Thermal Conductivity Measurements of Three Common Metals Using LabVIEW for Data Acquisition

John R. Porter III

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Abstract

This lab was conducted to experimentally determine the thermal conductivities of sample materials. Using a LabVIEW VI, temperature data was acquired from thermocouples strategically placed in rods of aluminum, brass, and steel that were heated at one end and open to the ambient temperature at the other end. The rate of heat flow through the rods was found by using the temperature data for the aluminum rod and its published thermal conductivity. This rate of heat flow was then used to determine the thermal conductivities of the other two metals. The thermal conductivity of brass was calculated to be $132.8 \pm 10.1\ \mathrm{W/m°K}$, which is reasonably close to the published value of $119\ \mathrm{W/m°K}$. The calculated value for steel was $176.6 \pm 1.5\ \mathrm{W/m°K}$, which is over 400% greater than the published value of $43.6\ \mathrm{W/m°K}$. It was concluded that this significant discrepancy is likely a result of erroneous temperature measurements of the sample rods. Other possible contributors to the incorrect results include experimental assumptions and non-ideal experimental conditions.

1. Introduction

Thermal conductivity is a physical property of materials of great importance. Unlike some physical properties, however, thermal conductivity cannot be directly measured. In order to determine a material's thermal conductivity, intermediate quantities must be determined from which the conductivity may be ultimately calculated.

The objective of this lab was to determine the thermal conductivity of two metals. To do so, it was necessary to examine the flow of heat through samples of these two metals as well as a third sample whose thermal conductivity was known. By determining the rate of heat flow through the material with known thermal conductivity making the experimental assumption that this rate a shared by all three samples, the thermal conductivity of the other two metals can be determined. This report presents the findings of the lab. The complete experimental procedure is detailed, the data retrieved is analyzed, and the accuracy of the findings as discussed.

2. Experimental Procedure

2.1 Materials and Equipment

The following materials were used in the experiment:

- One (1) aluminum sample rod with predrilled holes
- One (1) steel rod with predrilled holes
- One (1) brass sample rod with predrilled holes
- Roll of thermal tape

The following laboratory equipment was required:

- One (1) variable transformer
- One (1) wood-insulated heating block
- Three (3) LabVIEW workstations with BNC-2120 units
- Ten (10) K-type thermocouples
- A set of calipers

2.2 Initial Setup

Using the calipers, the diameter of each sample rod was measured and recorded. The distances between the three pre-drilled holes were also measured for each rod. The heating apparatus was then prepared by wiring a variable transformer to a wood-insulated heating plate. With the variable transformer powered off, the three sample rods were placed into holes in the wood such that they made solid contact with the heating plate within. This ensured uniform heat transfer to each sample rod.

To measure the temperature at different points along the path of heat flow, a thermocouple was inserted into each of the three holes in each sample rod. An additional thermocouple was inserted into the heating plate to monitor the source temperature. These thermocouples were wired to BNC-2120 data acquisition units, and were in turn monitored by the LabVIEW program "Thermal Conductivity." One workstation was tasked with recording temperature data for the steel sample rod and the heating plate temperature. Each of the other two workstations recorded temperature for either the aluminum or brass rod.

2.3 Data Collection

After the above setup, the variable transformer was powered up to begin the process of heating the samples. The transformer's output voltage was manually fine-tuned as needed until the heating block reached equilibrium, and the temperatures recorded by each thermocouple stabilized. At this point, the "Thermal Conductivity" program was initiated. It acquired temperature measurements from each thermocouple at a rate of approximately one measurement per second. Acquisition was stopped once the LabVIEW program had recorded data for 600 iterations (approximately 10 minutes), and the raw temperature data for each thermocouple was output to a text file.

3. Results and Discussion

3.1 Analysis Methodology

To interpret the recorded data and determine the experimental thermal conductivities, the most stable range of temperature measurements was selected from the recorded values. The averages and standard deviations were determined for each of the three thermocouples on each sample rod. From these values and the physical measurements taken during the setup, the rate of heat flow through the aluminum rod was calculated using the following equation.

$$\frac{Q}{t} = \frac{\lambda \cdot A \cdot (T_{hot} - T_{cold})}{d} \qquad \text{(equation 1)}$$

In this equation, the ratio $\frac{Q}{t}$ represents the rate of heat flow, λ is the thermal conductivity, A is the cross-sectional area of the sample rod, T_{hot} and T_{cold} are the temperatures at two adjacent thermocouple points, and d is the separation between these two points

To determine $\frac{Q}{t}$ for aluminum, its known thermal conductivity of $210\ {}^{W}/_{m\ °K}$ was used[1]. From this heat flow rate, which for this experiment was assumed to be the same for all three materials, the other two thermal conductivity values were calculated.

3.2 Data Analysis

The following table represents the temperature data used to calculate the thermal conductivities. The average temperature and standard deviation of each thermocouple was determined for a common range of 60 measurements. "Bottom," "Middle," and "Top" correspond to the three thermocouples and their relative positions on the rods.

Table 1: Temperature Data

	Average Temperature			**Standard Deviation**		
	Bottom	**Middle**	**Top**	**Bottom**	**Middle**	**Top**
Aluminum	360.131°K	352.459°K	351.107°K	0.186696°K	0.2793°K	0.345332°K
Brass	363.033°K	351.696°K	346.452°K	0.387166°K	0.384309°K	0.610530°K
Steel	359.352°K	345.571°K	342.312°K	0.290359°K	0.270277°K	0.900255°K

This table contains the physical rod measurements made at the beginning of the experimental process.

Table 2: Sample Rod Dimensions

	Rod Diameter	**Separation Between Thermocouples**	
		Bottom-Middle	**Middle-Top**
Aluminum	0.012700 m	0.051206 m	0.055143 m
Brass	0.012700 m	0.051943 m	0.052095 m
Steel	0.012649 m	0.052413 m	0.049987 m

With the thermal and dimensional data for aluminum, as well as its published thermal conductivity, its average rate of heat flow and uncertainty was calculated using equation 1 as follows:

$$\frac{Q}{t}(1) = \frac{210 \, ^{W}/_{m\,°K} \cdot 1.27\times10^{-4}\,m^2 \cdot (360.131°K - 352.459°K)}{0.051206\,m} \approx 3.985545\ W$$

$$\sigma\frac{Q}{t}(1) = \frac{210 \, ^{W}/_{m\,°K} \cdot 1.27\times10^{-4}\,m^2 \cdot (0.186696°K + 0.2793°K)}{0.051206\,m} \approx 0.242089\ W$$

$$\frac{Q}{t}(2) = \frac{210 \, ^{W}/_{m\,°K} \cdot 1.27\times10^{-4}\,m^2 \cdot (352.459°K - 351.107°K)}{0.055143\,m} \approx 0.652502\ W$$

$$\sigma\frac{Q}{t}(2) = \frac{210 \, ^{W}/_{m\,°K} \cdot 1.27\times10^{-4}\,m^2 \cdot (0.2793°K + 0.345332°K)}{0.055143\,m} \approx 0.301334\ W$$

$$\frac{Q}{t}(avg) = \frac{\left[\frac{Q}{t}(1) + \frac{Q}{t}(2)\right]}{2} \approx 2.319024 \pm 0.271711\ W$$

Since the average rate of heat flow is taken to be equal for all three sample materials, the above value was used to determine the thermal conductivity of the two remaining materials. To accomplish this, equation 1 was rewritten as below. The uncertainty equation is also shown.

$$\lambda = \frac{Q}{t} \cdot \frac{d}{A \cdot (T_{hot} - T_{cold})} \qquad \text{(equation 2)}$$

$$\sigma\lambda = \sigma_{rel}\frac{Q}{t} + \sigma_{rel}\frac{d}{A \cdot \Delta T} \qquad \text{(equation 3)}$$

The final calculated thermal conductivities are shown alongside published values in the below table.

Table 3: Calculated and Published Thermal Conductivities

	Calculated λ	**Calculated $\sigma\lambda$**	**Published λ**
Aluminum	N/A	N/A	210 $W/_{m\,°K}$ [1]
Brass	132.884 $W/_{m\,°K}$	10.0925 $W/_{m\,°K}$	119 $W/_{m\,°K}$ [2]
Steel	176.605 $W/_{m\,°K}$	1.51095 $W/_{m\,°K}$	43.6 $W/_{m\,°K}$ [3]

3.3 Discussion of Results

While the data acquired in this experiment yielded a final calculated thermal conductivity for brass that was fairly close to the published value (though not quite within the error margin), the calculated value for steel was far off expectations. In addition, the calculated thermal conductivity for steel was greater than that of brass, which is not correct. Therefore, this experiment failed to yield thermal conductivities that are qualitatively or quantitatively correct.

3.4 Discussion of Possible Error Sources

It is likely that the source of the problem was the initial temperature data recorded by the LabVIEW VI. In particular, the temperatures read from the thermocouple at the top of the aluminum sample rod differed from the temperatures in the middle of the rod by a very small margin. This behavior was not consistent with the other materials, and therefore is likely symptomatic of a thermocouple or data reception problem.

In addition, several key assumptions were made for this lab that in reality may contribute to error. The first of these concerned the rate of heat flow. It was assumed that the rate of heat flow through the brass and steel rods with identical to the rate through the aluminum rod. In reality, this is not necessarily an accurate assumption. Another assumption was that all of the heat absorbed through the bottom of the sample would travel up the rod and the only source of heat loss was through the top. Because the rods were not insulated, however, heat was radiated from the entire surface of the sample. A final assumption was that the thermocouples themselves would maintain solid contact with the sample in the pre-drilled holes. Should any separation have occurred during the course of the experiment, the thermocouple would have reported a temperature lower than the actual sample temperature.

4. Conclusions and Recommendations

The following conclusions were made regarding this experiment:

1. This lab failed to accurately determine the thermal conductivities of the sample materials
2. Several factors may have contributed to the experiment's failure, including:
    a. Suspicious temperature readings from aluminum rod
    b. Inaccurate assumptions made concerning heat flow rate and sources of heat loss
    c. Possible thermocouple separation

It is recommended that future versions of this experiment take steps to minimize the impact of these possible error sources. The sample rods should be properly insulated to minimize radiated heat loss. Rods should also be longer with more points of heat measurement along their length, so that slight errors due to defective or improperly inserted thermocouples will have a less significant impact on the final averaged results.

5. References

[1] "Aluminum, Al." MatWeb: Material Property Database. <http://www.matweb.com/search/DataSheet.aspx?MatGUID=0cd1edf33ac145ee93a0aa6fc666c0e0>. 20 October 2008

[2] "Overview of materials for Brass." MatWeb: Material Property Database. <http://www.matweb.com/search/DataSheet.aspx?MatGUID=d3bd4617903543ada92f4c101c2a20e5>. 20 October 2008

[3] "Overview of materials for Low Alloy Steel." MatWeb: Material Property Database. <http://www.matweb.com/search/DataSheet.aspx?MatGUID=d1bdbccde4da4da4a9dbb8918d783b29>. 21 October 2008

6 Appendices

Appendix A -- Temperature Data for Aluminum Rod

Bottom	Middle	Top
86.788	79.153	77.615
86.71	78.944	77.429
86.871	79.436	77.417
86.875	79.07	77.534
86.622	79.227	77.191
86.734	78.782	77.545
86.751	78.992	77.257
86.735	79.302	77.43
86.644	79.379	77.279
86.565	78.885	77.699
86.866	78.782	77.435
86.853	79.301	77.434
86.884	79.276	77.689
86.692	79.146	77.557
86.819	78.912	77.599
86.843	79.562	77.539
86.753	79.563	77.838
86.855	79.355	77.738
86.873	79.823	77.6
86.965	79.33	77.869
86.839	79.122	77.894
86.899	79.485	77.816
86.893	79.356	77.913
86.904	79.746	78.009
87	79.07	78.117
87.051	79.358	78.214
86.738	78.839	78.274
87.105	79.203	78.232
87.052	79.229	78.01
87.207	79.59	77.945
87.081	79.541	78.322
86.884	79.383	78.274
86.956	79.411	78.166
86.932	78.918	78.288
86.987	79.177	78.198
86.956	79.595	78.281
87.125	79.281	78.174
87.053	79.516	78.216
87.083	78.918	78.139

	Continued	
86.947	79.232	78.307
87.2	79.545	78.178
87.196	79.313	78.485
87.124	79.704	78.467
87.183	80.018	78.442
87.219	79.285	78.448
87.128	79.701	78.303
87.176	79.858	78.267
87.253	79.442	78.093
87.092	79.105	78.202
87.098	79.262	77.89
87.111	79.156	78.096
87.25	79.26	78.138
86.998	79.156	78.03
87.162	79.132	78.133
87.312	79.367	78.091
87.121	79.524	78.194
87.151	79.238	78.158
87.21	79.603	77.868
87.274	79.756	78.287
87.221	78.948	78.156

Appendix B -- Temperature Data for Brass Rod

Bottom	Middle	Top
89.247	78.352	73.097
89.405	78.501	72.546
89.272	77.664	72.576
89.454	78.737	72.498
89.231	77.717	73.537
88.877	78.277	73.356
89.304	78.084	73.696
89.346	78.373	74.01
90.068	78.223	72.992
89.93	78.337	73.515
89.442	78.254	72.918
89.762	78.536	73.281
90.07	78.044	73.489
89.966	77.66	74.893
89.877	77.889	73.125
89.727	77.99	72.453
89.642	78.729	73.047
90.43	78.722	73.724
90.317	78.769	74.32
89.78	78.433	73.749
90.13	78.65	72.139
89.926	78.626	74.141
89.414	78.71	73.126
90.07	78.38	72.372
89.901	78.794	72.918
90.136	78.764	73.177
89.515	78.698	73.488
90.394	78.084	72.996
90.297	78.872	73.385
90.436	78.885	72.007
89.998	78.339	73.259
90.19	78.254	72.423
90.095	79.274	72.216
90.179	78.362	73.413
89.71	78.441	73.542
90.287	78.381	73.048
89.884	78.189	73.514
90.388	78.428	73.412
89.311	78.507	74.219
89.907	78.364	72.555
89.776	79.096	73.36

Continued

90.673	78.827	72.633
89.615	79.03	73.128
89.524	78.165	73.907
89.548	79.065	73.489
90.094	78.639	73.804
89.902	78.05	73.231
90.365	78.747	74.373
89.824	78.704	73.413
89.745	79.136	73.047
90.095	78.964	74.453
90.016	78.826	72.736
90.432	78.994	73.127
89.314	79.115	74.298
90.041	78.959	73.802
90.372	78.94	73.337
89.855	78.587	73.437
90.06	78.707	74.015
90.139	78.828	72.971
90.277	79.061	73.415

Appendix C -- Temperature Data for Steel Rod

Bottom	Middle	Top
85.519	72.202	69.848
85.651	72.118	68.176
85.782	72.124	67.474
85.521	72.293	67.359
85.807	72.316	69.916
85.964	72.197	67.322
85.652	72.371	68.896
85.911	72.155	68.89
85.885	72.312	69.645
85.652	72.061	69.666
86.042	72.264	70.362
85.808	72.312	70.001
85.887	72.247	69.023
86.041	72.331	68.809
86.122	72.409	68.94
85.836	72.619	71.425
86.096	72.571	69.211
85.967	72.71	69.06
85.995	72.638	69.836
86.358	72.638	68.965
86.149	72.621	69.541
86.252	72.535	68.426
86.098	72.423	69.927
86.357	72.272	70.768
86.305	72.315	69.609
86.231	72.412	69.219
86.177	72.244	69.701
86.152	72.197	70.288
86.489	72.209	68.493
86.256	72.119	70.156
86.646	72.21	68.62
86.411	72.21	67.517
86.647	72.179	68.61
86.41	72.048	68.933
86.31	72.126	68.903
86.256	72.108	69.96
86.335	72.102	69.065
86.049	72.157	68.106
86.361	72.121	67.506
86.206	72.181	70.963
86.441	72.308	68.545

Continued

86.416	72.374	68.93
86.546	72.615	69.368
86.467	72.608	69.265
86.389	72.65	68.666
86.365	72.752	68.258
86.521	72.663	68.29
86.287	72.676	70.389
86.313	72.509	69.164
86.21	72.526	69.507
86.549	72.605	69.269
86.418	72.478	69.892
86.599	72.569	71.002
86.211	72.671	69.707
86.55	72.612	68.719
86.366	72.666	68.838
86.653	72.949	68.707
86.367	73.015	68.37
86.369	73.135	68.905
86.471	73.214	68.786