ASEN 3113: Heat Conduction Lab

ASEN 3113: Thermodynamics and Heat Transfer
University of Colorado at Boulder

Please refer to Canvas and the class schedule for lab groups, due dates, and supporting documents.

Objectives

- Understand transient and steady state heat conduction
- Understand the fundamentals of heat conduction through constant mediums
- Appreciate how partial differential equations and boundary value problems have real engineering use
- Continue to improve lab report technical writing skills

Experimental Background and Description

In this experiment you will analyze the steady state and transient heat conduction through solid metal rods. In the experiment there are 3 different material rods – Brass, Aluminum, and Stainless Steel. Each rod is individually housed in an insulated casing, with one side heated and the other chilled. You will know the voltage input at the heater side and can extrapolate the temperature of the chilled water on the other side. In addition, you will use the National Instruments USB Data Acquisition (DAQ) hardware and LabVIEW to view and record temperature data from evenly-spaced type K thermocouples along one of the material rod types.

Experimental Hardware

You will use the experimental apparatus shown below in Figure 1, and chilled water sourced from the building. Inside the apparatus is a solid metal rod, containing one of the three metals mentioned above. The metal rod is affixed at one end to chilled water, which is held at a nearly constant temperature. Inside the insulation, the other end has a band heater, which wraps around the circumference of the rod and provides constant heat flux (see Figure 2).

Fig. 1 Heat Conduction Rod Experimental Hardware

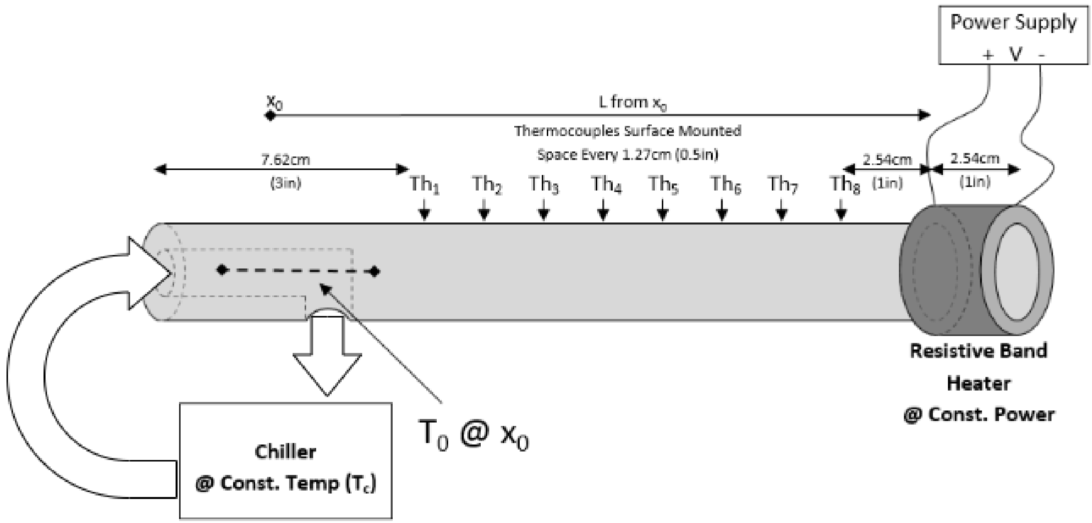

Fig. 2 Heat Conduction Rod Test Apparatus

NOTE: Insulation for the rod begins at 1 3/8 inches to the left of the first thermocouple (Th_1). For your calculations, let this location be represented by x_0. When you compute the length of the rod, take the beginning of the rod to be the location of x_0. The heater has an internal resistance of $110\,\Omega$. Additionally, use Table 1 as a reference for obtaining the required parameters for the different materials. **Use a diameter of 1 inch for all rods.** Also, make assumptions about the spacing distance between two thermocouples.

Table 1 Material Properties for Metal Rods

Material	**Properties**		
	Density (ρ) [kg/m^3]	Specific Heat Capacity (c_p) [J/(kg·K)]	Thermal Conductivity (k) [W/(m·K)]
Aluminum 7075-T651	2810	960	130
Brass C360	8500	380	115
Stainless Steel T-303 Annealed	8000	500	16.2

Experimental Procedure

1. Log in to a lab station.
2. Check that the USB thermocouple box is plugged into a USB port on the computer you are using.
3. Check that all 9 thermocouples are plugged into the thermocouple box receptacles.
4. Open “Thermocouple Testbench.vi”. This VI can be found in the Courses folder under AES - Software - VIs - General - Thermcouple Testbench.
5. After running the VI, set the desired sample time and select *Celsius* or *Fahrenheit* from the user inputs dialog box. (These cannot be changed while the VI is running.)
6. Check that water entrance and return lines are plugged into the experimental apparatus provided. The hose connections should be cold to the touch. If the connections are not cold, the valves for the chilled water may be closed, please ask a LA for assistance.
7. The entire rod is now being cooled to the initial temperature T_0. Allow some time for the rod to conduct to this initial temperature. You can run the VI to monitor the temperature, but you will not use this data. *Note that the chilled water has a temperature (T_c) of about 10 °C. However, due to heat loss through the hoses and connections, T_c will not equal T_0.*
8. Verify the power supply is set to the desired voltage between 15 V and 30 V.
9. When the apparatus has reached a rather uniform initial temperature T_0 according to the VI, restart the VI and turn on the power supply. You are now taking experimental data.
10. Monitor the data until the rod attains a steady state (All temperature lines become horizontal).
11. While waiting for the rod to reach steady state, investigate the hardware using the Stainless Steel rod experiment. Remove the PVC casing and insulation to expose the thermocouple connections, band heater and cooling lines. Make notes of how these attachments are made and how these might affect the assumptions that were made in the analytical solution.
12. Save data, and clean up.

Lab Questions

You will be given multiple sets of data to evaluate, but keep in mind that you must report on results from all types of materials (Aluminum, Brass, Stainless Steel) and all tested heater voltages. Use all of the provided data files on Canvas. Please include a basic mathematical analysis of error, you may assume that the thermocouples used in this lab have a precision of ±2 °C. Discuss in a formal lab report the following questions:

[Question 1] Assuming x_0 lies 1 3/8 inches to the left of the first thermocouple, determine the temperature at the cold end of the rod (T_0). This can be done using the same linear extrapolation that was performed in the prelab. Also, determine H_{exp} and plot the experimental and analytical steady states. Create a plot with the experimental and analytical slopes as well as the experimental steady state temperature distribution. Additionally, create a table containing T_0 in °C, H_{exp} in °C/m, and $H_{analytical}$ in °C/m for each data set. Compare these results. *Hint: T_0 is defined as the initial temperature of the rod. $H_{analytical}$ has an equation to determine its value.*

[Question 2] Recall from the lab discussion that the general solution for $u(x,t)$ involves taking the summation of n from 0 to ∞, and that the solution converges and can be approximated very accurately by the summation of n over a finite range. Plot the analytical temperature $u(x,t)$ versus time for each thermocouple location for the material types and heater voltages of all datasets and compare with the experimental results. *Hint: The analytical and experimental steady state temperatures should be within approximately 1 °C of each other. If they are not, how could you adjust your analytical solution implementation? What parameters could realistically be adjusted? Justify those changes with engineering reasons.*

[Question 3] Note that in question 2 we assumed that the initial temperature of the entire rod was constant, T_0. Is this assumption valid for each dataset? Justify your answer with experimental data. If the assumption is not valid, determine how the altered initial temperature profile will affect the transient solution - do this without solving any formulas. Can the transient solution be solved analytically given an initial temperature distribution? *Hint: The slope of a line over the different thermocouple temperatures at the cold steady state may be one option to show validity of the assumption.*

[Question 4] Recall that the thermal diffusivity can vary quite a bit within materials and the effect on the transient model if the thermal diffusivity α increases or decreases. What value for α gives the best correlation between analytical and experimental results for each material? Is this value consistent with the values found in the property table? What assumptions made about the hardware could contribute to any discrepancies?

[Question 5] What determines the time to steady state? In all Aluminum and Brass datasets (not Stainless Steel*), what is the approximate value of the time required to reach steady state? Compare the values of $\alpha t_{ss}/L^2$ (assume $L = 19.05\,\text{cm}$) for Aluminum and Brass datasets for consistency in the comparison. What do those values represent and how do they change for each of the datasets? Assuming $\alpha t_{ss}/L^2$ is kept at some fixed value, discuss how changing the length of the rod or the thermal diffusivity impacts the time to steady state.

*Stainless steel does not reach a good enough steady state value and is excluded for this comparison.

Report Rubric

Deliverable	Section	Points
Prelab		**20**
Lab Report	**Abstract & Nomenclature** • Write a concise description of the entire lab, including important aspects of the experiment, data analysis, and final results. • List the commonly used variable symbols and their descriptions.	**5**
	Introduction • Write a qualitative description of theory of heat conduction in a metal rod. • Discuss the various methods used in order to analyze the metal rod in this experiment (the derived heat equation and its initial and boundary conditions), along with any assumptions needed.	**15**
	Experimental Procedure • Write a high-level procedure (formatted as a list) that outlines the important steps someone would need to go through during testing, including steps for data collection and experimental setup. • In addition, include a diagram of the setup showing all critical elements.	**10**
	Results • Include all plots and tables of results obtained from the lab questions listed above.	**20**
	Analysis and Discussion • Discuss the methods and assumptions required to answer the lab questions listed above. • Discuss the results for each lab question.	**25**
	Error Analysis • Include basic mathematical analysis of error. • Discuss potential sources of error, both in experimental design and data collection. • Address ways to mitigate these errors.	**10**
	References • Please reference all sources used when completing the research for this lab. You do not need to reference class material.	**5**

Individual Conclusion	**Conclusion** • Concluding remarks, difficulties and challenges, and suggested improvements. These will be graded on knowledge and insight. • Individual conclusions will be completed by each group member and submitted completely separate from the lab report.	**10**
Total		**110**