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Memo: Lab 5

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Re:	Thermal Capacity Lab	**Date:**	October 14, 2024
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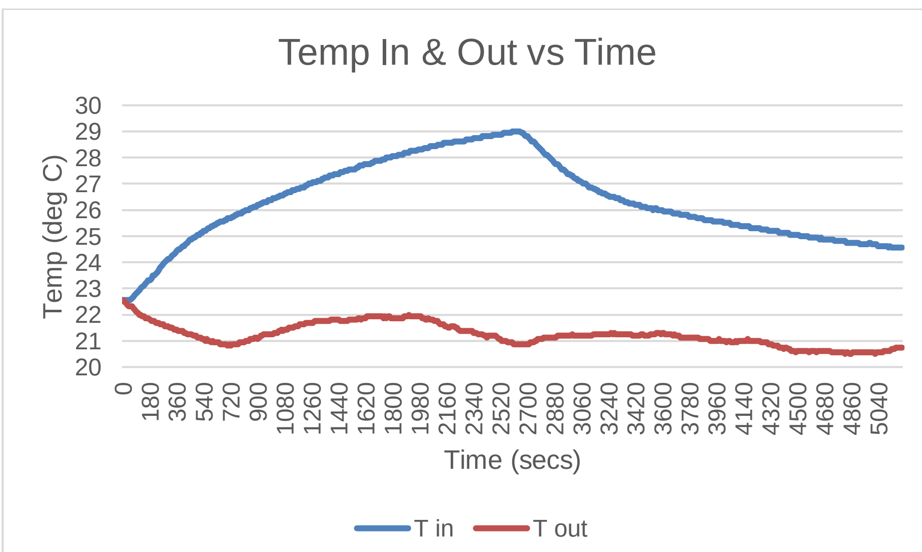
Challenge: measure the thermal capacity of an 8oz water bottle by observing the heating/cooling rates in a model building and compare the theoretical vs experimental thermal capacity values.

Calculating theoretical thermal capacity:

- An 8oz water bottle (assuming water density of 1000 kg/m^3) has a mass of 0.2kg
- The thermal capacity C_{th} (thermal energy needed to warm the water bottle 1 °C) is the product of the material's specific heat capacity (4200 J/kg°C) and mass (0.2kg), resulting in 1000 J/°C.

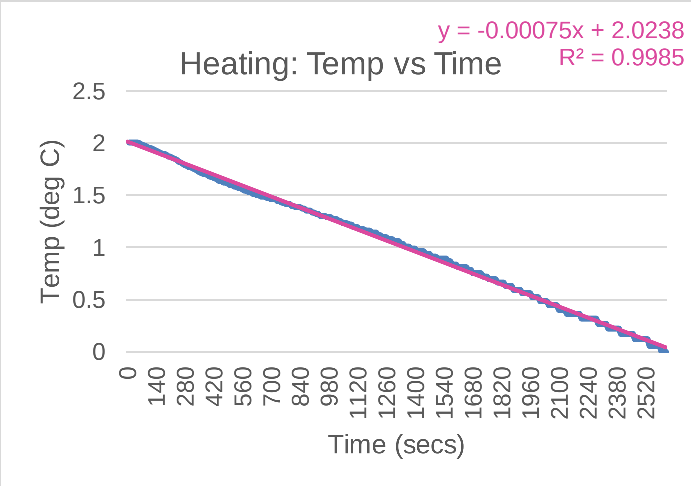
Experimental design: We added a consistent amount of energy to a contained space (matboard model building) using a 7-Watt lightbulb. We recorded data through temperature sensors both inside and outside the water bottle at 10 second intervals for a 40-minute heating period followed by a 40-minute cooling period.

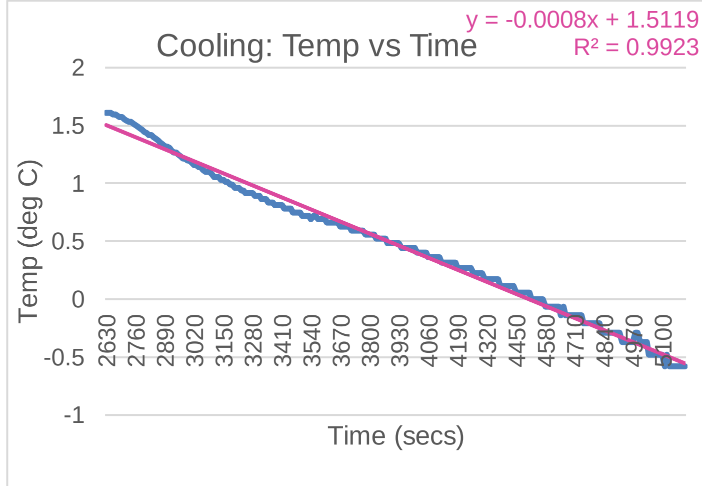
Results:



T_{out} remained relatively constant throughout with small fluctuations. T_{in} showed a pattern of logarithmic growth during the heating period, then transitioned to exponential decay during the cooling period.

This pattern reflects the expected exponential relationship between temperature & time: $\Delta T(t)=\Delta T(0)e^{-t/mcR_{th}}$, which can be rewritten as $\ln(\Delta T) = (-1/mcR_{th})t$. This new form shows a linear relationship, meaning separating the heating and cooling data and graphing $\ln(\Delta T)$ as a function of time will produce a linear graph.





The heating and cooling graphs are both negative and linear, with similar slope values and slightly different y-intercepts. Adding a best fit line provides an accurate a slope estimate, which is equal to $-1/mcR_{th}$, and can be used to calculate the thermal capacity R_{th}.

Calculating experimental thermal capacity:

Heating: $-0.00075 = -1/C_{exp}(1.2)$ -> C = 1,111.1 J/°C

Cooling: $-0.0008 = -1/C_{exp}(1.2)$ -> C = 1041.7 J/°C

Comparison: Calculating the percent difference between the theoretical and experimental thermal capacity values shows 11% for heating and 5% for cooling, which is extremely accurate given the experimental design. Several factors could have led to inaccurate data: gaps from the vents could allow heat to escape the model and the water temperature could be inaccurate due to the temperature sensor placement (not fully submerged in the water). Overall, despite these possible sources of error, we collected relatively accurate data that produced the expected results.

Applications: You are in a restaurant and order dinner and coffee. The waitress brings you your coffee right away before your dinner arrives. You want the coffee to be hot for your meal. Should you add the cream to your coffee now or once your meal arrives?

Using the equation $\Delta T/\Delta t = -1\ \Delta T / mcR_{th}$, the goal is to reduce $\Delta T/\Delta t$, the rate of cooling. The thermal resistance R_{th} remains constant because the coffee stays in the same container, and the thermal capacity c also stays relatively consistent. Adding the cream increases the mass m very slightly, but the main difference is in ΔT, the difference between the internal and external temperature. Adding the cream reduces ΔT because it brings the coffee closer to the temperature of the air around it. Decreasing ΔT in the numerator increases the rate of cooling, meaning adding cream earlier will make the coffee cool more slowly.