11/03/05

Experiment 2, Part 1

Heat Conduction in a long solid Rod

Armfield Heat Conduction Module

ASEN 3113

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1. Introduction

Perhaps the simplest phenomenon that can be modeled by the heat equation is heat conduction in a long uniform rod. In most instances heat conduction occurs in three dimensions - a situation that is complicated to analyze. In the laboratory, we use an apparatus that exhibits one-dimensional heat flow to demonstrate the basic concepts associated with the heat equation.

1.1 Goal

To solve the heat equation for a general long solid rod and to compare your predictions with the actual temperature measurements made in the lab, determining the composition of the removable section of the rod.

1.2 Experiment

The heat conduction apparatus consists of a cylindrical metal bar that is insulated. The metal bar is electrically heated with constant wattage on one end while the other end is exposed to cooling water. The cooling water is supplied when the tubes from the back of the apparatus and the electric cooler are attached. The cylinder is fitted with temperature sensors at evenly spaced locations along the rod.

1.3 General Apparatus Guidelines

The instrumentation provided permits accurate measurement of temperature and power supply. Fast response temperature probes, with a resolution of 0.1°C, give direct digital readout. The power control provides a continuously variable electrical output of 0-30 Watts with direct readout. Figure 1 depicts the Heat Transfer Module with the necessary equipment (excluding cooler) to perform the experiment.

2. Procedure

CAUTION: The apparatus will get hot during the experiment. Be extra cautious to avoid burns from hot samples. Also, you will be working with water and electricity in close proximity; make sure that any water outside of the system is cleaned up.

2.1 Setting-up the apparatus:

This module consists of five basic elements: a control box, power regulator, selector box, a linear conduction apparatus with various samples, and a radial conduction apparatus. You will also need to checkout the Neslab recirculating water chiller that will provide the cooling for the apparatus.

1) Make sure the Control Box (Figure 1A) and the Power Regulator (Figure 1C) are turned OFF.
2) Check that the Control Box is plugged into the Power Regulator.
3) Connect the P-1 Military Plug to the appropriate jack on the LabStation (P1A or P1B).
4) Connect the Heater Power Cable (Figure 1E) from the desired conduction apparatus to the front of the Control Box.

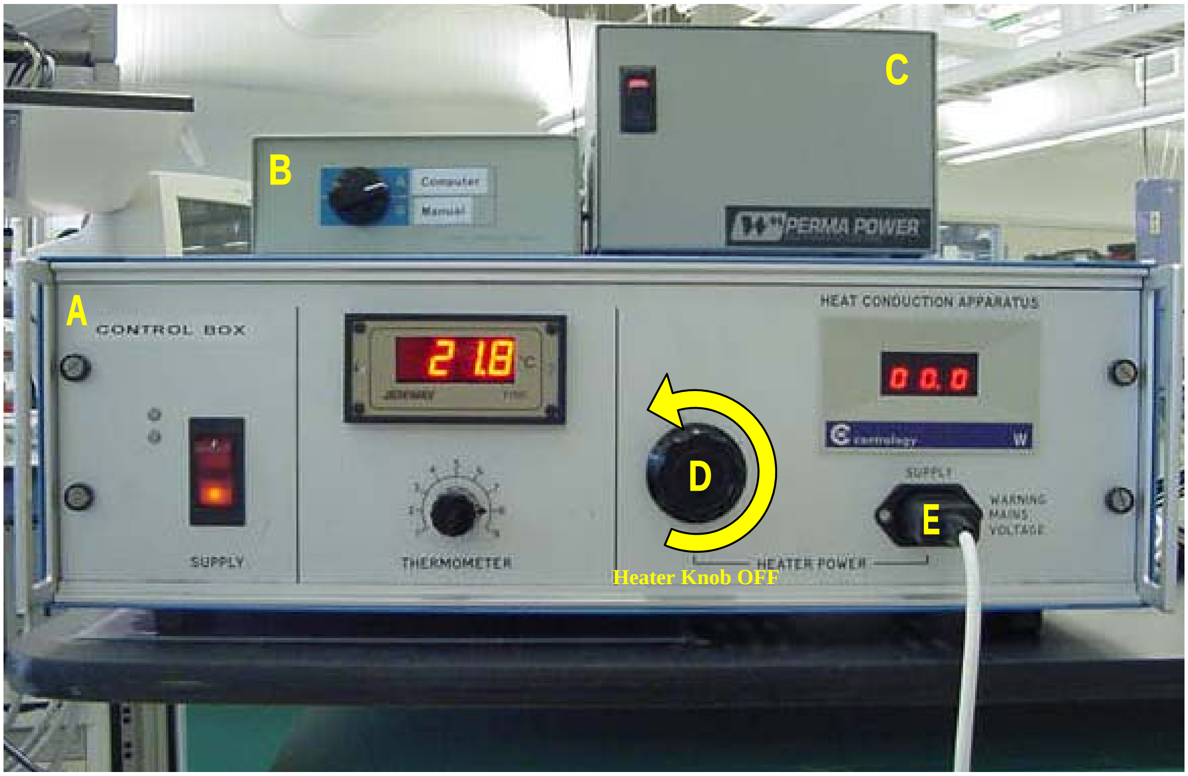

Figure 1: Heat Conduction Controls

A: Control Box
B: Selector Box
C: Power Regulator
D: Heater Knob (CCW is OFF)
E: Heater Power Cable (from either conduction apparatus)

5) Use the Linear Apparatus (Figure 2A). Install the desired sample into the middle of the rod. Determine which thermistors (Figure 2C) should be read by the computer. Connect these thermistor cables (Figure 2D) from the Conduction Apparatus to the connectors on the back of the control box labeled one through **seven**. The computer will read these thermistors if desired. It cannot read thermistors 8 and 9.

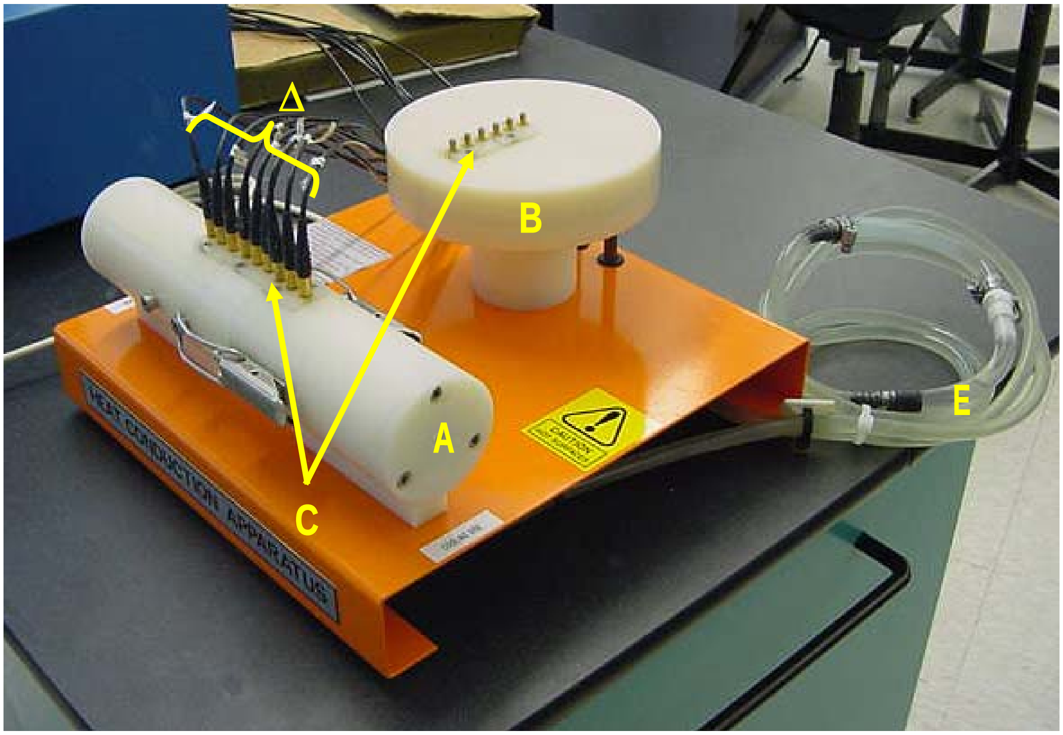

Figure 2: Heat Conduction Apparatuses

A: Linear Conduction Apparatus B: Radial Conduction Apparatus
C: Thermistors D: Thermistor cables
E: Tubing with quick disconnect fittings

6) Plug the Power Regulator into one of the outlets (either circuit #7 or #8) located next to the computer hard drives on the LabStation.

7) Plug the water chiller into the other outlet located next to the computer hard drives on the LabStation. Connect the hoses (Figure 2D) to the water chiller. Place the part of the hose which has the connections in the bucket to catch any spillage.

8) Begin cooling the water in order to get one end of the rod to a steady state (this takes about 10 minutes). Instructions for the water chiller are indicated on the top of the unit. Set the chiller to 5 - 10°C (record this value) and let it run for 10-20 minutes until the end temperature of the rod has stabilized. (If the cooler makes unhappy noises, it may be low on water; seek help.)

IMPORTANT: Do not plug both the Power Regulator and the Water Chiller into the same outlet. Use two different outlets that run off of separate circuit breakers.

9) Select the mode on the Selector box (Figure 1B) to computer. Remember that the computer can only read thermistors 1-7 on the control box.

2.2 Running an experiment:

10) Turn the heater knob (Figure 1D) on the control box fully counterclockwise (this is the OFF position).
11) The middle section of the rod is removable so you can change samples. Make sure the connection is tight.
12) Open the "Heat Conduction Apparatus.vi" within H:\ITLL Documentation\ITLL Modules\Armfield Heat Conduction\Heat Conduction Apparatus.llb
13) When the VI opens, enter the following information into the "User Inputs" dialogue box:
    a. Indicate the temperature units desired
    b. Specify the time interval between samples (in minutes)
    c. Enter the watts applied for the experiment. This is the same wattage that will be dialed on the control box when running the experiment. When you run LabView (using the white arrow in the upper left-hand corner) the program will double-check to see that the watts applied is entered in the VI by telling you to fill it in before pushing stop. When you press OK, LabView will begin taking data.
14) Turn ON the Power Regulator and control box.

    WARNING: If the heater temperature reaches 100º C the control box will shut down. Monitor your temperature readings carefully.
15) Turn up the power on the heater to 10W or so and enter this value in the VI.
16) Press OK on the LabView VI to begin collecting temperature data.
17) Once the temperature has stabilized at the ninth thermistor location (chilling side) you will start the experiment by plugging in the heater power cord to the control block. Take care to record the temperatures at each of the points just prior to plugging in the heater cord; this will be the initial temperature distribution.
18) When you are ready to begin the heating part of the experiment, apply power to the heater using the heater knob
19) Continue to collect data until you're sure you have reached steady state or 25 minutes has gone by.
20) When you are finished taking data, hit "STOP" to save the data to a file and stop the VI. The tab-delimited file will record the watts applied, the temperature units, and each data point.

Program Behavior

- While the program is running, it will tell you how many samples it has taken, how long it has been running, and how long until the next sample.

- The plot shows the various temperatures of each thermistor with a different color in a temperature versus time format. The graph will remain blank until the second data point is taken because two data points are needed to create a line.

3. Analysis

In this analysis you are making at least two assumptions:

- The temperature at the right end of the rod (the ninth probe) is equal to the average of the temperatures that you actually observed there. Ideally the temperature at this probe would be constant providing us with a time-independent boundary condition. However, since it does change a little bit throughout the course of the experiment, we will assume it was constant at the average of the observed temperatures.
- The power source provides a constant non-zero heat flux to the left end of the rod. This will be used as a boundary value when you are solving the steady-state problem before you solve the transient problem.

3a. Steady Heat Conduction Analysis

Employ the steady heat conduction approach to the problem.

1) Describe the complete heat conduction setup in terms of a thermal resistance network.
2) Discuss your data set and specify what time portion of the measurement will be used for the steady heat conduction analysis.
3) Determine the thermal contact resistance between the middle sample section and the outer brass rods. How does it compare to the thermal resistance of the brass rod and describe the technique used to reduce the thermal contact resistance? (be descriptive about the technique – don't just say what it is but demonstrate an understanding of its use and properties.). Compute its thermal conductivity and compare with what you believe to be the culprit.
4) Using the proper heat equation determine the sample specimen used for your particular experiment, brass or stainless steel.
5) Calculate the steady state temperature profile over the entire length using the boundary conditions given and the material properties of the rod. Compare this with the actual profile and discuss any differences. Now compute an effective thermal conductivity using the steady state heat equation that best fits the data over the entire length. Use this effective thermal conductivity in your transient heat conduction calculation.

3b. Transient Heat Conduction Analysis

The assumption of steady heat conduction may only be achieved at the latter times of your data taking record, possibly never at all. Prior to that time the temperature within the rod at any given position is changing with time. Employ the transient heat conduction approach to theoretically evaluate the temperature behavior over time at each thermistor location.

1) Assume the Biot number is infinite at the chiller end of the rod such that there is a specified surface temperature that is fixed for all time, setting up one of your boundary

conditions. The other boundary condition is a fixed heat flux (assume all the electrical power provided is converted to heat) on the other end of the rod.

2) Plot the theoretical transient heat conduction curves of temperature versus time for each thermistor location over the measured temperature versus time curves using the effective thermal conductivity determined in section 3a, part 5.
3) Discuss the differences between the theory results and your measurements. Do your theory results reach steady state? What parameters dictate when steady state will occur?

4. Useful Information

Reference for materials information can be found in the following books located in the Engineering Library.

- ASM Handbook, Volume 18, TA 459 A5 V.18, 1992
- Standards Handbook; Copper, TA 480 C7C655
- Engineering Formulas 4th Edition, TA151.G4713, 1983

Dimensions of the brass cylinder:

- Diameter: 25 mm, Length: 80 mm, Distance between probes: 10 mm

The composition of the **Brass specimen:**	The composition of the **Stainless Steel specimen**:
K value of 117 $\frac{W}{mK}$	K value of 25 $\frac{W}{mK}$
60 to 65% Copper	.08% Carbon, 2% Manganese
35 to 40% Zinc	1% Silicon, 16 to 18% Chromium
	10 to 14% Nickel, 2 to 3% Molybdenum