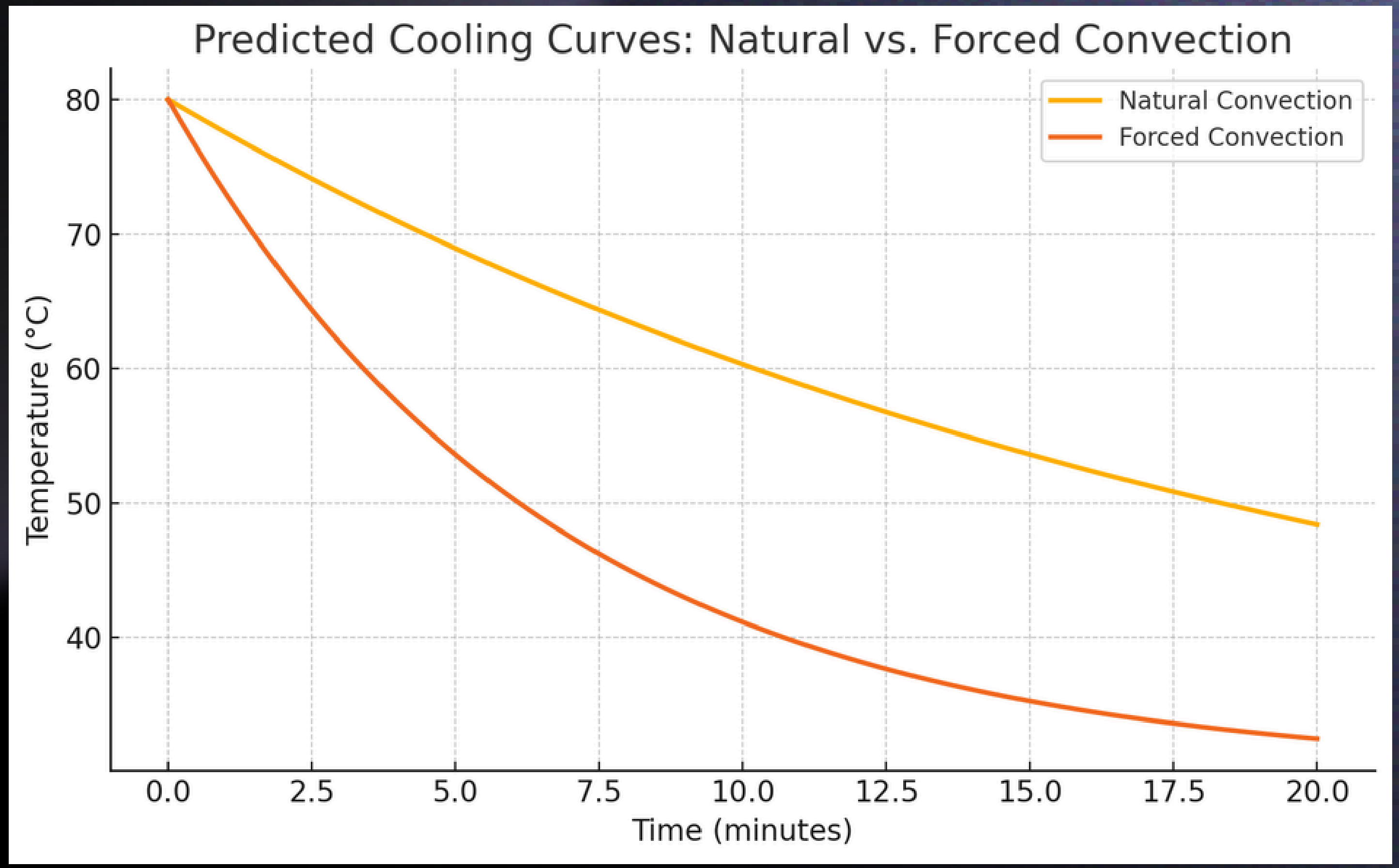
Churchill–Bernstein Correlation

$$Nu_D = 0.3 + \frac{0.62 Re_D^{1/2} Pr^{1/3}}{[1 + (0.4/Pr)^{2/3}]^{1/4}} \cdot \left[1 + \left(\frac{Re_D}{282000}\right)^{5/8}\right]^{4/5}$$

• Results:-

• Expected Results

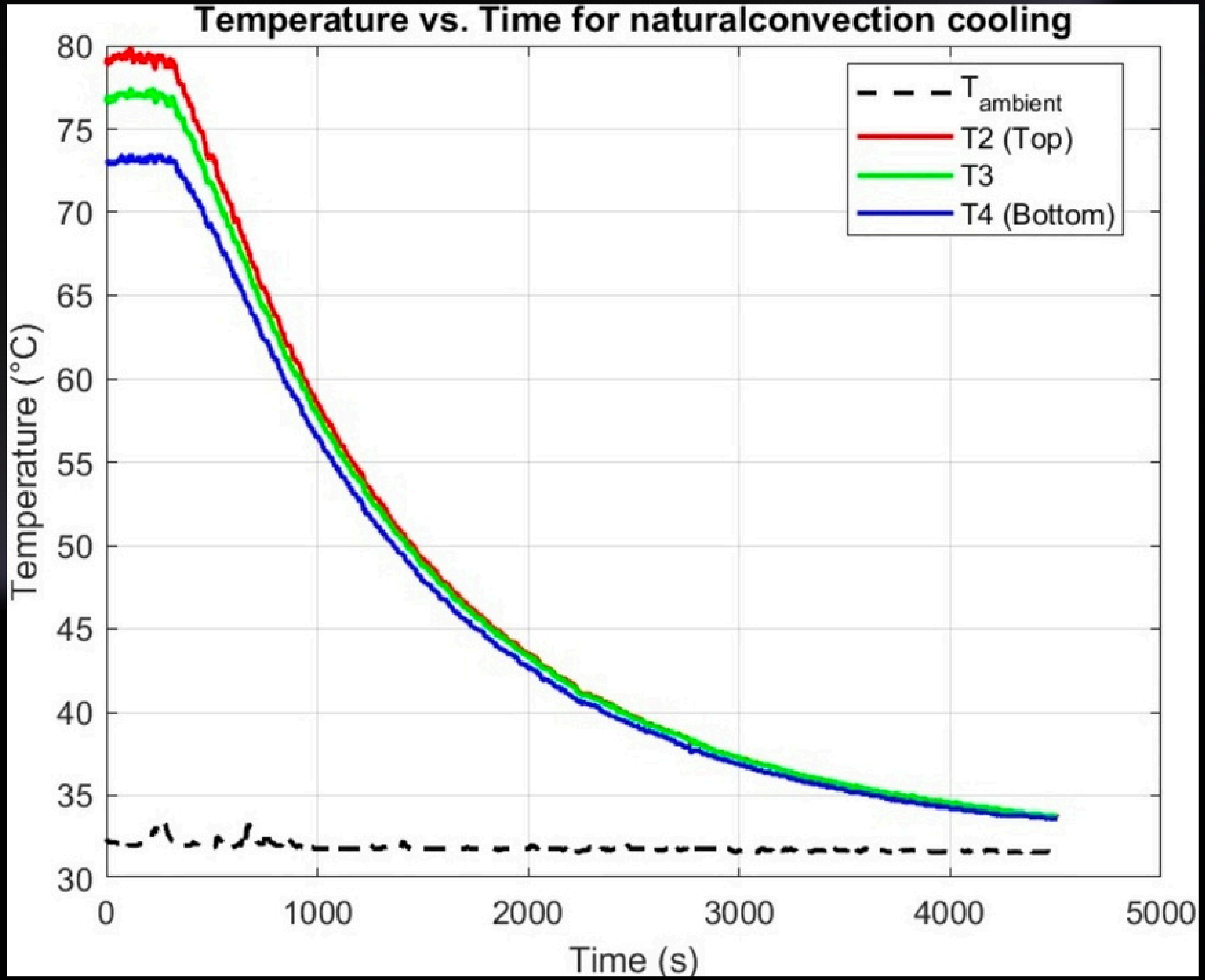
- **Simulation Graph:** Predicted T(t) curves for natural vs. Forced convection.



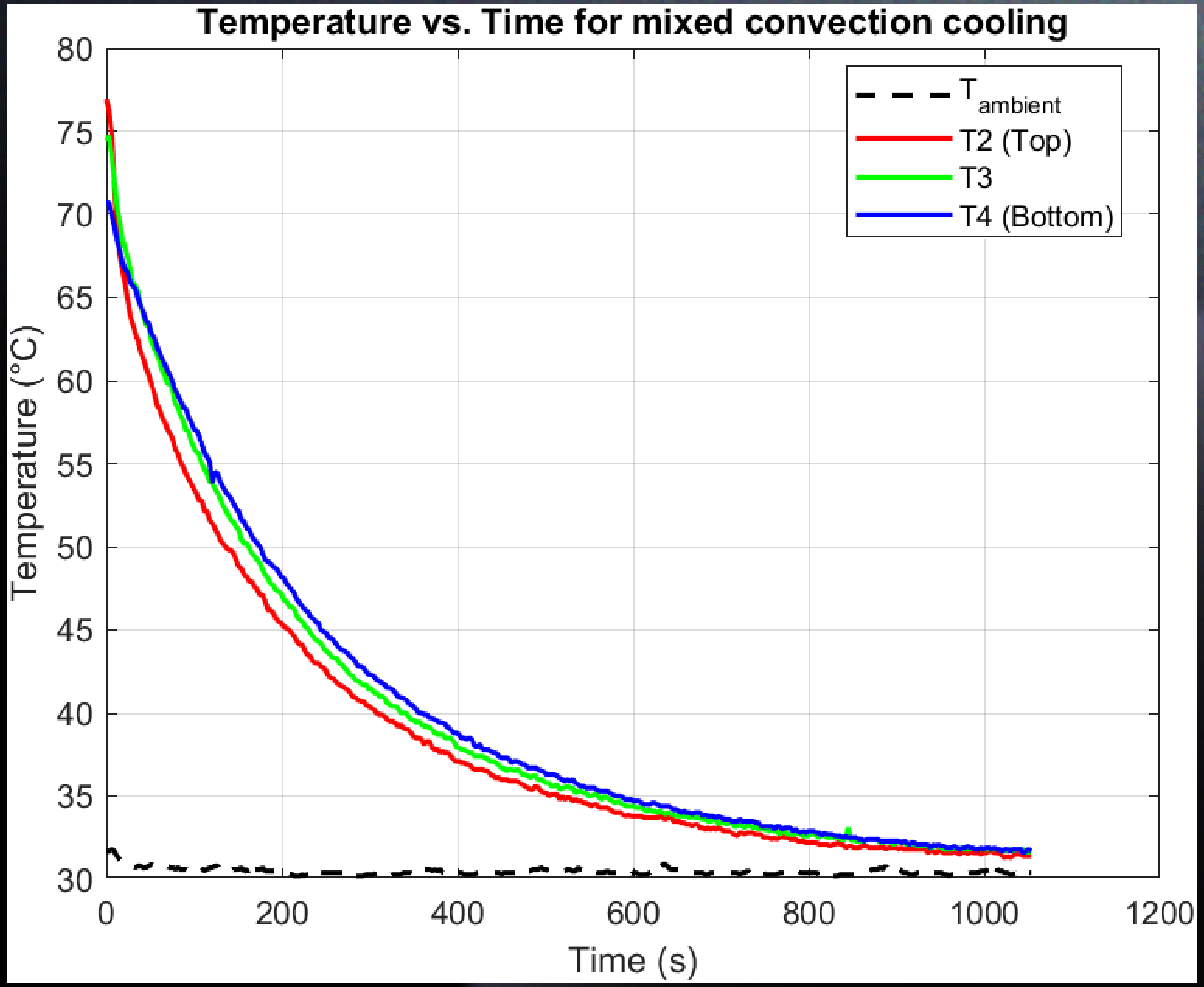
- **Assumptions:** Negligible radiation, Uniform airflow (Forced), steady.

• Temperature vs. Time graph

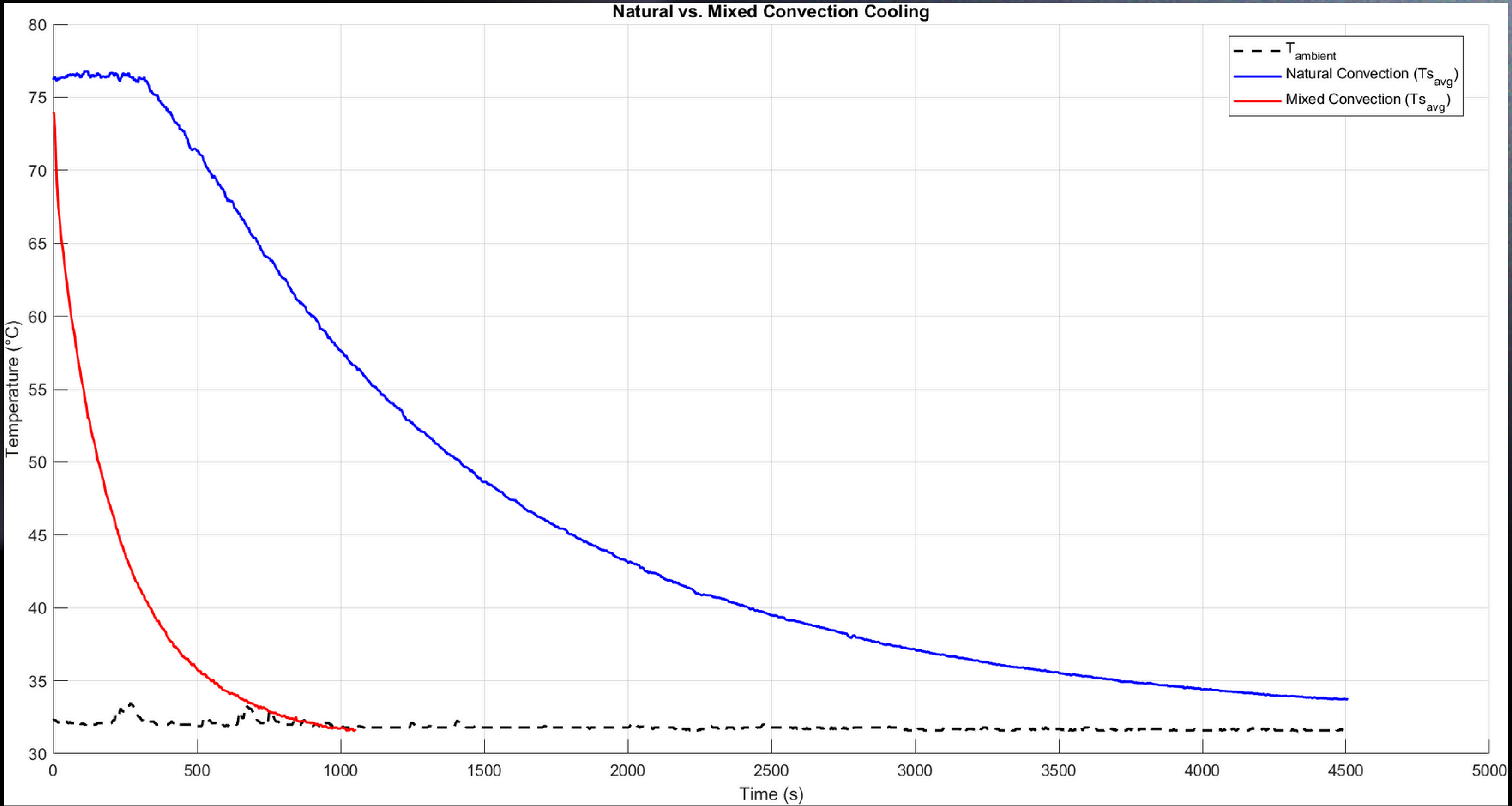
- **Natural convection**



- **Mixed convection(forced - natural): Rapid cooling.**



- **Natural vs Mixed Convection Cooling**



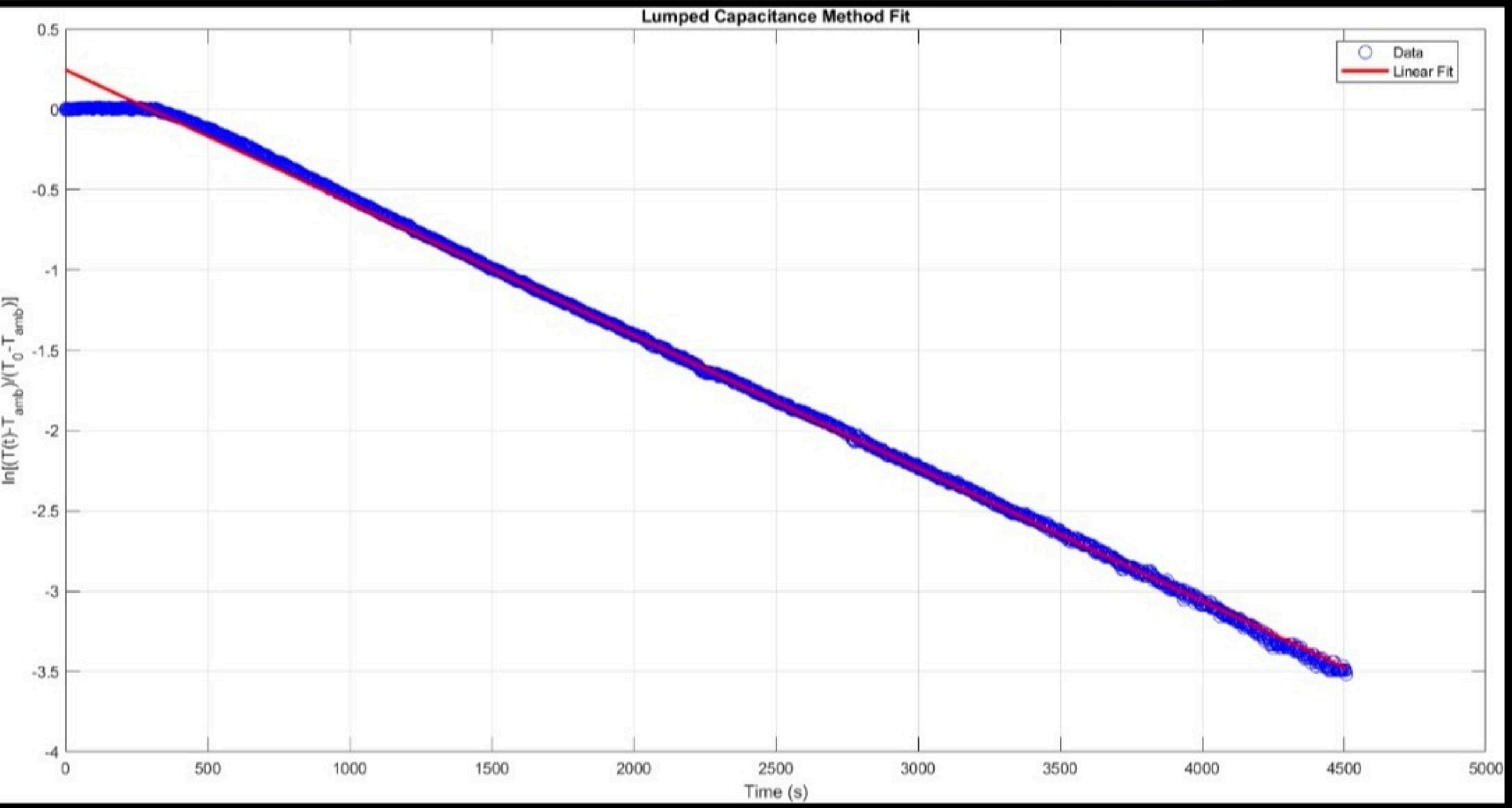
• Logarithmic Plots & Linear Fit:

In (ΔT) vs. t for both cases.

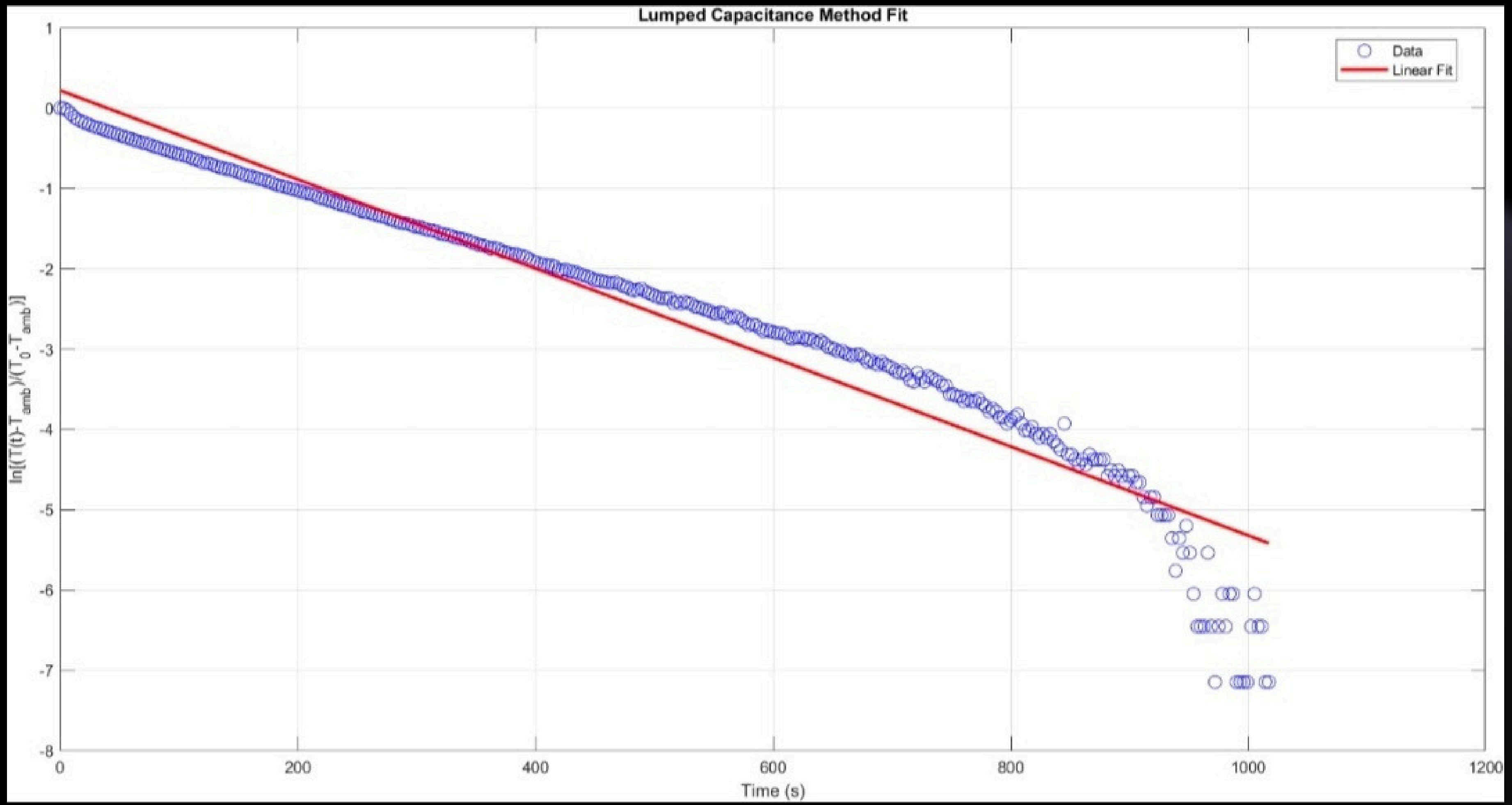
Natural: Slope = - 0.0008 → h_{exp} = 8.2 W/m^2- K

Mixed (forced - natual): Slope = -0.0055 → h_{exp} = 49.76W/m^2-K

Natural convection



Mixed Convection



Sample Calculation

Natural convection

G_r = Grashof number

$$G_r = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2}$$

$$= \frac{(9.81)(0.0034)(76.33-32.1)(0.2)^3}{2.25\times10^{-10}}$$

$$= \frac{(9.81)(0.0034)(44.23)(0.0008)}{2.25\times10^{-10}}$$

$$\boxed{G_r = 52.453\times10^{5}}$$

$\alpha_{copper} = 1.11\times10^{-4}$

$$P_r = \frac{\nu}{\alpha} = \frac{1.5\times10^{-5}}{1.11\times10^{-4}} = 1.35\times10^{-1} = 0.135$$

$$Ra_L = G_r \cdot P_r = (52.453\times10^{5})(0.135)$$

$$\boxed{Ra_L = 7.081155\times10^{5}}$$

For $[10^4 < Ra_L < 10^9]$, $Nu_L = 0.59(Ra_L)^{1/4}$

$$= (0.59)(708115.5)^{1/4} = 0.59\times29.01$$

$$\boxed{Nu_L = 17.11}$$

$$h_{theoretical} = \frac{Nu_L \cdot K}{L} = \frac{(17.11)(0.026)}{0.2}$$

$$\boxed{h = 2.243\ W/m^2 \cdot K}$$

Mixed convection

Sample Calculation

→ Fan Velocity calculation

Electrical parameter

→ Voltage = 18.6V

→ Current = 0.28

Power = $VI = 18.6\times0.28 = 5.21$ watt

fan flow rate estimation

→ standard 80-90 mm computer fan operating at 5.21W

→ Typical flow rate: approx. 30CFM (cubic feet per minute)

Air velocity calculation

→ Fan Area (A) = $\pi\times(0.045)^2 = 0.00636\,m^2$ (90 mm fan)

→ Flow rate: 30CFM = $0.0142\,m^3/s$

→ Raw velocity: $\frac{\text{Flow rate}}{\text{Area}} = \frac{0.0142}{0.00636} = 2.23\,m/s$

→ Effective velocity at cylinder surface (80% efficiency)

$= 2.23\times0.8 = 1.78\,m/s$

2) Mixed ~~Calculation~~ Convection calculation

Parameters:

copper rod outer diameter (OD) = 0.03986 m

Copper rod inner diameter (ID) = 0.03426 m

Length (L) = 0.2 m

$L_c = 0.2$

Surface Area = $\pi\times OD\times L = 0.02504\,m^2$

$K_{copper} = 401\,W/m\cdot K$

$\rho_{copper} = 8960\,kg/m^3$

$C_{p\,copper} = 385\,J/kg\cdot K$

$m = \rho\times\frac{\pi}{4}\times(OD^2 - ID^2)\times L = 0.311\,kg$

Air property

$K_{air} = 0.02662\,W/m\cdot K$

$Pr = 0.7255$

$\nu = 1.702\times10^{-5}\,m^2/s$

$\rho_{air} = 1.127\,kg/m^3$

→ Forced Convection

$$Re = \frac{V_\infty\times OD}{\nu} = 4171$$

correlation (Churchill-Bernstein):

for $Re\times Pr > 0.2$

$$Nu = 0.3 + \frac{0.62\times\sqrt{Re}\,Pr^{1/3}}{[1+(0.4/Pr)^{2/3}]^{1/4}}\left[1+\left(\frac{Re_D}{282000}\right)^{5/8}\right]^{4/5}$$

Putting all values we get

$Nu_f = 31.92$

$$h_{forced} = \frac{Nu\times K_{air}}{OD} = 21.31\ \frac{W}{m^2K}$$

Mixed convection (forced opposing natural)

we use following correlation for this case

$$h_{mixed} = (|h_{forced}^3 - h_n^3|)^{1/3}$$

$$h_{mixed} = (|21.31^3 - 2.24^3|)^{1/3}$$

$$h_{mixed} = 21.34\ \frac{W}{m^2K}$$

Theoretical vs. Experimental h

Comparison

- Natural convection h_{theory} = 2.243 W/m^2-K vs. h_{exp} = 7.43 W/m^2-K
- Mixed convection: h_{theory} = 21.34 W/m^2-K vs. h_{exp} = 49.76 W/m^2-K
- Forced convection: h_{theory} = 21.31 W/m^2-K

Conclusions & Future Work

• Conclusions :

- Forced convection significantly increased heat dissipation compared to natural convection.
- The setup provided clear insights into transient vs. steady-state heat transfer behavior.

• Future Work :

- Changes the direction of forced convection like in direction of natural convection or in opposite direction of natural convection
- Extend the experiment to vary air flow velocities and study transition from laminar to turbulent external flow.
- Compare results for different materials (e.g., aluminum, stainless steel) to explore thermal conductivity effects.