



Experimentation of Heat Transfer Using Lumped System Analysis



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Introduction

When the temperature of a body is not in equilibrium with its surroundings, heat transfer between the body and the surroundings will occur until an equilibrium temperature is attained. Most of the time heat transfer analysis is done on a body that is very small with respect to its surroundings. This allows for the assumption that the average temperature of the surrounds does not change drastically with time. Therefore the body usually approaches the temperature of the surroundings. This heat transfer continues until the bodies are the same temperature, which is equilibrium and the point of maximum heat transfer. A special case of heat transfer is lumped system analysis. This means that the points on and within the body can be approximated at the same temperature. A lumped system analysis can be used when the Biot number satisfies:

$$Bi = \frac{h}{k} \left(\frac{\Delta T}{\Delta T} \right) = \frac{\text{Convection at the surface of the body}}{\text{Conduction within the body}} \leq 0.1$$

Where, h is the convection heat transfer coefficient at the surface, k is the conduction heat transfer coefficient in the body, L_c is the characteristic length of the body, and ΔT is the change in temperature

If the Biot number condition is satisfied then the system follows the following equation:

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

Here, $T(t)$ is the temperature of the system at a given time, T_{∞} is the temperature of the ambient, T_i is the initial temperature of the system, t is the time (in seconds) and b is a constant (under the assumption of constant properties) whose reciprocal is the time constant with units of seconds, particular to the given system, based on the heat convection at its surface (h) and its surface area (A_s), density (ρ), volume (V), and specific heat (c_p).

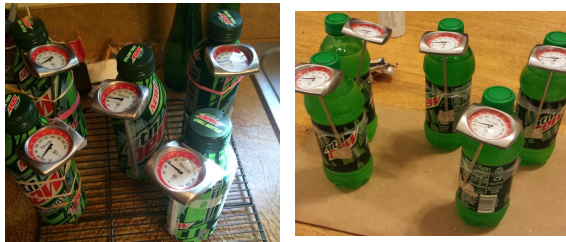


Figure 1: Warming Set-up for Aluminum and Plastic Bottles

Objectives

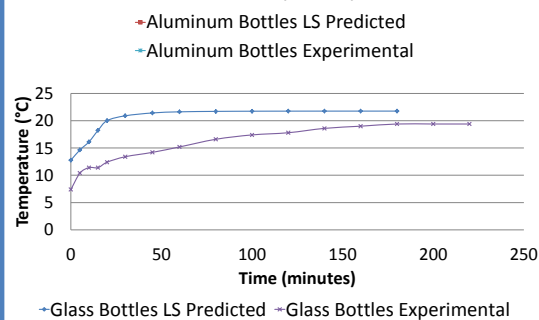
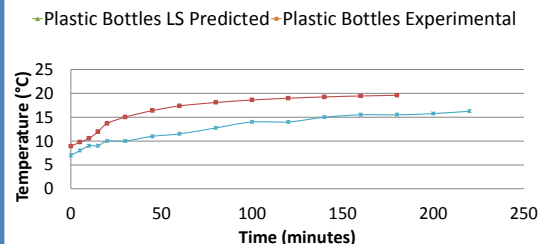
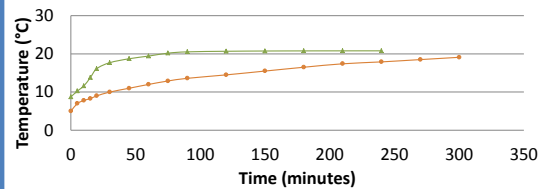
- Use lumped system analysis to analyze heat transfer from aluminum, glass, and plastic bottles
- Compare the experimental values to the theoretical values

Methods

Procedure:

- Place all the bottles on an elevated surface with a thermometer attached to each bottle
- Place them in the refrigerator overnight so the temperature is constant
- Take the bottles out of the fridge and place them on the counter
- Take the temperature at specified intervals until the temperature is constant

Results



The data was compiled into an excel file where the formulas were implemented to analyze the results. The time vs temperature was plotted for each of the different types of bottles on a different graph. All of the bottles increased in temperature rapidly when they were initially taken out of the refrigerator. As the temperature of the bottles neared the surrounding temperatures the change was much smaller which resulted in an almost flat line on the plot.

Conclusion

This experiment showed that none of the bottles behaved as a lumped system. This can be seen in the graph where the experimental curves did not follow the theoretical curves for each type of bottle. However the glass bottles were closest to the theoretical curve followed by the plastic and aluminum bottles. This can be attributed to the open environment that the experiment was conducted in, the thermometers used, and the assumption that the exponent b could be calculated from the initial temperature values.



Figure 2: Warming Set-up for Glass Bottles

Future Work

- Better thermometers
- A more controlled environment
- Try to find out what system these bottles actually follow
- Try to modify the bottles to obtain a slower rate of heat transfer

Acknowledgements

- Cleveland State University
- Choose Ohio First
- National Science Foundation
- Dr. Kiril Streletzky