ME 4005 Lab Report 4 – Thermocouples & Heat Flux

Zachary Rohloff VT-ID:

Introduction

Lab four covers the experimental performance of a simple calorimeter. The key objectives outlined for this lab require a student to take data from the calorimeter to measure the temperature and heat flux over time and then subsequently interpret and process said data to evaluate calorimeter performance. The model used to calculate values for the experiment is the Lumped Capacitance Model (LCM) which is governed by the below equations.

$$-hA_s(T - T_\infty) = \rho V c_p \frac{dT}{dt} \tag{1}$$

$$\frac{T(t) - T_\infty}{T_i - T_\infty} = e^{-\left(\frac{hA_s}{\rho V c_p}\right)t} \tag{2}$$

$$\frac{T(t) - T_\infty}{T_i - T_\infty} = e^{-\frac{t}{\tau_t}} \tag{3}$$

$$Bi = \frac{hL_c}{k} \tag{4}$$

One of the requirements for the LCM to be a valid model is that the Biot number (Bi) as seen in Equation 4 must be less than 0.1. This is very likely for this experiment given the relatively high expected thermal conductivity and relatively low characteristic length. [1]

Methods

In conducting lab two the student is tasked to collect data on the LCM via use of the provided MSP432 DAQ, therefore the first step is to open the Graphical User Interface for the MSP432 via MATLAB. The MSP is set up to collect data via plugging in wires as seen below

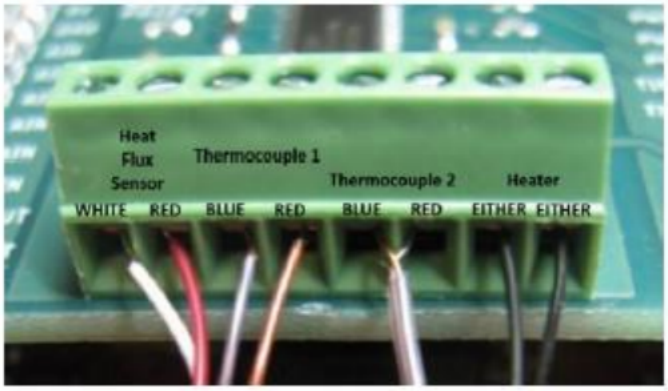


Figure 1: Requisite Wiring Configuration

Before the student moves on to collect useful data it is helpful for the data processing for the student to run the DAQ for a short burst of time to determine the positive and negative side of the heat flux sensor. The thermocouple sensor on the Heat Flux sensor is located such that it

produces a positive result when heat passes through the thermocouple then the rest of the heat flux sensor (ie it is on the bottom of the sensor). Once the positive and negative sides have been determined the student will follow the procedure outlined here for both the first and second configuration for the experiment. The student will first construct the calorimeter using a cold (room temp) piece of aluminum as the material. Figures 2 & 3 below show both configurations for the calorimeter.

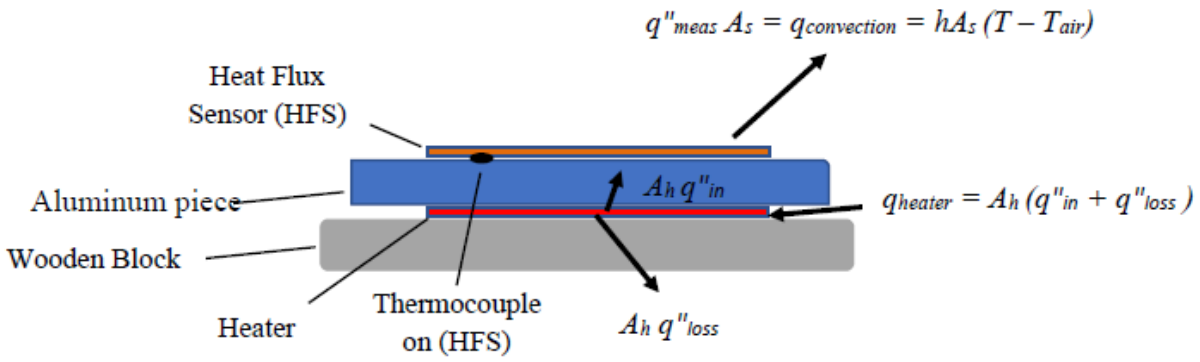


Figure 2: Configuration 1

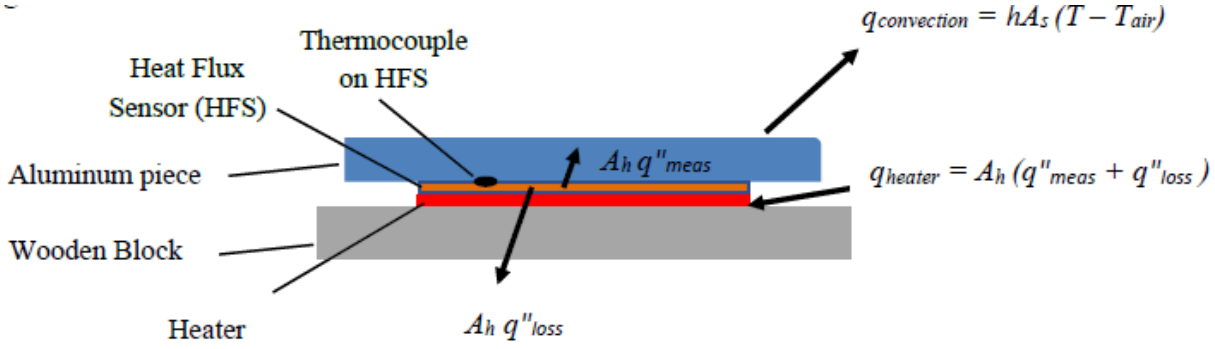


Figure 3: Configuration 2

The student should record data with the heater on for 80-90 seconds for both configurations. Expected “steady state” values for the heat flux are 100-200 for the first configuration and 1000-2000. If values do not fall within this range the student should repeat the data collection and if issues persist call over a TA to discuss why and see if there is a problem somewhere within their configuration. [1]

Results and Discussion

The table below shows the average heat transfer coefficient value.

Table 1

h	13.88 W/m^2k

The resultant experimental heat transfer coefficient is less than expected for typical aluminum values [2], possible explanations for this include losses to area not exposed to the heat

flux sensor such as the sides and extremities of the top, possible differences between local air temperature and the temperature at the location of the second thermocouple sensor, and inaccuracies within the sensor. Of those options the most likely by far is that the area not covered accounts for the rest of the heat flux that was not accounted for exiting at the sensor and as such was retained within the sample. The below figure show the calculated and measured values of heat flux and temperature respectively versus time.

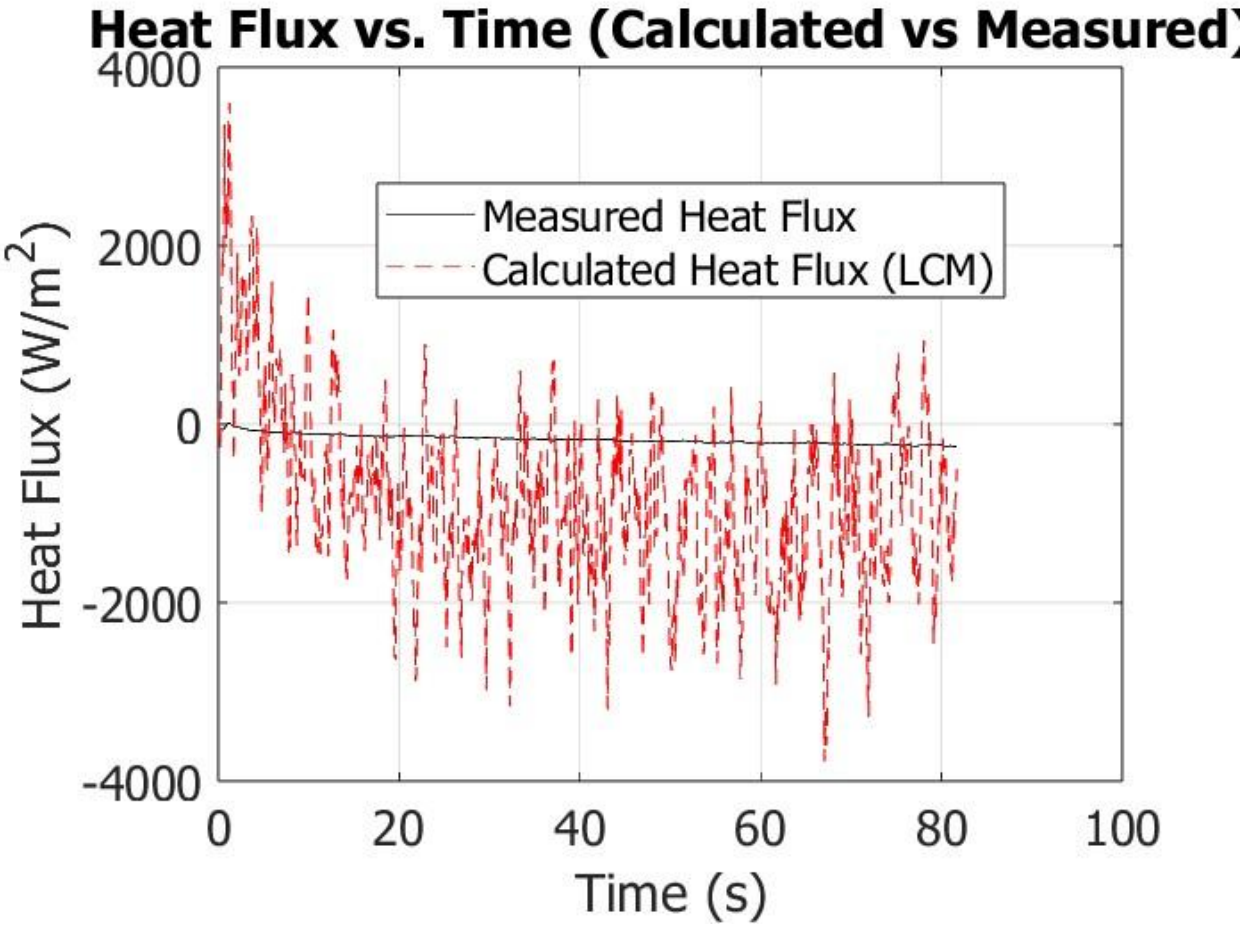


Figure 4: Heat Flux Graph

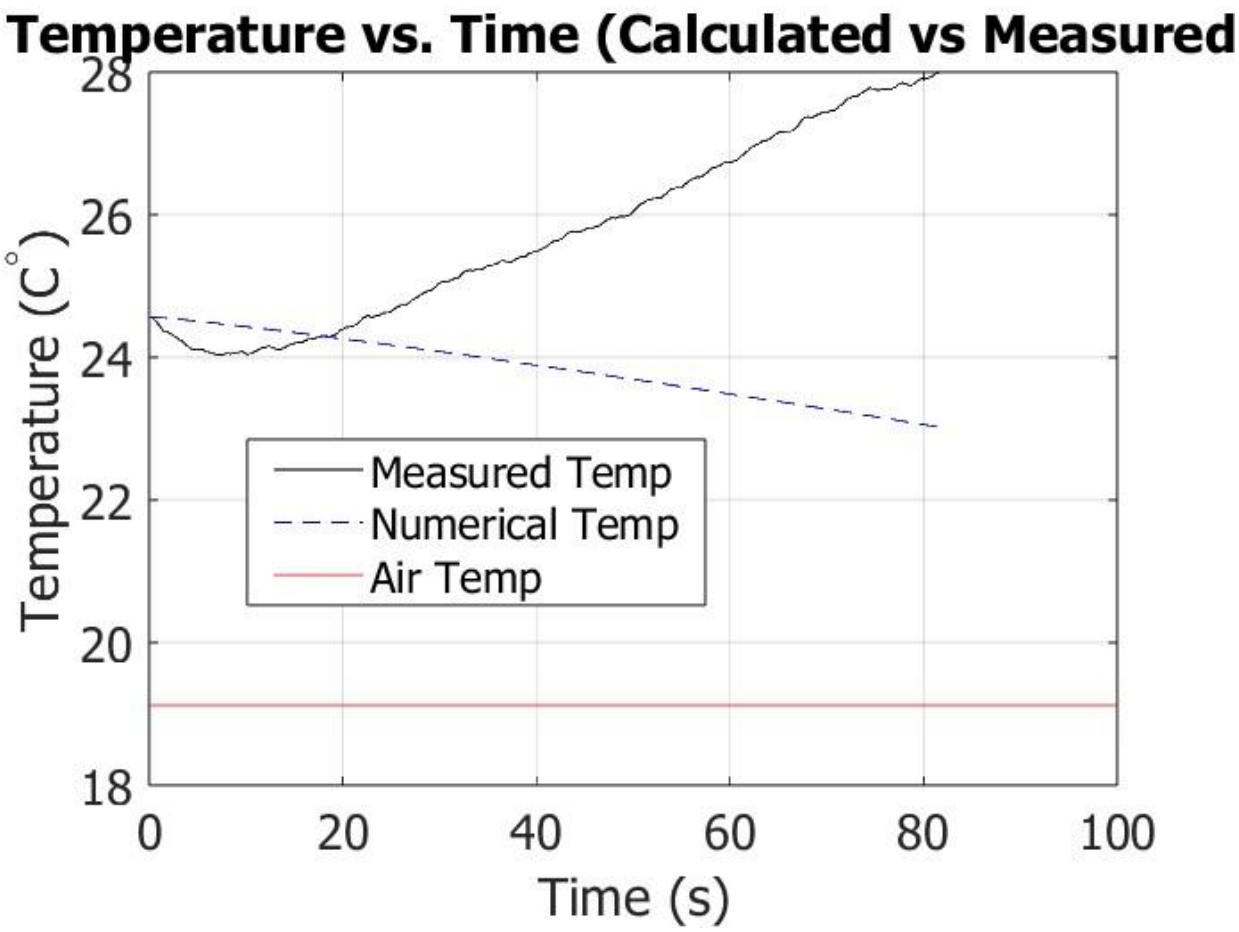


Figure 5: Temperature graph

As can be seen in the graphs there are noticeable differences between the calculated and measured values, the measured value for heat flux appears to be depressed in comparison to the average calculated value and the measured value for heat seems to be increased. This tracks given that the heat of the aluminum would be expected to rise if the measured flux out of the block is lower since that would indicate a greater capacity for the aluminum to hold heat within itself. The noisy look of the calculated flux is due to the amplification of electrical noise that occurs during the backwards difference numerical differentiation, if a small amount of noise changes the flux value at all it is then divided by a very small-time value which explodes out the noise and creates the randomness seen. The temperature difference between sides is very low to negligible which indicates a low Biot number and allows for us to say with reasonable confidence that the LCM model approximates the actual real world scenario, other sources of error however have thrown the model off and would require changes made to the calorimeter to fix. A proposed fix to the calorimeter would be to have a larger sensor that covered the sides and the entire top face which would allow for a better capturing of the escaping heat flux. The mass of said larger sensor would have to be minimized, however, to reduce the sensor inertia effect although at values approaching steady state such an effect would be negligible anyway. Overall the calorimeter performed within an expected error range for the experiment given the materials used and methods of construction, given the scope of the class no improvements to the calorimeter design are necessary but if a more accurate reading is desired a thinner aluminum

piece to minimize losses to the thickness side and a more bespoke made to sensor top size would both improve the accuracy.

References

[1] ME 4005 Course Materials. Available: https://canvas.vt.edu/courses/187828
[2] Engineering ToolBox, "Metals and Alloys - Thermal Conductivities." [Online]. Available: https://www.engineeringtoolbox.com/thermal-conductivity-metals-d_858.html. [Accessed: Apr. 5, 2026].