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Structural and Thermal Analysis R&D

Energy Saving by Insulating a Cooking Pot

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Introduction

Sandia National Laboratories is one of the most technologically advanced and resourceful national laboratories in the United States. Their mission is to use science and technology, innovative research, and global engagement to counter threats, reduce dangers, and respond to disasters. To achieve this mission, Sandia is divided into ten divisions that are overlooked by Dr. Stephen Younger, the Laboratories Director. Amongst the ten divisions, the internship will take place in Division 8000, which is Integrated Security Solutions. Inside this division, the internship will be a Structural and Thermal Analysis R&D. Apart from being strictly focused on security, the division performs research for small companies that do not count with the resources to perform it themselves. During the summer internship, one of these cases is being attended. A small company invented an insulating cover that is supposed to be placed over the top of a cooking pot lid. They claim that the insulating cover helps in the saving of energy. As an intern and researcher, the task is to determine how much energy is effectively saved by placing the insulating cover over the cooking pot. To achieve the goal, mathematical analyses, experiments and simulations will be done. Then, if appropriate, a better design will be made to increase the energy saved by the insulating cover. For the mathematical analysis, the thermal resistance method was used, resulting in energy saved at a rate of 14.2795 W. After the mathematical analysis was done, a test plan was developed and presented to the supervisor for approval. After some recommendations, the test plan will be modified accordingly.

Energy Saving by Insulating a Cooking Pot

Problem Statement:

Sandia National Laboratories counts with an initiative to help small companies perform the research and experimentation that they are not able to do on their own products. A small company invented an insulating cover that goes on top of the lid of a cooking pot, claiming it helps save energy. The team in charge of the project is tasked with proving the functionality of the product by proving doing a mathematical analysis, designing and performing an experiment, run simulations of the product, and look for a better design of the product, if needed.

Objectives / Requirements and Deliverables:

The first objective of the project is to quantify the amount of energy saved by placing the insulating cover on top of the cooking pot's lid. After the first objective is achieved, a test plan will be made to brainstorm and determine the most ideal way to perform the experiment on the product. An experiment will be designed and performed, following the strategy suggested by the test plan. A simulation of the product will be performed, of which the results will be compared with the experiment performed. If necessary, according to the results obtained, a better design for the insulating cover will be made to increase the amount of energy saved.

Student Responsibilities:

To quantify the amount of energy saved a mathematical analysis must be performed on the cooking pot with and without the insulating cover. To achieve that, a heat transfer analysis is done for both cases, for which the results are compared, and the energy saved is determined. For the non-insulated pot, the rate of energy saved was 32.9301 W, while for the insulated pot it was 18.6506 W. This resulted in 14.2795 W being saved by the insulating cover. After performing the analysis and obtaining results that are representative of reality (considering the assumptions that were made), the student must design a test plan for the project. This enables the development of a strategy that describes how the experimentation should be performed. The test plan was presented to the supervisor and needed to be approved. Before approval, some recommendations were made, and the test plan will be updated to meet the standard. Following the strategies suggested by the test plan, an experiment that helps determine the amount of energy saved must be designed by the student. Also, a simulation of the cooking pot with the insulating cover will be performed by the student using ANSYS. Finally, depending on the results obtained, the student must help with the design of a product that manages to achieve a higher amount of energy saved.

Methodology & Work Performed

Heat Transfer Analysis:

As established, the purpose of the project was to quantify the energy being saved by placing an insulating cover over a cooking pot lid. To find that required value, a heat transfer analysis had to be done on the cooking pot with and without insulation. The analysis involved in the problem required to consider a tridimensional, transient problem, which could be done by using the heat equation in cylindrical coordinates, as shown in **equation (1)**.

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r * k\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial}{\partial \varphi}\left(k\frac{\partial T}{\partial \varphi}\right) + \frac{\partial}{\partial z}\left(k\frac{dT}{dz}\right) + \dot{q} = \rho c\frac{\partial T}{\partial t} \quad \textbf{(1)}$$

Where *T* is the temperature, *r* is the radius, ϕ is the angle, *z* is the height, *k* is the thermal conductivity, $\dot{q}$ is the heat generation, *ρ* is the density of the material, *c* is the specific heat of the material, and *t* is the time. Seeking to simplify the problem, it was assumed that there is no heat generation and that the temperature does not change with respect to the angle. Therefore **equation (1)** became **equation (2)**.

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r * k\frac{\partial T}{\partial r}\right) + \frac{\partial}{\partial z}\left(k\frac{dT}{dz}\right) = \rho c\frac{\partial T}{\partial t} \quad \textbf{(2)}$$

However, the partial differential equation was still too complicated to effectively solve, since there were no specific boundary conditions available. For that motive, a mathematical manipulation was done to find a solution to the problem that could approximate the actual amount of energy saved. The pot was modeled as a composite structure, which led to the use of the thermal resistance circuit method. Thermal resistance circuits consider that the heat transfer is one-dimensional, but the heat loss at the sides of the pot also needed to be quantified, which is where the mathematical manipulation came into play. The resistance present on the sides of the pot were added to the thermal resistance circuit using the surface area of the side of the pot. Using this method, the heat transfer was calculated for a non-insulated pot and an insulated pot.

Considering the heat transfer rate can be calculated as:

$$\dot{Q} = C\Delta T = \frac{\Delta T}{R} \quad \textbf{(3)}$$

Where C is the heat conductance and R is the heat resistance, the formula for the thermal resistance circuit can be derived.

Considering the resistances for conduction and convection:

$$R_{conduction} = \frac{L}{kA} \quad \textbf{(4)}$$

$$R_{convection} = \frac{1}{hA} \quad \textbf{(5)}$$

The heat transfer was determined by the following resistance circuits (**equation 6** and **equation 7**):

For the non-insulated pot:

$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{\frac{L_{wall}}{k_{SS} * A_{vertical}} + \frac{L_{water}}{k_{water} * A_{vertical}} + \frac{L_{wall}}{k_{SS} * A_{vertical}} + \frac{L_{wall}}{k_{SS} * A_{sides}} + \frac{1}{h_{air} * A_{vertical}}} \quad \textbf{(6)}$$

For the insulated pot:

$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{\frac{L_{wall}}{k_{SS} * A_{vertical}} + \frac{L_{water}}{k_{water} * A_{vertical}} + \frac{L_{wall}}{k_{SS} * A_{vertical}} + \frac{L_{wall}}{k_{SS} * A_{sides}} + \frac{L_{felt}}{k_{felt} * A_{vertical}} + \frac{1}{h_{air} * A_{vertical}}} \quad \textbf{(7)}$$

Where *L* is the length of the conductive medium, *k* is the thermal conductivity, *h* is the coefficient of heat transfer, and *A* is the cross-sectional area of heat transfer.

The thermal resistance circuits for the respective cases are illustrated in **Figure 1** and **Figure 2**.

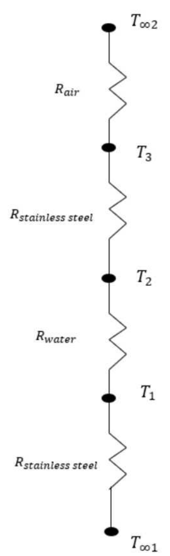


Figure 1: *Thermal circuit for non-insulated pot.*

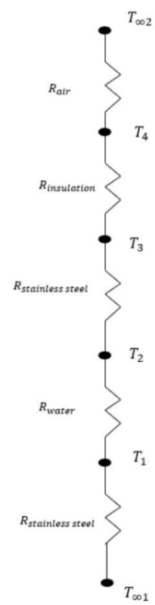


Figure 2: *Thermal circuit for insulated pot.*

Test Plan:

After the mathematical analysis was realized, a test plan had to be developed to run the experiment. During the experiment, the purpose is to obtain a value for the saved energy by measuring the heat losses from the non-insulated pot and the insulated pot.

First, safety was considered. Due to the hazard that hot surfaces and boiling water can be, it was recommended that gloves and safety goggles were used. The gloves should reduce the danger of burning when a handling a hot surface and the googles protect the eyes from the hot water.

A list of the materials needed to perform the experiment was done. It was divided into specimens to be tested and instrumentation:

- Specimens to be tested
    - Stainless steel cooking pot with lid
    - Water
    - ¾ in. felt insulating cover
- Instrumentation
    - Hot plate with temperature control – *Thermo Scientific Cimarec Hot Plate*
    - 6 Type K Thermocouples – *PerfectPrime TL1004 K-Type Sensor*
    - Data Acquisition System (DAQ) – *PICO USB TC-08*
    - 8-gauge galvanized steel wire

After the materials were chosen, the software to be used for the experiment needed to be chosen. Considering the instrumentation that was picked, it was determined that LabVIEW was a good option to the record the data picked up by the thermocouples. Additionally, to analyze the data, Excel was chosen to create the graphs needed to determine the energy saved.

Before starting the experiment, it was recommended that the instrumentation was tested. The thermocouples should be connected to the DAQ system and observed in LabVIEW. If the thermometer display in LabVIEW shows room temperature, the thermocouple is working. As the thermocouple approaches a warmer or colder surface, the temperature shift should be noticeable. In the hot plate's case, it should be turned on and set to the required temperature. A thermocouple can be used to record that temperature. If the hot plate reaches the temperature required, it is working.

Finally, after the instrumentation was tested, the following steps had to be followed to perform the experiment:

1. Set up 6 thermometer displays on LabVIEW to monitor the thermocouples. Turn on the DAQ system and connect it LabVIEW. After the software is up, plug in the thermocouples and check the displayed thermometers are reading.

2. Set up the pot for the experiment. Stretch the 8-gauge steel wire across the diameter of the pot (if handles on the pot are available, they might be helpful). Make sure the wire is as tense as possible. Place the thermocouples on the wire with 1 ½ in. (3.81 cm) gaps between them. After the thermocouples are paced, make sure they are submerged at different depths.

Thermocouple	**Depth**
Thermocouple A	1 cm
Thermocouple B	4 cm
Thermocouple C	9 cm
Thermocouple D	14 cm

Table 1: *Depth of each thermocouple under the water's surface.*

After the inside thermocouples are set up, place a thermocouple on the lid of the pot and denote it "Thermocouple E."

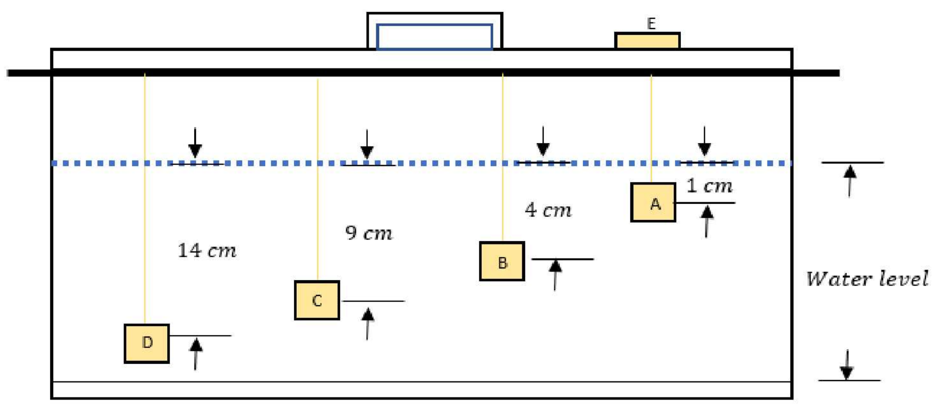


Figure 3: *Thermocouple placement on the non-insulated pot.*

3. While the hot plate is unplugged, place a thermocouple on top of it and denote it "Thermocouple F." Also, place a heat flux gauge on the surface of the hot plate to monitor

the heat flux through the actual hot plate. Plug in the hot plate and set the temperature to 150°C.

4. After the hot plate has reached 150°C, place the pot setup on top of it. Just after placing the pot, start running LabVIEW. Observe how the temperature measures change with respect to time.

5. After the temperatures seem to remain constant, stop the experiment. Make sure to record the time it takes to reach that point.

6. Extract the data from LabVIEW and import it to Excel. Once the data is imported prepare a Temperature vs. Time graph and a Temperature vs. Position graph.

7. Set the pot aside to cool. After it has reached room temperature, repeat steps 4 through 6 up to three times.

8. Repeat steps 4 through 7 by increasing the temperature in increments of 50°C until reaching 300°C.

9. Detach "Thermocouple E" from the pot lid. Place the insulating cover on top of the lid. Place "Thermocouple E" on top of the insulating cover and repeat steps 4 through 8.

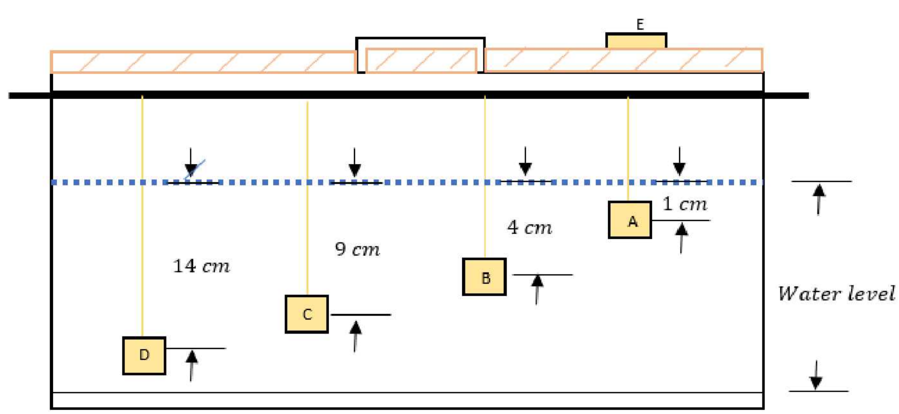


Figure 4: *Thermocouple placement on insulated pot.*

10. After the experiment is over, turn off and unplug the hot plate. Make sure the pot and hot plate are cooled down before removing the setup. Once they have cooled down, discard the water. Pat the thermocouples dry with a paper towel and store them carefully. Close LabVIEW and disconnect the DAQ system.

Experiment:

At the moment of writing the report, the experiment was yet to be done. In order to conduct the experiment, the test plan needs to be approved. After the test plan is approved, the experiment will be conducted in a laboratory with the proper gear and instrumentation. It is expected that certain trainings will be needed before using the laboratory.

Simulations:

After the experiment is done, the simulations will be made using ANSYS Mechanical, ANSYS Thermal, and ANSYS Fluent. A model of the cooking pot will be made, and the proper constraints will be determined. The results from the simulations will be compared to the results from the experiment and the results from the mathematical analysis.

Product Design / Re-design:

Depending on the results obtained from the experiment and simulations, a new design for the product will be suggested. A design that more effectively achieves the goal of the product will be made using a CAD software, most likely SolidWorks.

Results & Discussion

Heat Transfer Analysis:

Given Data:

- Diameter of the pot: 0.1778 m
- Height of the pot: 0.1143 m
- Thickness of the pot walls: 0.002 m
- Thickness of the felt insulation: 0.00635 m
- Temperature of the stovetop ($T_{\infty 1}$): 300°C
- Temperature of the surroundings ($T_{\infty 2}$): 25°C
- Heat transfer coefficient of air (h_{air}): $40\,\frac{W}{m^2K}$
- Thermal conductivities:
    - $k_{stainless\ steel} = 14.4\ \frac{W}{mK}$
    - $k_{water} = 0.606\ \frac{W}{mK}$
    - $k_{felt} = 0.04\ \frac{W}{mK}$

The temperatures given needed to be converted to the absolute scale to make the units match.

$$T[K] = T[°C] + 273.15 \quad \textbf{(8)}$$

$$T_{\infty 1}[K] = 300°C + 273.15 = 573.15\ K$$

$$T_{\infty 2}[K] = 25° + 273.15 = 298.15\ K$$

To calculate the heat transfer through the pot, the thermal resistance circuit approach was used. Since the problem was two-dimensional, a mathematical manipulation had to be realized to obtain an approximation of the energy released by the pot. The surface area of the sides of the pot was used as part of the circuit as way to consider the heat lost through it.

The calculation for the areas depended on the geometry of the surfaces:

$$Area_{vertical} = \pi \frac{D^2}{4} \quad \textbf{(9)}$$

$$Area_{vertical} = \pi \frac{(0.1778\ m)^2}{4} = 0.0248\ m^2$$

$$Area_{sides} = HL = H\pi D \quad \textbf{(10)}$$

$$Area_{sides} = (0.1143\ m)\pi(0.1778\ m) = 0.0423\ m^2$$

To calculate the conduction through a certain material, it is necessary to know the length through the heat is conducted. For the stainless-steel parts of the thermal circuit, the length is equal to the thickness of the pot walls. On the other hand, the length through the water was calculated by subtracting the walls from the total height of the pot.

$$L_{water} = H - 2 * th \quad \textbf{(11)}$$

$$L_{water} = 0.1143\ m - 2(0.002\ m) = 0.1103\ m$$

Applying the thermal resistance circuit approach, the heat transfer through the non-insulated pot resulted to be 32.9301 W. A script was written in MATLAB to make the calculating process easier.

$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{\frac{L_{wall}}{k_{SS} * A_{vertical}} + \frac{L_{water}}{k_{water} * A_{vertical}} + \frac{L_{wall}}{k_{SS} * A_{vertical}} + \frac{L_{wall}}{k_{SS} * A_{sides}} + \frac{1}{h_{air} * A_{vertical}}}$$

$$\dot{Q} = \frac{573.15\ K - 298.15\ K}{\frac{0.002\ m}{14.4 \frac{W}{mK} * 0.0248\ m^2} + \frac{0.1103\ m}{0.606 \frac{W}{mK} * 0.0248\ m^2} + \frac{0.002\ m}{14.4 \frac{W}{mK} * 0.0248\ m^2} + \frac{0.002\ m}{14.4 \frac{W}{mK} * 0.0423\ m^2} + \frac{1}{40 \frac{W}{m^2 K} * 0.0248\ m^2}}$$

$$\dot{Q} = 32.9301\ W$$

Editor - C:\Users\cmolin\Documents\MATLAB\Pot.m

Pot.m | Pot_insulated.m

```matlab
clc, clear, close all

disp('ANALYSIS FOR POT WITHOUT INSULATION')
disp('-----------------------------------')
disp(' ')
disp('POT DIMENSIONS:')
D1 = input('Insert the diameter of the pot in [m]: ');
H = input('Insert the height of the pot in [m]: ');
disp(' ')
disp('TEMPERATURES:')
Tinf1 = input('Insert the temperature of the stovetop in [K]: ');
Tinf2 = input('Insert the temperature of the surroundings in [K]: ');
disp(' ')
disp('LENGTHS OF CONDUCTION:');
L1= input('Insert the thickness of the pot walls in [m]: ');
L3=L1;
L4=L3;
L2= input('Insert the height of the water inside the pot in [m]: ');
disp(' ')
disp('MATERIAL PROPERTIES:')
k1= input('Insert the thermal conductivity of stainless steel in [W/m*K]: ');
k3=k1;
k4=k3;
k2= input('Insert the thermal conductivity of water in [W/m*K]: ');

h = input('Insert the coefficient of heat transfer of air in [W/m^2*K]: ');



A1 = pi*(D1^2)/4;
A2=A1;
A3=A2;

C = D1*pi;

A4 = H*C;

alpha = L1/(k1*A1);
gamma = alpha;
beta = L2/(k2*A2);
delta = L4/(k4*A4);
epsilon = 1/(h*A1);

Rtotal = [alpha;beta;gamma;delta;epsilon];

Q = (Tinf1-Tinf2)/(sum(Rtotal));
disp(' ')
disp(['The rate of the total energy released by the cooking pot is ',num2str(Q),' W.'])
```

Figure 4: *MATLAB script that calculates heat transfer through non-insulated pot.*

Command Window

```
ANALYSIS FOR POT WITHOUT INSULATION
-----------------------------------

POT DIMENSIONS:
Insert the diameter of the pot in [m]: 0.1778
Insert the height of the pot in [m]: 0.1143

TEMPERATURES:
Insert the temperature of the stovetop in [K]: 573.15
Insert the temperature of the surroundings in [K]: 298.15

LENGTHS OF CONDUCTION:
Insert the thickness of the pot walls in [m]: 0.002
Insert the height of the water inside the pot in [m]: 0.1103

MATERIAL PROPERTIES:
Insert the thermal conductivity of stainless steel in [W/m*K]: 14.4
Insert the thermal conductivity of water in [W/m*K]: 0.606
Insert the coefficient of heat transfer of air in [W/m^2*K]: 40

The rate of the total energy released by the cooking pot is 32.9301 W.
fx >>
```

Figure 5: *MATLAB results for heat transfer through non-insulated pot.*

To calculate the energy released by the insulated pot, the same approach was used. However, the resistance corresponding to the felt insulation was added.

$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{\frac{L_{wall}}{k_{SS} * A_{vertical}} + \frac{L_{water}}{k_{water} * A_{vertical}} + \frac{L_{wall}}{k_{SS} * A_{vertical}} + \frac{L_{wall}}{k_{SS} * A_{sides}} + \frac{L_{felt}}{k_{felt} * A_{vertical}} + \frac{1}{h_{air} * A_{vertical}}}$$

$$\dot{Q} = \frac{573.15\ K - 298.15\ K}{\frac{0.002\ m}{14.4 \frac{W}{mK} * 0.0248\ m^2} + \frac{0.1103\ m}{0.606 \frac{W}{mK} * 0.0248\ m^2} + \frac{0.002\ m}{14.4 \frac{W}{mK} * 0.0248\ m^2} + \frac{0.002\ m}{14.4 \frac{W}{mK} * 0.0423\ m^2} + \frac{0.00635\ m}{0.04 \frac{W}{mK} * 0.0248\ m^2} + \frac{1}{40 \frac{W}{m^2 K} * 0.0248\ m^2}}$$

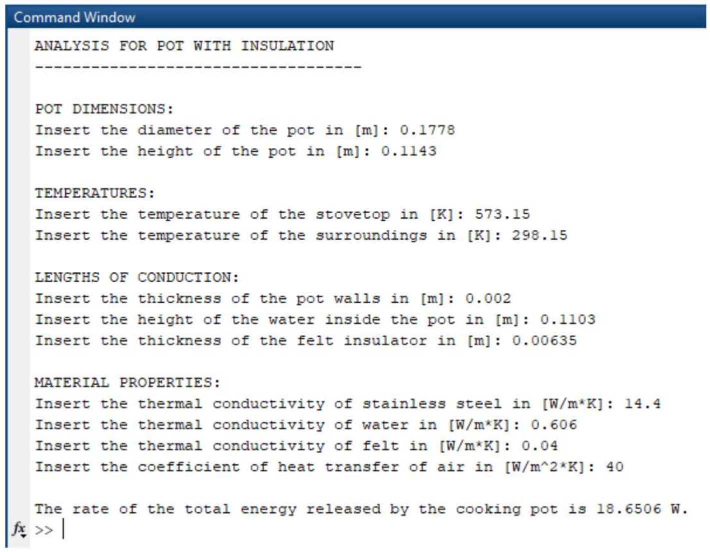
$$\dot{Q} = 18.6506\ W$$

Editor - C:\Users\cmolin\Documents\MATLAB\Pot_insulated.m

Pot.m | Pot_insulated.m

```
clc, clear, close all

disp('ANALYSIS FOR POT WITH INSULATION')
disp('-----------------------------------')
disp(' ')
disp('POT DIMENSIONS:')
D1 = input('Insert the diameter of the pot in [m]: ');
H = input('Insert the height of the pot in [m]: ');
disp(' ')
disp('TEMPERATURES:')
Tinf1 = input('Insert the temperature of the stovetop in [K]: ');
Tinf2 = input('Insert the temperature of the surroundings in [K]: ');
disp(' ')
disp('LENGTHS OF CONDUCTION:');
L1= input('Insert the thickness of the pot walls in [m]: ');
L3=L1;
L4=L3;
L2= input('Insert the height of the water inside the pot in [m]: ');
L5= input('Insert the thickness of the felt insulator in [m]: ');
disp(' ')
disp('MATERIAL PROPERTIES:')
k1= input('Insert the thermal conductivity of stainless steel in [W/m*K]: ');
k3=k1;
k4=k3;
k2= input('Insert the thermal conductivity of water in [W/m*K]: ');
k5= input('Insert the thermal conductivity of felt in [W/m*K]: ');
h = input('Insert the coefficient of heat transfer of air in [W/m^2*K]: ');


A1 = pi*(D1^2)/4;
A2=A1;
A3=A2;

C = D1*pi;

A4 = 0.1143*C;

alpha = L1/(k1*A1);
gamma = alpha;
beta = L2/(k2*A2);
delta = L4/(k4*A4);
epsilon = 1/(h*A1);
phi = L5/(k5*A1);

Rtotal = [alpha;beta;gamma;delta;epsilon;phi];

Q = ((Tinf1-Tinf2)/sum(Rtotal));
disp(' ')
disp(['The rate of the total energy released by the cooking pot is ',num2str(Q),' W.'])
```

Figure 6: *MATLAB script that calculates heat transfer through insulated pot.*



```
Command Window
ANALYSIS FOR POT WITH INSULATION
----------------------------------

POT DIMENSIONS:
Insert the diameter of the pot in [m]: 0.1778
Insert the height of the pot in [m]: 0.1143

TEMPERATURES:
Insert the temperature of the stovetop in [K]: 573.15
Insert the temperature of the surroundings in [K]: 298.15

LENGTHS OF CONDUCTION:
Insert the thickness of the pot walls in [m]: 0.002
Insert the height of the water inside the pot in [m]: 0.1103
Insert the thickness of the felt insulator in [m]: 0.00635

MATERIAL PROPERTIES:
Insert the thermal conductivity of stainless steel in [W/m*K]: 14.4
Insert the thermal conductivity of water in [W/m*K]: 0.606
Insert the thermal conductivity of felt in [W/m*K]: 0.04
Insert the coefficient of heat transfer of air in [W/m^2*K]: 40

The rate of the total energy released by the cooking pot is 18.6506 W.
>>
```

Figure 7: *MATLAB results for heat transfer through insulated pot.*

To quantify the energy saved, the rate at which energy was released from the non-insulated pot was subtracted from the one released from the insulated pot.

$$\dot{E}_{saved} = \dot{Q}_{non-insulated} - \dot{Q}_{insulated} \quad \textbf{(12)}$$

$$\dot{E}_{saved} = 32.9301\ W - 18.6506\ W$$

$$\dot{E}_{saved} = 14.2795\ W$$

As observed, the heat transfer rate through the non-insulated pot was *32.9301 W*, while it resulted to be *18.6506 W* on the insulated pot. The energy rates were subtracted to obtain the energy saved, which resulted in *14.2795 W*. Since the difference between the two cases resulted to be positive, it was determined that, considering the assumptions made to find a solution, energy was saved by placing an insulating cover over the cooking pot lid. It is expected that the results will have a certain degree of inaccuracy when compared to the results of the experiment, but they should not be completely incorrect.

Test Plan:

A presentation was made to show the test plan to the mentor (supervisor). This was done because it is Sandia policy that a test plan must be presented to different audiences before realizing the experiment. During the presentation, certain observations and suggestions were made to have a more realistic test plan. The information about the instrumentation had to be more specific. For example, the voltage tolerances of the thermocouples and the DAQ system had to be found to determine if they were compatible. Also, the use of heat flux sensors was suggested to more accurately determine the heat flux, and consequently the energy, that was went in and out of the pot. A reduction in the number of thermocouples was also recommended, since it is expected that the water should remain at boiling temperature due to the phase change. Finally, to analyze the data and obtain the required results, it was suggested that MATLAB or Python was used to process the data coming from LabVIEW.

Experiment, Simulations, Product Design / Re-design:

No results have been obtained from the experiment, simulations, or product design / redesign. When those sections of the project are performed, the respective results will be recorded and discussed to achieve the main objective more effectively.

Conclusion

For the mathematical analysis, a mathematical manipulation had to be done to simplify the problem enough to be able to solve in an effective manner. The pot was considered as a composite structure and the thermal resistance circuit method was applied. To consider the heat lost through the sides of the pot, the resistance on the sides was added to the circuit. For the non-insulated pot, the heat transfer rate resulted to be 32.9301 W and 18.6506 W for the insulated one. The rate of energy saved was 14.2795 W. These results showed that, considering the manipulation and assumptions, energy is effectively saved by placing an insulating cover over the cooking pot lid. The amount of energy saved obtained from the method used for the analysis deviates from the real value, but it should not result to be too far off. However, to make a mathematical analysis that is more realistic, it is necessary to choose a more realistic method.

Regarding the test plan, the recommendations made by the supervisor will be applied. From the first draft of the test plan it is obvious that a better understanding of the situation is needed before moving on to designing a new experiment. As stated, the number of thermocouples used in the experiment should be reduced. This is due to the water being expected to be at phase change, so the temperature won’t be too far from the boiling point. Also, the MATLAB code to process the data should be acknowledged in the test plan, since there were no specifications about how the data will be analyzed.

Gantt Chart

Proposed Gantt Chart

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
	June 3 - June 7	June 10 - June 14	June 17 - June 21	June 24 - June 28	July 1 - July 5	July 8 - July 12	July 15 - July 19	July 22 - July 26	July 29 - August 2	August 5 - August 9
Heat Transfer Analysis										
Test Plan										
Experiment										
Simulations										
Product Design / Re-design										

Actual Gantt Chart

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
	June 3 - June 7	June 10 - June 14	June 17 - June 21	June 24 - June 28	July 1 - July 5	July 8 - July 12	July 15 - July 19	July 22 - July 26	July 29 - August 2	August 5 - August 9
Heat Transfer Analysis										
Test Plan										
Experiment										
Simulations										
Product Design / Re-design										

The Gantt Charts show the timeline proposed and the actual timeline. On the actual timeline, the green indicates the work that has been done, the yellow indicates the work in progress, and the red shows the work that hasn't been started.

Lessons Learned

The most important thing I learned from the internship experience is the importance of teamwork in the work environment. My co-worker, Itzel Torres, is responsible for the figures shown in the report and the theoretical research section of the heat transfer analysis. I expected to be in a more hands-on environment from the beginning of the internship, since the organization is called Structural & Thermal Analysis R&D. However, once I arrived, I learned that to research in an effective manner, there must be a learning process that can take a long time. As of now, I have had to learn about heat transfer, partial differential equations, Python, and MATLAB. I expect to learn more about many other different subjects during the remaining time of the internship. I have realized that the work environment is a good place to notice how small is the amount of information you obtain from the university classes. Understandably, the classes taken are only meant to teach the fundamentals of engineering, which means that, to perform well in the industry, you must always keep learning and expanding your knowledge. The information obtained in an academic environment is never enough. Regarding the work ethic, the differences can be monumental, depending on the person. In a university environment, the communication between peers can be more informal, while it is important to keep a degree of respect to the peers in a work environment. Also, the responsibilities carry more weight in a work environment, since other people depend on your work. If you do not meet deadlines or do not perform well in general, the company can be affected by it. In the university, the student is the only one affected is the performance is subpar. The differences in the timeline are due to the final report having to be delivered before the 10 weeks have ended. Up to now, the proposed timeline has been followed as stated. The only difference is that the mathematical analysis was done at the beginning of Week 3, so we were able to start developing the test plan on that same week. However, as shown it is still in progress and is expected to pass the deadline at Week 4.