ME 315 Laboratory

Project Proposal Assignment

Name of your group members:

- Lokesh
- Owen
- Albert
- Senthilkumar

Overview

Problem Statement/Research Question:

How does the heat distribution uniformity across the cooking surface differ among three types of pans (stainless steel, cast iron, and aluminum), and which pan material provides the most uniform heat distribution when considering spreading resistance and temperature uniformity?

Background Information:

Different cookware materials exhibit varying thermal properties that affect heat distribution across the pan surface. Stainless steel has relatively low thermal conductivity (14-15 W/m·K), while aluminum has high thermal conductivity (205 W/m·K), and cast iron falls in between (50-80 W/m·K). These differences can lead to variations in cooking performance and food quality. Spreading resistance, a measure of how easily heat spreads from a source across a surface, plays a crucial role in determining the uniformity of heat distribution in cookware.

Real World Importance/Impact:

Understanding heat distribution in cookware can help both home cooks and professional chefs select the most appropriate pans for different cooking tasks, potentially improving food quality, cooking efficiency, and energy use in kitchens. This knowledge can also inform cookware manufacturers in designing more efficient and effective cooking utensils.

Hypothesis (optional):

The aluminum pan will demonstrate the lowest spreading resistance and most uniform heat distribution due to its high thermal conductivity, followed by cast iron, with stainless steel showing the highest spreading resistance and least uniform distribution.

Assumptions:

1. The spray paint will provide a uniform emissivity close to 1 for all pans.

2. The heat source (stovetop burner) will provide consistent heat output for all tests.

3. Ambient conditions (room temperature, air currents) will remain constant during testing.

4. The pans are of similar thickness and diameter.

5. The thermocouple measurements are accurate and not significantly affected by contact resistance.

6. 1-D conduction (spreading resistance is calculated)

Materials List:

- 1 stainless steel pan

- 1 cast iron pan

- 1 aluminum pan

- High-temperature black spray paint (link to product)

- Infrared camera (FLIR E4 or similar) (link to product)

- Gas stovetop or electric hotplate

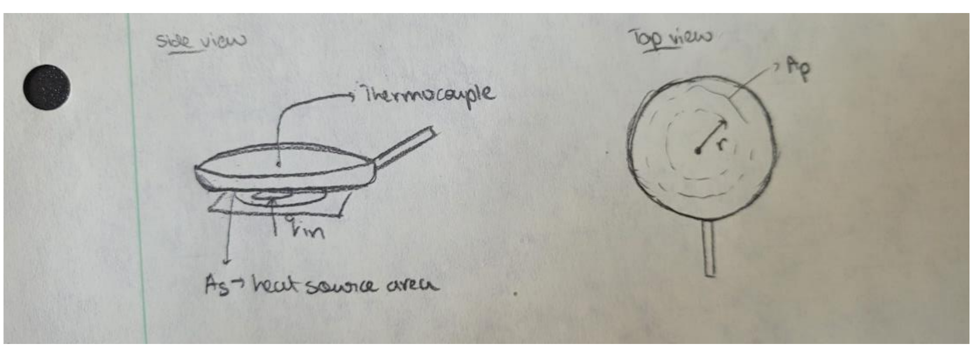
- Stopwatch

- Thermocouples and data logger (for verification)

- Insulation

- Safety equipment (heat-resistant gloves, safety glasses)

Schematic:



Rough Procedures:

1. Clean and dry all pans thoroughly.

2. Apply high-temperature black spray paint evenly to the top surface of each pan.

3. Allow paint to dry completely according to manufacturer's instructions.

4. Set up the heat source and ensure it's at a consistent setting for all tests.

5. Attach thermocouple at center of the pan

6. Place the first pan on the heat source and start the stopwatch.

7. At 30-second intervals, use the IR camera to capture thermal images of the pan surface.

8. Simultaneously record thermocouple readings at each interval.

9. Continue until the pan reaches a steady state indicated by the thermocouple at the center

10. Allow the heat source to cool, then repeat steps 6-9 for the other two pans.

11. Ensure

Analysis:

Data Collection:

- Thermal images of each pan at 30-second intervals using the IR camera

- Temperature readings across the pan surface from IR images

- Thermocouple measurements at center of the pan surface

- Time to reach steady state for each pan

Assumptions:

- Uniform emissivity of painted surfaces

- Consistent heat input from the source

- The thermocouple measurements are accurate and not significantly affected by contact resistance

- 1D radial heat transfer

Known and Unknown:

Known:

- Pan materials, dimensions, and thermal conductivities
- Heat source settings
- Time intervals for measurements

Unknown:

- Temperature distribution across pan surfaces
- Time to reach steady state for each pan
- Spreading resistance for each pan
- Quantitative measure of heat distribution uniformity

Objective:

To determine which pan material provides the most uniform heat distribution by analyzing spreading resistance and temperature uniformity.

Analytical Methods:

1. Calculate spreading analytical resistance (R_c) for each pan:

$$R_c = \frac{\psi(\varepsilon)}{k\sqrt{A\_s}}$$

$$\psi(\varepsilon) = \frac{1-1.410\varepsilon + 0.344\varepsilon^3 + 0.043\varepsilon^5 + 0.034\varepsilon^7}{1-1.410\varepsilon + 0.344\varepsilon^3}$$

$$\varepsilon = \sqrt{\frac{A_s}{A_p}}$$

Where k is the thermal conductivity of the pan material, A_s is the heat source area, and ψ(ε) is the dimensionless constriction resistance.

Also calculate actual spreading resistance for pan at each temperature point on the radial line using energy balance

$$q_{in} = \frac{(T_r - T_s)}{R_{sp}}$$

2. Use image processing software to extract temperature data from IR images along a radius line.

4. Calculate average temperature and standard deviation across the pan surface for each time point using IR data.

6. Compute a uniformity index (UI) for each pan:

UI = 1 - (Standard Deviation of Temperature / Average Temperature)

7. Analyze the relationship between calculated spreading resistance and observed temperature uniformity.

8. Compare time to reach steady state for each pan type.

10. Correlate spreading resistance with observed heat distribution patterns and UI values.

Integration of Thermocouple and IR Measurements:

1. Use thermocouples at cemter(e.g., center) to validate IR camera readings.

2. Ensure proper thermocouple extension and connection to maintain measurement accuracy.

3. Compare thermocouple and IR readings to identify any discrepancies and potential sources of error.

4. Use thermocouple data to calibrate IR measurements if necessary, considering emissivity variations.

By analyzing these factors, we can quantitatively compare the heat distribution characteristics of the three pan types. The pan with the lowest spreading resistance and highest uniformity index is likely to provide the most even heating. However, we will also consider the correlation between calculated spreading resistance and observed temperature uniformity, the time taken to reach steady state, and any discrepancies between thermocouple and IR measurements. This comprehensive analysis will provide a robust evaluation of each pan's heat distribution properties, helping to determine which pan offers the most uniform heating for cooking purposes.

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Overview:

- **Problem statement/research question**
  Can drilling holes into fins improve heat dissipation? In this project, we would like to introduce holes into the traditional fin structure and see how they affect the fins' cooling performance compared with fins without holes.
- **Background information**
  Typically, fins are elongated and aim to increase the surface area to enhance heat dissipation. What if we drill holes in the fins? Wouldn’t that make the surface area bigger while reducing materials?
- **Real world importance/impact of your result**
  If this project proves its point, this method could benefit every industry that requires fins to cool down their products, such as semiconductors, electronics, and so on. It could reduce the cost and the weight of the finned part while maintaining or improving their cooling performance.

Hypothesis:

Drilling holes into fins will improve convective heat transfer by expanding the surface area. This could sustain or improve its cooling performance compared to the traditional fins.

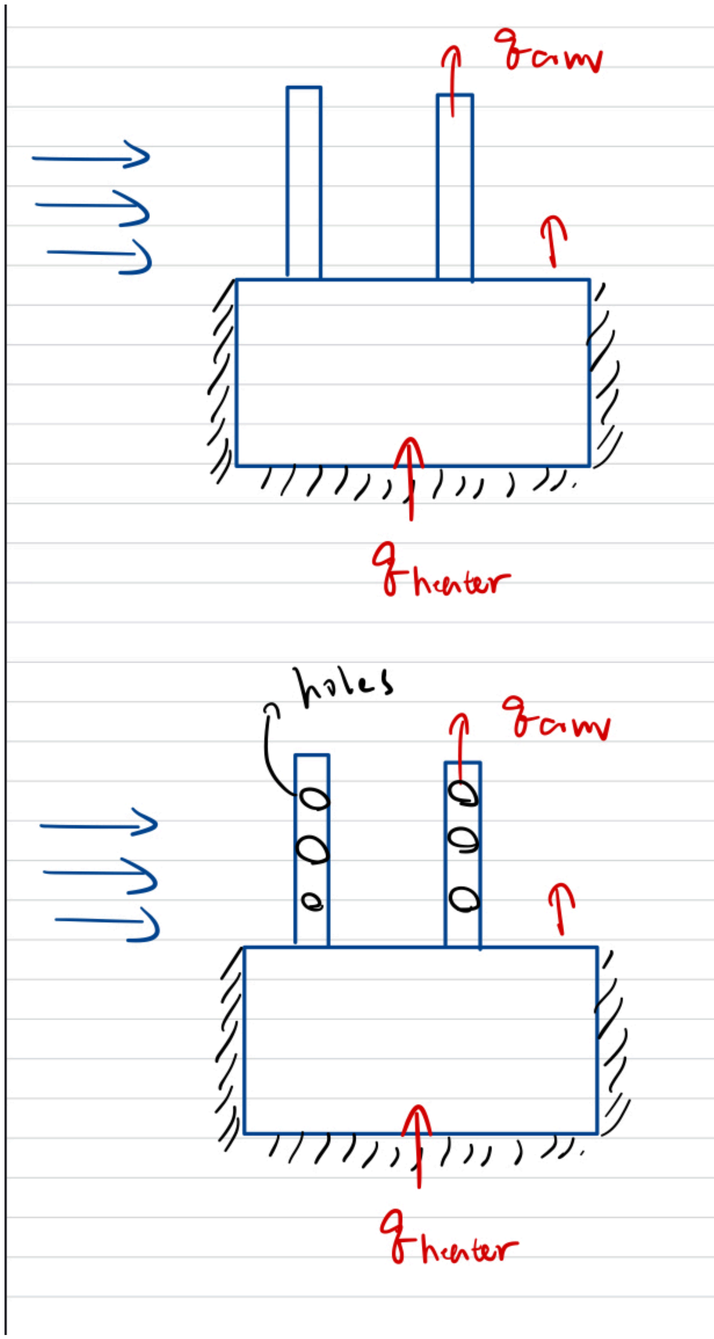
Assumptions:

- The fins have constant thermal property
- The radiative heat transfer is negligible
- The bottom and the sides of our block are perfectly insulated
- The airflow across the fins is steady and laminar
- Same ambient temperature

Materials list:

- Polyethylene terephthalate glycol (PETG) as 3D printer filament
- 3D-printed fins (PETG)
- 3D-printed fins with holes (PETG)
- Heater
- Thermocouples
- IR camera
- Air blower
- Insulations (wood block or
- Black paint (to reduce radiation's effect)

Schematic:



Rough Procedures:

1. Set up the IR camera
2. Calibrate thermocouples
3. Apply black paint to the surface and finned area

4. Embed thermocouples to the bottom and surface of the test object
5. Insulate the test object by fitting it into a wood block
6. Set up air blower
7. Set up the heater
8. Heat up the test object from the bottom
9. Monitor the highest temperature in the block (the bottom) and ensure it won't exceed 70°C
10. After a certain time interval, use an IR camera to take thermal images

Analysis:

- **What data do you collect?**
    1. Ambient temperature
    2. Heat input
    3. Experiment time
    4. Temperature profiles from the thermocouples
    5. Thermal image from IR camera
    6. Temperature readings from the thermal images

- **What are your assumptions?**
    1. Radiation is negligible
    2. Uniform heat generation
    3. Constant thermal properties
    4. Consistent airflow
    5. Room temperature will not fluctuate throughout the whole experiment
    6. Convection will be the primary heat loss
    7. Holes will increase airflow through the fin surface
    8. The system reaches steady state at the end of the experiment

- **What is your known and unknown?**

Known:

1. Material properties
2. Heat input
3. Fin dimensions
4. Ambient temperature
5. Convection heat transfer coefficient

Unknown:

1. Effect of holes on heat dissipation

- **What are you trying to figure out?**
  Determine if drilling holes in fins can improve heat dissipation
- **How do you intend to arrive at your answer? (Analytical methods, equations needed, heat transfer mechanism involved)**
  1. Compare their temperature readings from the IR camera, the lower one has better heat dissipation
  2. Compute the convective heat loss using ($Q=hA*(T_s-T_\infty)$) and compare their values