Lab 6: Transient Conduction

Justin Francis
Tuesday, Feb 25

Overview

When an object is suddenly subjected to a change in environmental conditions, some time will elapse before a new equilibrium temperature is established. In the transient heating or cooling process between the initial and final equilibrium states, the analysis must consider the change in internal energy of the object with time, and the boundary conditions must be modified to match the physical situation. Figure 1 displays an example of this problem, whereby an object at an initial temperature Ti is submerged in a liquid at a colder temperature T1. In the case that the object as an infinite thermal conductivity, i.e., the temperature inside the object responds instantaneously to changes on the surface so as to yield a uniform temperature distribution inside the object, then the first law of thermodynamics states that the rate of change of the energy stored in the object, Est, must be balanced by the rate of heat lost, Eout, at the surface to the surroundings,

1 Figures

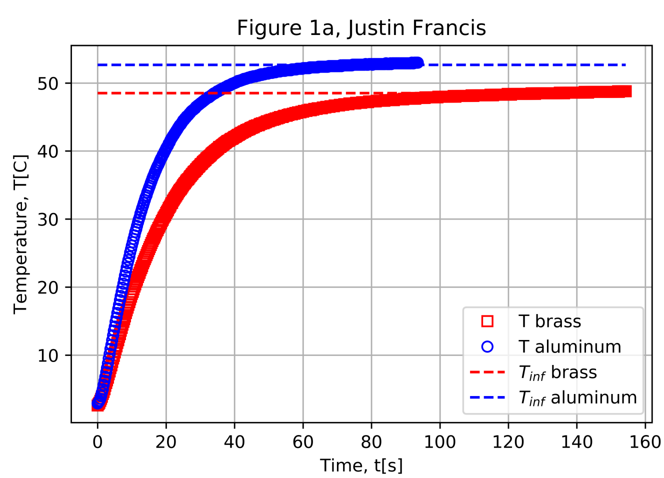

Figure 1: This shows the trimmed data for the experiment where $t_0 = 0$ on the graph. It can be seen that the two specimen have different steady state values and time constants. This is due to their physical properties and the experimental setup.

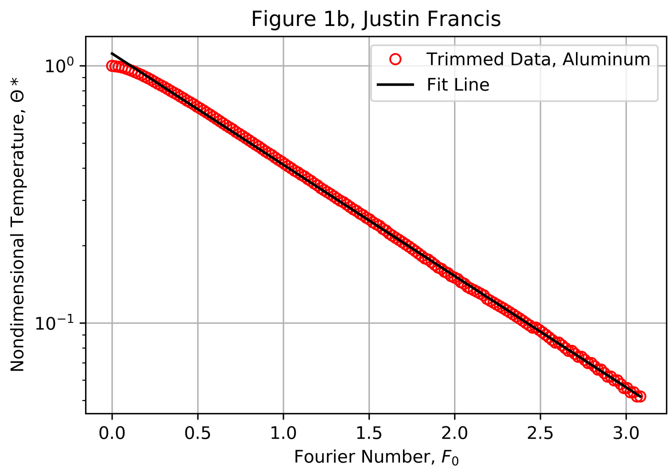

Figure 2: This shows the Nondimentional Temperature of the aluminum specimen vs the Fourier number along with a fit line. The data has been trimmed to where $\Theta^* >= 0.05$ to reduce noise form the thermocouple. It can be seen that the fit is incredibly good, almost exact.

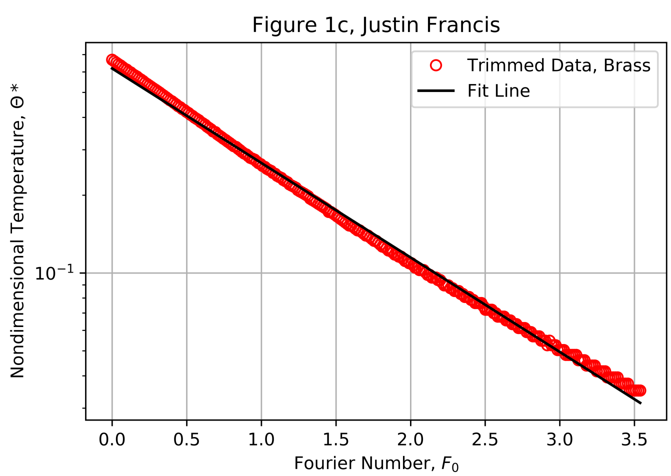

Figure 3: This shows the Nondimentional Temperature of the brass specimen vs the Fourier number along with a fit line. The data has been trimmed to where $\Theta* >= 0.05$ to reduce noise form the thermocouple. It can be seen that the fit is quite good.

Sphere	B_i	Q [J]	tau (s)		h (W/m^2K)	
			LC	ES	LC	ES
Alum	0.217	1333556	13.198 ± .099	13.152 ± .483	2083.91 ± .285	1036.01 ± .0183
Brass	0.251	2698529	20.612 ± .047	18.615 ± .970	2741.09 ± .321	1145.79 ± .0246

Table 1: This shows the heat transfer rate and coefficients from the experiments calculated using both the LC method and the one-term approximation of the analytical solution. The given values are paried with their calculated error with a confidence interval of 5%.

2 Short Answer Questions

1. State the percent difference, e_h, between the heat transfer coefficients for the brass and aluminum spheres obtained using the one-term approximation to the exact solution, Based on your engineering judgment, is this difference reasonable? Briefly discuss any ideas you have for why there is an observed difference. Offer at least one suggestion for improving the experiment (either the apparatus or procedures) in order to increase the accuracy of the h values obtained. [4-6 sentences].

   Answer: The percent difference was $\epsilon_h \approx 10.06\%$ using the one-term approximation. This difference is completely reasonable. The experiment was not conducted by me, so there could be a lot of testing error. A large error could be from the under circulation of the bath.

2. State the "goodness-of-fit" (R2 values, using 5 significant digits) for your curve fits to the Lumped Capacitance model for each test specimen. Interpret these R2 values and comment on what these indicate about the quality of your curve fits. Note, your goodness-of-fit calculations should be placed in your Matlab code with the output displayed to the screen. [2 sentences]

   Answer: The goodness-of-fit values are: $R^2_{brass} \approx 0.97093$, $R^2_{alum} \approx 0.99989$. These are incredibly good, I honestly think I might have miscalculated them, at least for the brass specimen due to visual inspection of the plot. The curves have been fit very well to the data and that shows in the R2 values. The closer to 1, the better (R2=1 indicating a perfect fit).

3. Based on your experimental results, explain why it is or is not appropriate to use the Lumped Capacitance Model to calculate the heat transfer coefficient h from your experimental data. Note, your response should indicate the magnitude of the Biot number calculated for each test. Describe how you could modify the experiment to reduce the Biot number even further to better ensure that the Lumped Capacitance Model remains valid for a wider range of test specimens. Your statement must be specific and must include a justification. For example, if you suggest decreasing the size of the specimen, then state the exact dimension you would use (assuming the material composition is brass or aluminum). If, instead, you suggest changing the material composition of the specimen (e.g., by 3D printing the specimen), then state which material you would use and justify this choice. Other changes could be made as well, e.g., altering the ow speed. [2-4 sentences]

   Answer: Based on the Biot number, $Bi_{Alum} = 0.217$ and $Bi_{Brass} = 0.251$, these are greater than the threshold of 0.1 for the Lumped Capacitance method. Although there are exceptions, this is probably too large to be acceptable for this experiment. To make Lumped Capacitance viable for this expeirment the radius would need to be decreased. For aluminum, the radius would need to be decreased to 5.8 [mm] and the brass would need to be decreased to 4.2 [mm]. This would lower the Biot number to the required threshold of 0.1.

4. Electric resistance heating, like the type used to heat the recirculating water bath, is 100% energy efficient in the sense that all of the supplied electric energy is converted to heat. Based on this knowledge, state how much power (in Watts) was consumed by the heating element during the two experiments in order to maintain the bath temperature at T1. Include a separate estimate for each test specimen. Explain any observed discrepancies between the different test specimens. [2-3 sentences]

   Answer: If the electric heating is 100% efficient then the heat loss must be due to the surroundings. If we assume that the experiment losses 5% of its energy to the surroundings, then we can calculate the amount of heat energy consumed by the heating element as follows: $P_{brass} = 1.33e^6 * 1.05 =$

$1.39e^6[W]$ and $P_{alum} = 2.69e^6 * 1.05 = 2.83e^6[W]$ The discrepancies between the specimen can be due to the large difference in specific heat energy and density.