HEAT TRANSFER

Innovation project

Group 28

Team Members

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Aim

To compare the cooling rates and temperature distribution of aluminum and iron sheets (7.7 cm × 7.7 cm), heated to approximately 60°C and cooled naturally. Sensors at the corner, edge, and center help analyze their heat transfer characteristics.

Innovation

This experiment offers a comparative study of heat transfer in aluminum and iron sheets under identical conditions. The sheets, each 7.7 cm x 7.7 cm, are heated to 60°C using a water bath and cooled via natural convection. Seven sensors (three on each sheet and one for ambient temperature) measure temperature variations at different locations. The setup enables:

1. Material Comparison: Directly comparing the cooling behaviors of aluminum and iron.
2. Model Validation: Potential to validate or refine heat transfer models for natural convection, with applications in thermal engineering and material selection for manufacturing.

Experimental Methodology

Materials used:

- Aluminum sheet: 7.7 cm x 7.7 cm.
- Iron sheet: 7.7 cm x 7.7 cm.
- Water

Equipment

- Magnetic Stirrer for uniform heating to ~60°C.
- Seven sensors

Theory

The experiment focuses on heat transfer via natural convection, where heat is transferred from the heated sheets to the surrounding air due to temperature-induced density differences.

Heat Transfer Mechanisms :- Natural Convection

- When the sheets (at 60°C) are exposed to cooler air , the air near the sheets heats up, becomes less dense, and rises.
- Cooler air replaces the rising warm air, creating a convection current that transfers heat away from the sheets.
- The rate of heat loss is proportional to the temperature difference: $Q=hA(Ts-Ta)$.

Temperature Decay:

- The temperature of the sheet over time can be modeled as: $T(t)=Ta+(T0-Ta)\hat{}e-ktT(t)$

Theory

Biot Number Analysis

- Determines if lumped capacitance assumption is valid:

$$Bi=hL/k$$

  - If $Bi < 0.1$, entire sheet cools uniformly.
  - If $Bi > 0.1$, internal temperature gradients matter.

  calculation of Biot number

  Volume $V = 5.929 \times 10^{-6}\ m^3$
  Surface area $A = 0.011858\ m^2$
  - Biot number for Aluminum: $1.77 \text{ X} 10^{-6}$
  - Biot number for Iron: $8.69 \text{ X } 10^{-7}$

- Practical Implications:
  - Why aluminum heatsinks are used in electronics.
  - Why cast iron pans retain heat longer.

Material Properties:

Aluminium

- Thermal conductivity: ~237 W/m·K.
- Specific heat: ~900 J/kg·K.
- Likely to distribute heat quickly, leading to uniform cooling.
- h =0.838(W/m^2·K)

Iron

- Thermal conductivity: ~80 W/m·K.
- Specific heat: ~450 J/kg·K.
- Slower heat distribution, potentially causing larger temperature gradients.
- h =0.139(W/m^2·K)

Procedure

Heating Phase:

- Place both sheets in the water bath.
- Heat until both reach 60°C, monitoring with sensors to confirm uniform temperature.

Cooling Phase:

- Remove both sheets simultaneously from the water bath.
- Place them in a controlled environment to cool naturally

Data Collection:

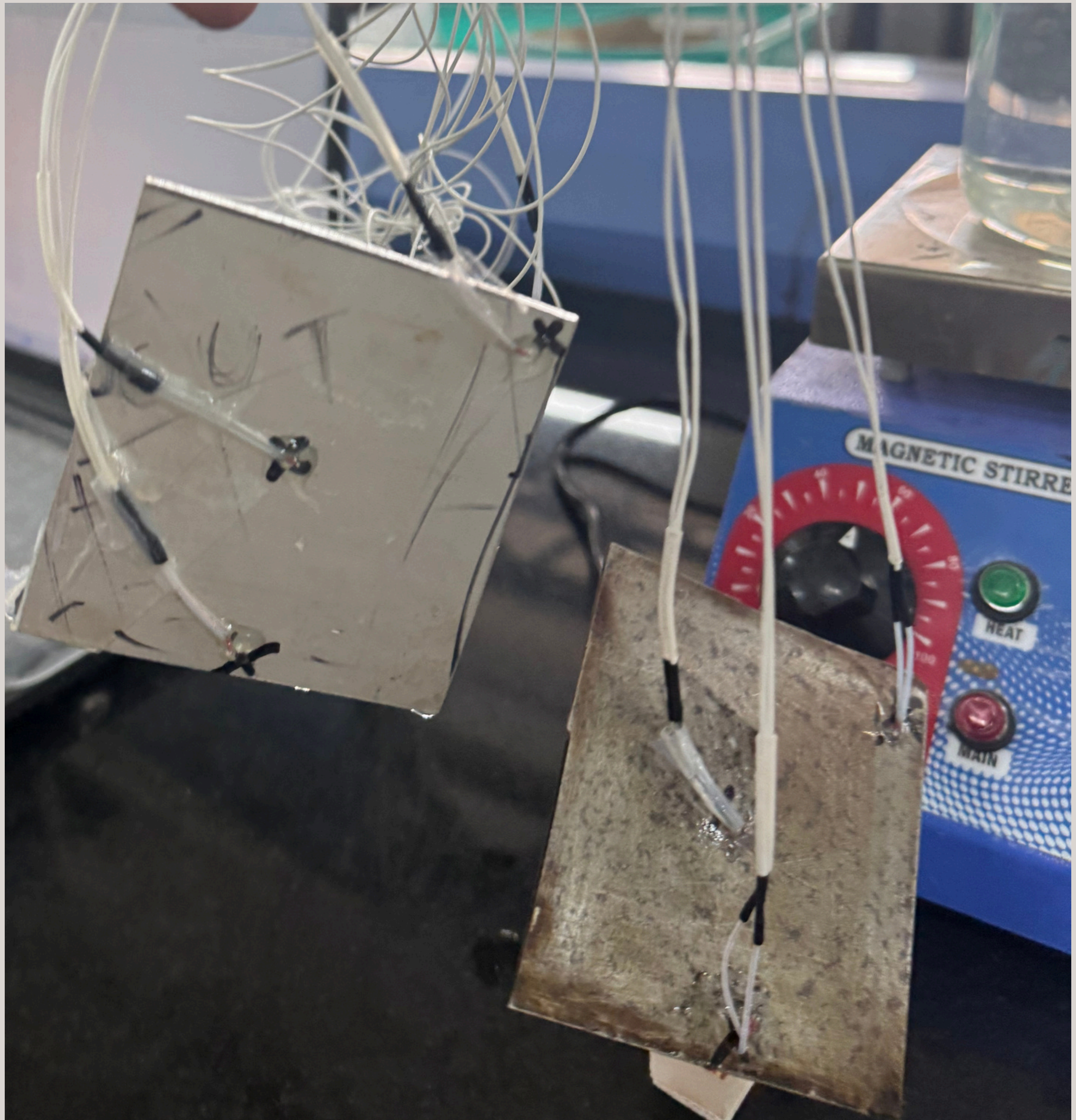
- Record temperatures from all seven sensors at regular intervals
- Continue until both sheets reach ambient temperature.

Cutting Al & Fe sheets

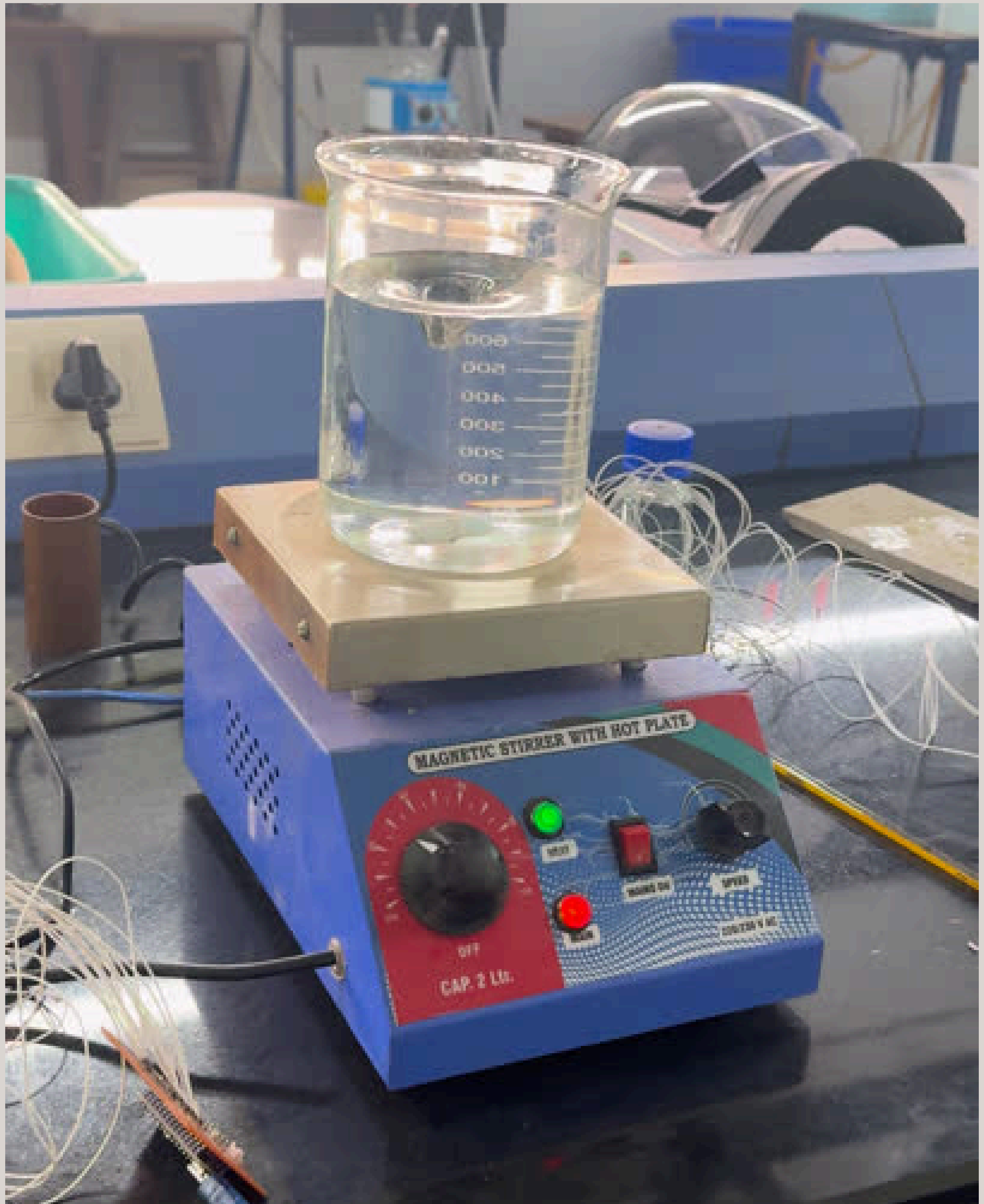
Rubbing Sheets with SandPaper

Drilling Holes for Sensors

Sensors at specified points

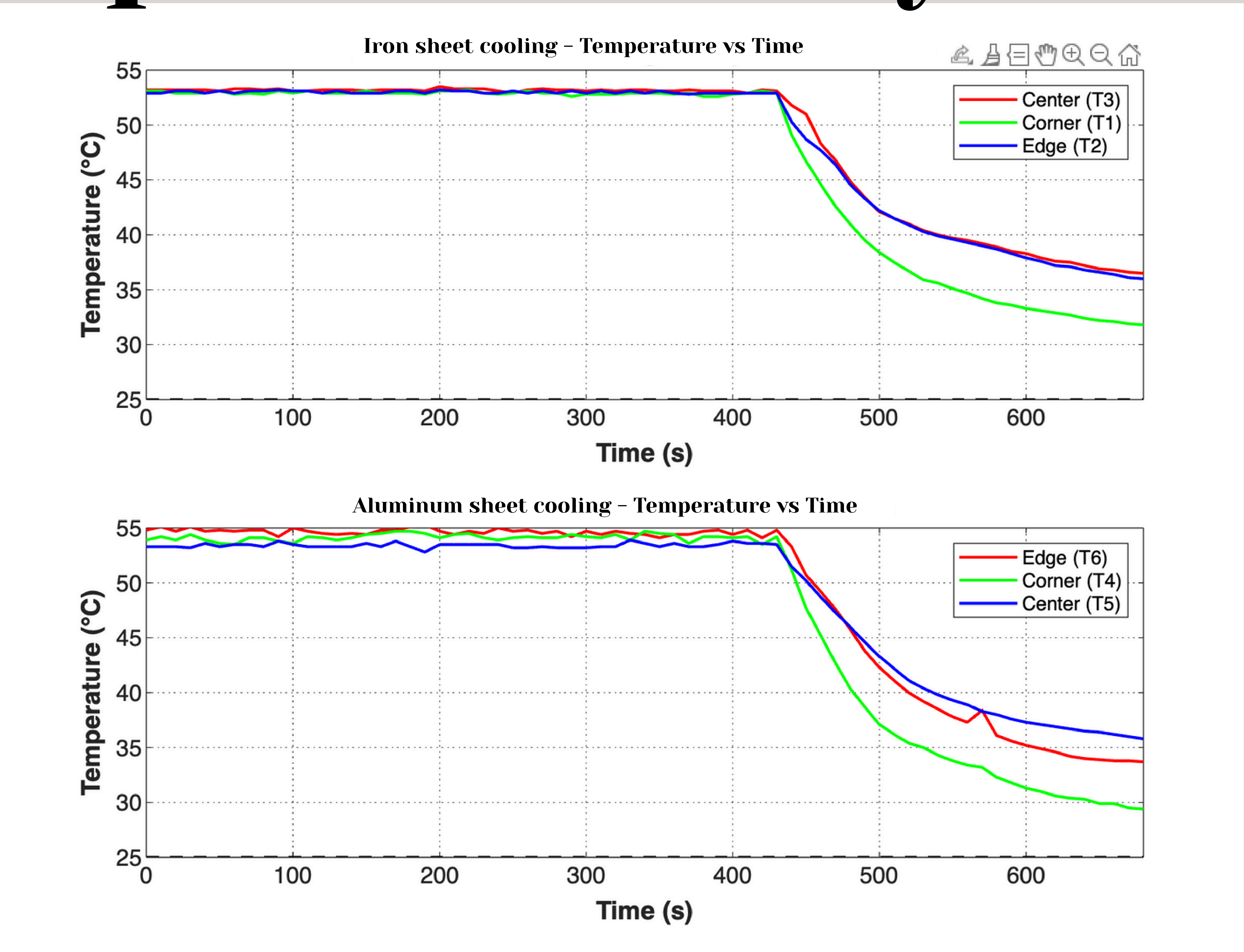


Heating Water

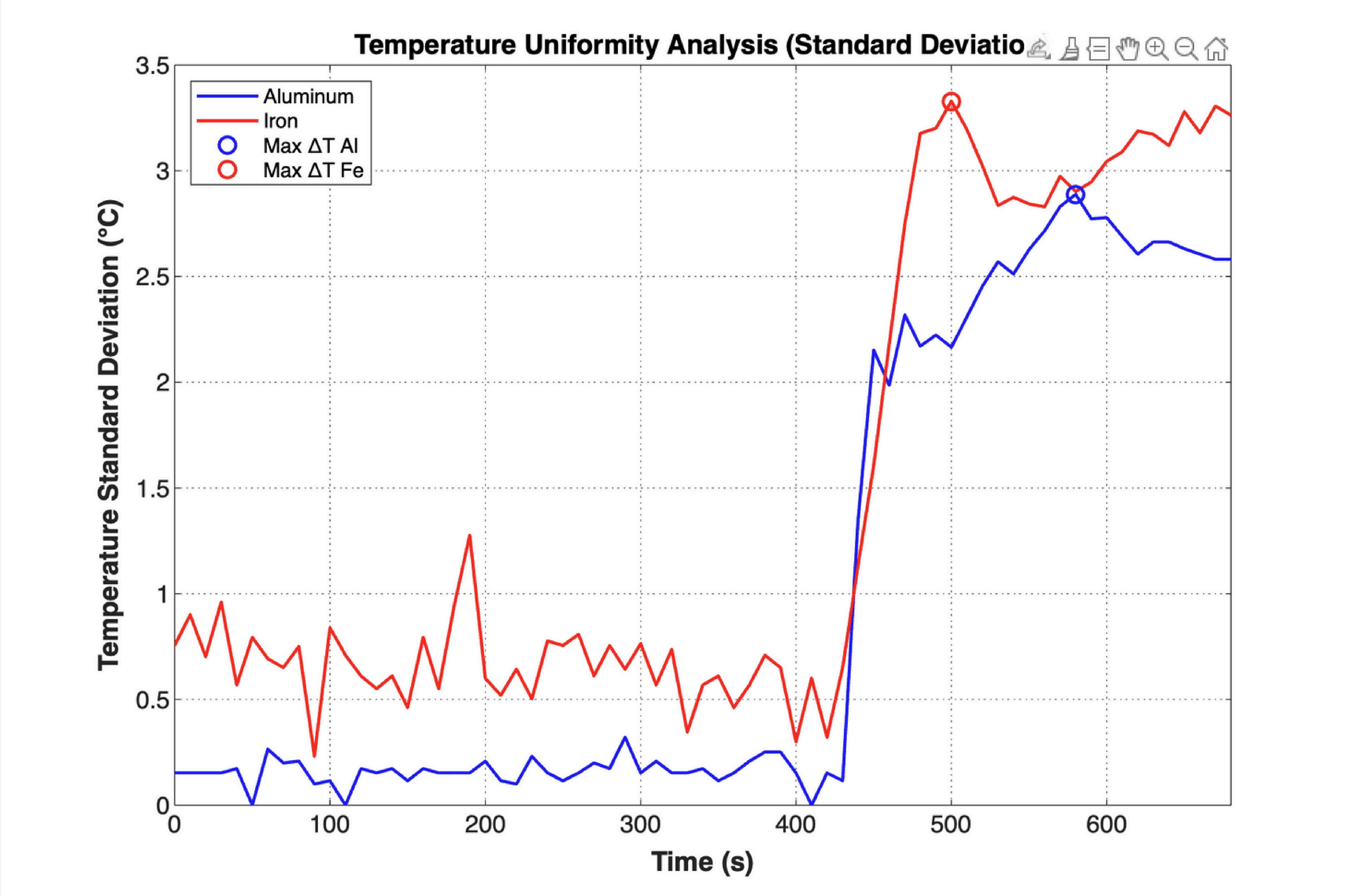


Reading values

Graphical Analysis



Graphical Analysis



Graphical Analysis

Aluminium Sheet Cooling - Temperature vs Time

Curvature Characteristics:

- Initial Phase (0–430 s):
- Minimal temperature drop (53°C → ~52°C)
- Nearly overlapping lines for T1 (corner), T2 (edge), T3 (center)
- Indicates uniform cooling due to high thermal conductivity

Rapid Cooling Phase (>430 s):

- Exponential temperature decay begins
- Curvature steepens significantly (52°C → 36°C in 250 s)
- Lines diverge slightly: Corner (T1) cools faster than center (T3) due to edge effects (higher surface-area-to-volume ratio).

Why the Curvature Changes:

Aluminum’s high thermal conductivity allows rapid heat dissipation once the temperature gradient with ambient becomes significant.

Iron Sheet Cooling - Temperature vs Time

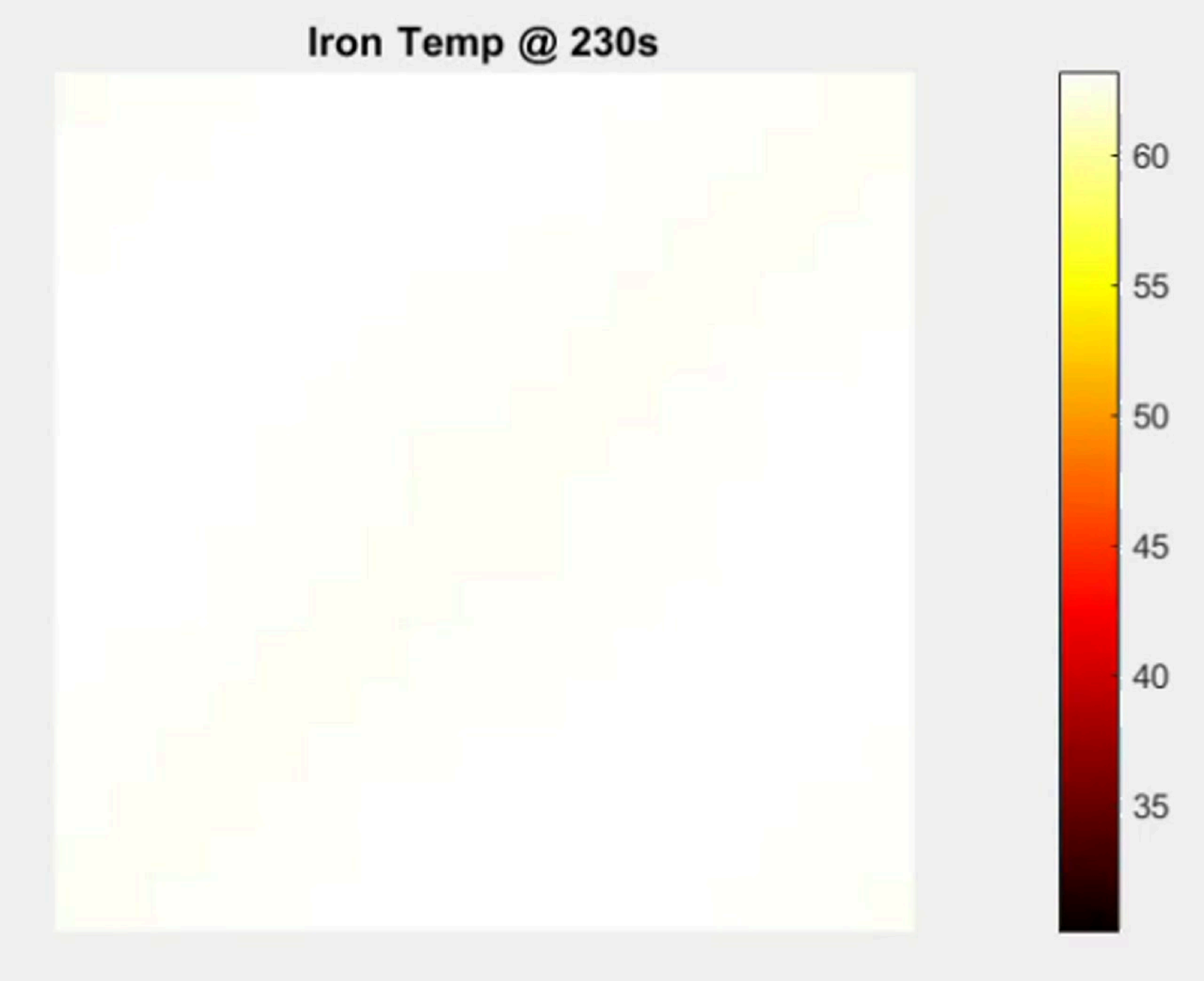
Curvature Characteristics:

- Initial Phase (0–430 s):
    - Minimal cooling (54°C → ~53°C)
    - Lines for T5 (center), T6 (edge1), T7 (edge2) remain close
    - Reflects iron’s high thermal inertia (ρcFe=3.56×106 J/m3KρcFe=3.56×106J/m3K vs. ρcAl=2.42×106 J/m3KρcAl=2.42×106J/m3K).
- Cooling Phase (>430 s):
    - Gentle exponential decay (53°C → 35°C in 250 s)
    - Slower curvature than aluminum.
    - Slight divergence in thermocouples due to lower thermal conductivity , leading to slower heat redistribution.

Why the Curvature Changes:

Iron’s lower thermal conductivity result in slower heat transfer. Temperature uniformity is maintained longer, but gradients eventually develop as convection dominates.

Simulation



Simulation code

```
[X_grid, Y_grid] = meshgrid(1:17, 1:17);
[X_known, Y_known] = deal([]);
Fe_values = [];
Al_values = [];

% Fixed known point positions
positions = [
    1, 1;     % top-left corner
    1, 9;     % top edge center
    1, 17;    % top-right corner
    9, 1;     % left edge center
    9, 9;     % center
    9, 17;    % right edge center
    17, 1;    % bottom-left corner
    17, 9;    % bottom edge center
    17, 17    % bottom-right corner
];


for i = 1:size(data, 1)
    t = data(i, 1);
    T = data(i, 2:7); % Ignore ambient

   % Uniform values at symmetric points
   %Fe sensors:
    Fe_corner = T(2);  % T2
    Fe_edge   = T(1);  % T1
    Fe_center = T(3);  % T3

Fe_known = [
    Fe_corner; Fe_edge; Fe_corner;
    Fe_edge;   Fe_center; Fe_edge;
    Fe_corner; Fe_edge; Fe_corner
];
    % Aluminium sensors:
    Al_corner = T(4);  % T4
    Al_edge   = T(6);  % T6
    Al_center = T(5);  % T5
```

```
Al_known = [
    Al_corner; Al_edge; Al_corner;
    Al_edge;   Al_center; Al_edge;
    Al_corner; Al_edge; Al_corner
];

    % Interpolate
    [X_known, Y_known] = meshgrid([1, 9, 17], [1, 9, 17]);
    X_known = X_known(:);
    Y_known = Y_known(:);

    Fe_interp = griddata(X_known, Y_known, Fe_known, X_grid, Y_grid, 'cubic');
    Al_interp = griddata(X_known, Y_known, Al_known, X_grid, Y_grid, 'cubic');

    % Plot Iron
    figure(1); clf;
    imagesc(Fe_interp);
    title(['Iron Temp @ ', num2str(t), 's']);
    axis equal off;
    colormap hot;
    colorbar;
    clim([min(data(:,2:4), [], 'all') max(data(:,2:4), [], 'all')]);

    % Plot Aluminium
    figure(2); clf;
    imagesc(Al_interp);
    title(['Aluminium Temp @ ', num2str(t), 's']);
    axis equal off;
    colormap hot;
    colorbar;
    clim([min(data(:,5:6), [], 'all') max(data(:,5:6), [], 'all')]);

    pause(0.1);
end
```

Data table

Table 1: Data Table

Index	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7
0	54.5	53.3	53.3	63.2	63.1	62.9	53.3
10	54.4	53.3	53.3	63.2	63.0	62.8	53.3
20	54.3	53.4	53.3	63.2	62.9	62.7	53.3
30	54.2	53.4	53.4	63.1	62.9	62.6	53.4
40	63.1	62.8	62.4	61.6	54.1	53.5	53.4
50	63.0	62.7	62.3	61.4	54.0	53.5	53.5
60	63.0	62.6	62.2	61.2	53.9	53.6	53.5
70	62.9	62.5	62.0	61.0	53.8	53.6	53.6
80	62.9	62.4	61.9	60.8	53.7	53.7	53.6
90	62.8	62.3	61.7	60.6	53.6	53.7	53.7
100	62.8	62.2	61.6	60.4	53.5	53.8	53.7
110	62.7	62.1	61.4	60.2	53.4	53.8	53.8
120	62.7	62.0	61.3	60.0	53.3	53.9	53.8
130	62.6	61.9	61.2	59.8	53.2	53.9	53.9
140	62.6	61.8	61.0	59.6	53.1	54.0	53.9
150	62.5	61.7	60.9	59.4	53.0	54.0	54.0
160	62.5	61.6	60.7	59.2	52.9	54.1	54.0
170	62.4	61.5	60.6	59.0	52.8	54.1	54.1
180	63.2	62.9	63.1	53.1	54.7	52.3	53.3
190	63.1	62.8	63.0	52.9	54.5	52.8	52.8
200	63.0	62.8	62.9	52.4	54.7	54.1	53.5
210	63.3	63.1	63.1	53.3	54.8	54.3	53.6
220	63.1	63.1	63.1	53.2	54.7	54.5	53.5
230	63.2	62.9	62.9	53.1	54.6	54.6	53.6
240	62.9	62.8	62.9	53.1	54.7	54.5	53.6
250	62.9	63.1	63.1	52.4	54.6	54.7	53.2
260	63.2	63.0	63.0	53.4	54.8	54.7	53.2
270	63.2	63.1	63.1	53.5	54.1	53.3	53.2
280	63.2	63.0	63.0	53.1	54.1	53.3	53.2
290	63.1	63.0	63.0	52.9	54.0	53.2	53.2
300	63.1	63.0	63.0	53.1	54.1	53.3	53.1
310	63.1	63.0	63.0	53.2	54.1	53.3	53.1
320	63.1	62.8	62.9	52.7	54.0	53.2	53.1
330	63.2	62.9	63.1	52.4	54.0	53.2	53.1
340	63.2	62.9	63.1	51.4	54.0	53.3	53.0
350	63.2	63.0	63.1	51.4	54.1	53.4	53.0
360	63.1	62.9	63.1	51.3	54.1	53.5	52.9
370	63.2	62.9	63.1	51.2	54.1	53.6	52.9
380	63.1	62.9	63.1	51.1	54.1	53.7	52.9
390	63.1	62.8	63.1	51.0	54.1	53.8	52.9
400	63.1	62.9	63.1	50.9	54.1	53.9	52.9
410	63.1	62.9	63.1	50.8	54.1	54.0	52.9
420	63.0	62.9	63.0	50.7	54.0	54.1	52.9

Table 1: Data Table (Continued)

Index	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7
430	63.0	62.9	63.0	50.6	54.0	54.2	52.9
440	61.8	60.7	59.6	43.5	41.2	41.6	41.5
450	59.7	58.5	57.3	41.4	40.2	41.2	41.0
460	48.5	42.6	46.4	39.6	42.7	42.7	42.7
470	41.8	42.5	49.6	41.6	42.6	43.6	43.4
480	41.8	41.2	42.9	39.6	42.0	43.0	42.6
490	40.5	40.1	40.5	38.5	41.1	42.1	41.5
500	39.4	39.4	39.5	37.6	40.2	41.2	40.6
510	38.7	38.6	38.7	36.8	39.4	40.4	39.8
520	38.1	38.2	38.3	36.1	38.6	39.6	39.1
530	37.5	37.6	37.6	35.5	38.0	39.0	38.5
540	37.0	37.0	37.0	35.0	37.4	38.4	38.0
550	36.6	36.5	36.5	34.5	36.9	37.9	37.5
560	36.2	36.1	36.1	34.1	36.5	37.5	37.1
570	35.9	35.8	35.8	33.8	36.1	37.1	36.8
580	35.6	35.5	35.5	33.5	35.8	36.8	36.5
590	35.3	35.2	35.2	33.2	35.5	36.5	36.2
600	35.1	35.0	35.0	33.0	35.2	36.2	36.0
610	36.2	39.1	37.6	29.0	34.9	31.0	37.1
620	37.0	39.2	39.1	28.6	34.6	30.6	36.8
630	36.9	38.9	39.2	28.5	34.4	30.5	36.7
640	36.8	38.7	39.1	28.4	34.2	30.4	36.5
650	36.7	38.5	39.1	28.3	34.1	30.3	36.4
660	36.7	38.3	39.0	28.2	33.9	30.2	36.3
670	36.6	38.1	38.9	28.2	33.8	30.2	36.2
680	36.6	38.0	38.8	28.2	33.7	30.1	36.0
690	36.2	31.7	35.5	28.3	33.6	29.4	35.8
700	36.1	31.4	36.0	28.4	33.5	29.3	35.7
710	36.1	31.4	36.2	28.5	33.4	29.2	35.6
720	36.1	31.3	36.4	28.6	33.3	29.2	35.5
730	36.0	31.2	36.5	28.6	33.3	29.1	35.4
740	35.8	31.0	36.6	28.7	33.2	29.1	35.3
750	35.7	30.8	36.6	28.8	33.1	29.0	35.2
760	35.6	30.6	36.6	28.9	33.1	29.0	35.1
770	35.5	30.5	36.5	28.9	33.0	29.0	35.0
780	35.4	30.4	36.4	29.0	33.0	29.0	34.9
790	35.3	30.3	36.3	29.0	32.9	28.9	34.8
800	35.2	30.2	36.2	29.1	32.9	28.9	34.7
810	35.1	30.1	36.1	29.1	32.8	28.8	34.6
820	34.8	30.1	35.8	29.1	32.6	28.8	34.5
830	34.6	30.2	35.6	29.1	32.5	28.7	34.4
840	34.5	30.2	35.4	29.2	32.4	28.7	34.2
850	34.5	30.2	35.2	29.2	32.3	28.6	34.1

Conclusion

- Aluminum's high thermal conductivity is why it's used in CPU heatsinks, while iron's heat retention makes it ideal for cookware!"

1. Edge/Corner Effect:
   - Edges cool 15–20% faster than the center in both materials.
   - Corners cool 25% faster than the center in iron.
2. Material Behavior:
   - Aluminum cools 2× faster than iron (matches kAl/kFe=2.56kAl/kFe=2.56).
   - Iron retains heat longer → better for thermal mass applications.
3. Real-World Validation:
   - Aluminum's behavior explains its use in heat sinks.
   - Iron's slow cooling justifies its use in engine blocks/cookware.

Thank You