CYLINDRICAL CONDUCTION HEAT TRANSFER EXPERIMENT

The purpose of this experiment is to determine the thermal conductivity of low *k* materials through direct measurement.

INTRODUCTION AND BACKGROUND

The basis for analysis of conduction heat transfer is known as *Fourier's Law of Heat Conduction*. The "Law" was submitted as part of a 234 page paper by Joseph Fourier in 1807, but was not published until 1822. The empirical law that he stated is:

"The heat flux resulting from thermal conduction is proportional to the magnitude of the temperature gradient and opposite to it in sign."

This experiment is designed to measure the value of the proportionality factor through knowledge of the heat flux, temperature difference, and the distance of conduction.

APPARATUS

The apparatus is a cylindrical rod heater surrounded by a close-fitting tubular pipe insulation. The electric heater is in the shape of a cylinder rod with a diameter of 0.393 inches (1 cm) and a length of 14.173 inches (36 cm). Thermocouples are attached on the outer surface of the heating element along its length in the axial direction. The heater is covered by a tubular-shaped rubber foam pipe insulation that slides directly onto the heating rod. The rubber foam insulation has an inner diameter approximately equal to the diameter of the heating element and a thickness of 0.75 inches. Additional thermocouples are attached on the outer surface of the rubber foam insulation, along its length. The ends of the heating rod and cylindrical rubber foam insulation are supported and insulated by blocks of Temperlite 1200°. The applied electric potential and resulting current through the heater are measured, and the thermal power dissipated by the heater can be determined by the relation $P = IV$, where I is current, and V is potential. A single thermocouple is mounted in the vicinity of the apparatus to measure ambient air temperature.

MEASUREMENTS

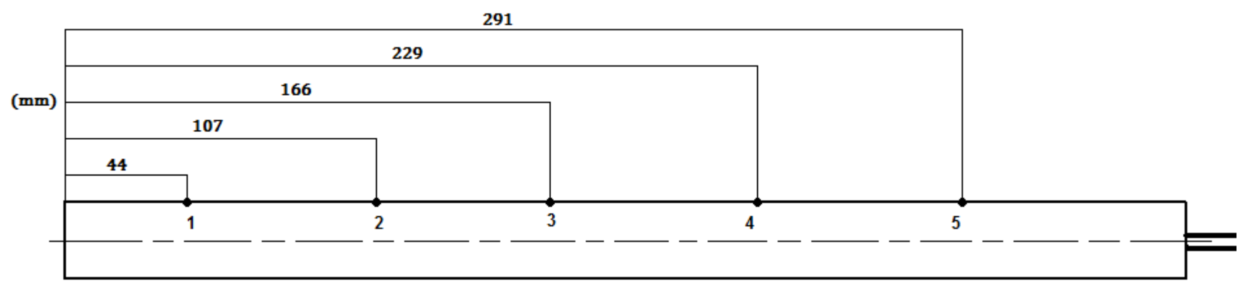
Temperature measurements from eleven thermocouples are taken with a data acquisition (DAQ) system, and the power to the cylindrical rod heater is calculated from the potential and the current, which are measured using multi-meters.

When taking data in the laboratory, be sure to note on paper the time of the experiment and the following: 1) the electric potential across the heater as indicated by the top voltmeter above the experiment and 2) the current through the heater as indicated by the bottom voltmeter. These values will be used to check the heater power measured by the DAQ. Be sure to also note any relevant information about the tubular insulation material.

The system will reach steady-state approximately two hours after the heater is powered. Decide on a way to ensure that the system has reached steady-state conditions. For this laboratory, you are only required to analyze the steady-state data that you collect.

Thermocouple locations are as follows: five are on the heating rod (TCs 1, 2, 3, 4, 5); five are on the exterior surface of the rubber foam insulation (TCs o1, o2, o3, o4, o5); and one thermocouple (channel 12) is in the vicinity of the experimental apparatus to measure the ambient air temperature. Typical air temperature variations in the heat transfer lab are within +/-0.5 ° F. Record a time-averaged value for the air temperature, and for each of the thermocouples on the heating rod surface and outer surface of the insulation. Express each of the temperature measurements as some nominal value centered within uncertainty (±) limits. You can judge the uncertainty of the measurements by watching the fluctuations of the readings. Record at least ten sets of measurements for all eleven thermocouples in order to get a statistical distribution of the fluctuations at each measurement location.

THERMOCOUPLE LAYOUT ON HEATER AND OUTER SURFACE OF INSULATION



The thermocouples are Type K, chromel-alumel, made from 30 gauge wire. As shown in the figure above, thermocouples 1 through 5 are mounted at the specified distances in mm from the end of the rod heater. Likewise, thermocouples o1 through o5 are respectively mounted at these same axial distances on the outer surface of the tubular insulation material.

The heater is a Stainless Steel HOTWATT Cartridge Heater. The model number is #SC37-14.12 rated at 50 Watts. The system is operated at a lower power than 50 W due to the maximum temperature for the rubber foam insulation which is 220°F.

The cylindrical rod and surrounding tubular insulation are supported on each end by two Temperlite 1200° blocks. Temperlite has a nominal conductivity of 0.06 W/m·K at room temperature. It is a rigid, high temperature, water resistant molded perlite thermal insulation available in many forms.

ANALYSIS AND DISCUSSION

1. Calculate the thermal conductivity of the rubber foam using two methods:
    a. Take an average of the outside surface temperatures and an average of the inside surface temperatures. Use the difference between these two to calculate a value for k. In this method of calculating k, what assumptions if any are made about the heat flux? Does it vary along the length of the rod?
    b. Calculate separate k values for each pair of thermocouples (1&o1, 2&o2, 3&o3, etc). Determine an average for these five values of k.

2. Compare the measured values of thermal conductivity for the rubber foam insulation with values published by the manufacturer. Do the measured values seem reasonable?

3. Account for differences between the measured values of thermal conductivity and the published value. What potential sources of error are there? Estimate heat losses and discuss how this might contribute to error.

4. Construct a graph of temperature vs. longitudinal distance for the outside surface thermocouples and the inside surface thermocouples. Does temperature vary in the longitudinal direction? If so, why would the rod temperature vary? Hint: consider how the heating rods are designed, and what implications this has on the uniformity or variation of the heat flux.

5. Briefly discuss one or two alternate methods for measuring thermal conductivity. How does this system for measuring k compare to other methods?