ME 3122 Heat and Fluids II Lab:

Determining the Thermal Conductivity Values of Various Materials

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Objective:

The student will find the values of thermal conductivity, k $\left(\frac{W}{m*K}\right)$ for various materials and compare them to values determined in A Heat Transfer Textbook[1].

Equipment Needed	QTY
• Empty Soup Can	1
• Cast Iron Skillet	1
• Stainless Steel Drinking Cup	1
• Stove Top	1 Burner
• Kettle	1
• Oven Mitts	2
• Tap Water	¾ Gallon
• Kitchen Thermometer	1

Background:

Heat can transfer three main ways, by conduction, convection or radiation. This lab will focus on conduction, specifically conduction through a material. How well this heat conducts can be characterized by the material's thermal conductivity value. The higher the conductivity value the better the material is at conducting heat. Inversely the lower the conductivity value the better insulator the material is. This value can be related to the temperature readings on either side of the material and to the heat flux by using Fourier's Law:

$$q = -k\frac{dT}{dx}$$

Where the dT is the change in temperature of the walls in Kelvin, dx is the thickness of the wall in meters and q is the heat flux. Utilizing this equation leaves two unknowns however, k the

[1] John H Lienhard IV and John H Lienhard V, "A Heat Transfer Textbook," 5th Edition

value for which the student will be solving for and q. This lab will use different vessels and be filled with boiling water. Therefore, the convection of the boiling water can be related to the temperature of inner vessel wall. This convection heat flux can be described using the equation:

$$q = \bar{h}\,(T_{body} - T_{\infty})$$

Where $\bar{h}$ is the heat transfer coefficient, T_{body} is the temperature of the inner wall of the vessel and the T_{∞} is the temperature of the water. When convection and conduction are related the equation becomes:

$$-k\frac{dT}{dx} = \bar{h}\,(T_{body} - T_{\infty})$$

Once isolated the thermal conductivity becomes:

$$k = -\frac{\bar{h}\left(T_{body} - T_{\infty}\right) * dx}{dT} \qquad (EQ.1)$$

The heat transfer coefficient is an additional unknown. An additional experiment would be needed to solve for this value. For this lab, the coefficient is estimated as: $\bar{h} = 11077\ \frac{W}{m^2K}$

<u>Sources of Error:</u>

It is important to acknowledge that this is a crude experiment and further refinements will be needed. Additionally, this lab uses less sophisticated equipment and test materials to make this lab more accessible. In the future, it would be necessary to use a more appropriate thermometer with a more sensitive measurement and have a setting where other forms of heat transfer are isolated or eliminated. One major assumption by using the equations given previously is that this temperature change is at steady state, which does not occur until the temperatures in the system reach equilibrium. Here, the thickness of the materials could be limited to try to reach this steady state value more quickly than that of a thicker material.

Procedure:

Before the lab:

If possible, calibrate the thermometer before beginning the lab to ensure the best temperature values are collected. This is usually done by calibrating to a freezing or a boiling point.

Step 1.

Take the temperature of the inside of the vessel wall. Record this value.

Step 2.

Measure the thickness of the vessel walls. Record this value.

Step 3.

Boil water in an external kettle. Once boiled, pour water into the vessels filling to the top. Wait 30 seconds. **CAUTION**: Be careful with the water, as water at this temperature is warm enough to cause a third-degree burn in seconds.

Step 4.

Take the temperature of the outside of the vessel wall. Record this value.

Step 5.

Using oven mitts, carefully pour out the water somewhere safe and free of other materials (such as an empty sink). Make sure that the vessel is placed in a safe place and allow it to cool down gradually. Take the temperature of the vessel after 5 minutes, repeat until the vessel reaches 30 °C, then it can be safely handled.

Step 6.

Repeat steps 1 – 5 for each of the vessels and take care to record all the data.

Figure 1: Experiment Set Up

Data Collection:

	Soup Can	Cast Iron Skillet	Stainless Steel Cup
Initial Wall Temp, T_0 (°C)	23.89	26.90	21.67
Final Outside Wall Temp, (°C) $T_{Outside\ Wall}$	40.00	58.89	43.33
Wall Thickness, dx (m)	0.0011	0.004	0.001

Use Equation 1 to solve for the Thermal Conductivity Value K.

Soup Can

$$k = -\frac{\bar{h}\left(T_{body} - T_\infty\right) * dx}{dT} = -\frac{11076.78 * (23.89 - 100) * 0.0011}{(100 - 40.00)} = 15.46\ \frac{W}{m * K}$$

Cast Iron Skillet

$$k = -\frac{\bar{h}\left(T_{body} - T_\infty\right) * dx}{dT} = -\frac{11076.78 * (26.90 - 100) * 0.004}{(100 - 58.89)} = 78.80\ \frac{W}{m * K}$$

Stainless Steel Cup

$$k = -\frac{\bar{h}\left(T_{body} - T_\infty\right) * dx}{dT} = -\frac{11076.78 * (21.67 - 100) * 0.001}{(100 - 43.33)} = 15.31\ \frac{W}{m * K}$$

Compare these values to the values given in: A Heat Transfer Textbook 5th Edition

Vessel	Experimental k Value	Textbook k Value[2]	Percentage Error
Soup Can	15.46	13.8[3]	12.03%
Cast Iron Skillet	78.80	52	23.16%
Stainless Steel Cup	15.31	13.8 (304 S.S.)	9.78%

[2] John H Lienhard IV and John H Lienhard V, "A Heat Transfer Textbook," 5th Edition Appendix A. 714-19

[3] Soup cans are commonly considered to be tin, however, steel is now much more widely used for their cost effectiveness. Source: *Wikipedia: Steel and tin cans*