Transient Unsteady Convection of Aluminum and Brass Objects

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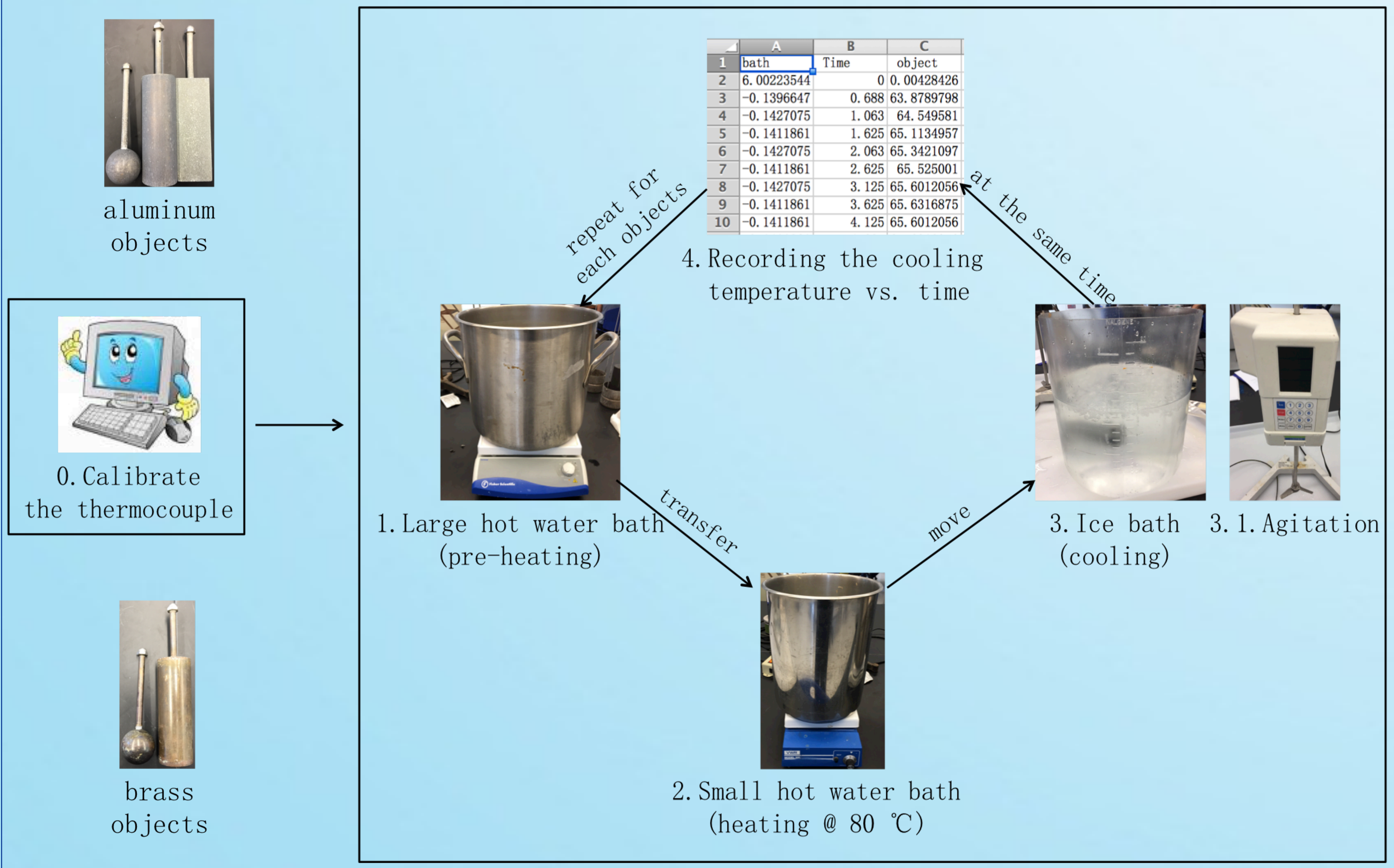
Abstract

Natural (Free) convection is the primary mechanism of heat transfer that applies to many applications in a lab or everyday environment. Unsteady heat transfer, using the Lumped Heat Capacity Method, allows us to estimate the time required for any system to reach a steady state in a process. The heat transfer coefficient and time to steady state was found in this experiment at a fixed bulk temperature. Three different geometries (block, cylinder, sphere), made of either aluminum or brass, were studied during free and forced convection scenarios. Effects of geometry, material, and agitation were studied on the effects of the heat transfer coefficient and time to steady state. Convection coefficients for Brass objects were found to be larger than the Aluminum objects, as well as having faster times to steady state. The Brass sphere came to steady state the quickest of any geometry or material during free and forced convection (50 s, 35 s). However, the Aluminum block had the lowest convection coefficient value (540.87 W/m2K) and longest time to steady state (200 s).

Introduction

- **Background:**
  - Natural convection is used to cool electronics such as computers and refrigerators
  - Also used as a means to cool buildings with ambient air [1]
  - Our bodies use sweat and a breeze to keep our core temperature regulated when it's hot [2]
- **Problems:**
  - Difficulty in predicting time required for objects to reach a certain temperature
- **Hypothesis:**
  - Brass objects will have larger convection coefficients, h, than Al
  - Spheres will have the largest h values of all objects
  - Agitation will increase h
- **Goals:**
  - To determine the effects of material, geometry, and agitation of the medium on the heat transfer coefficient and the time required to reach steady state.

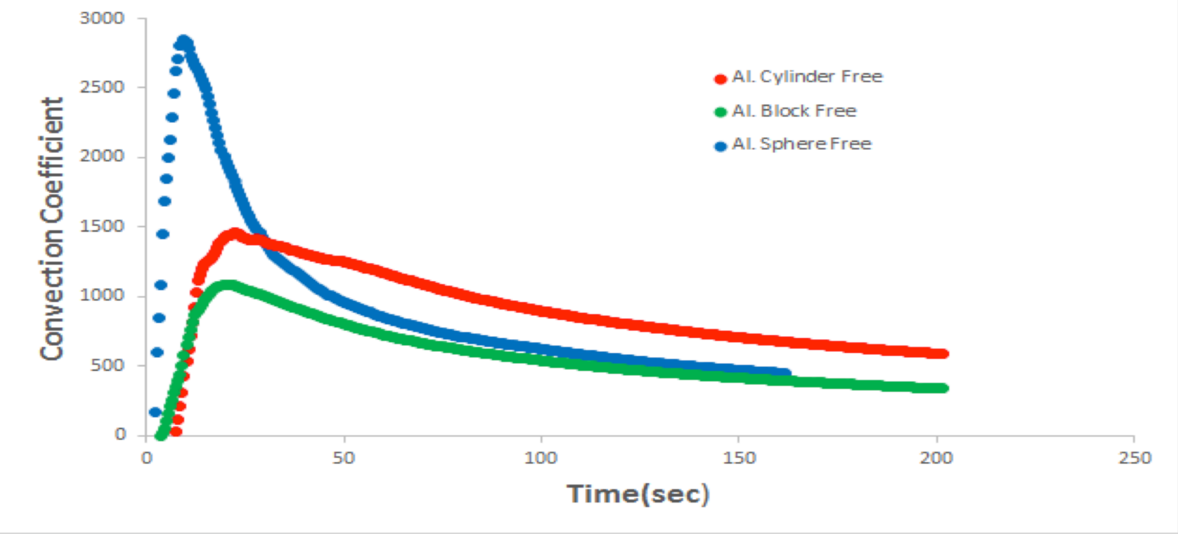
Methods



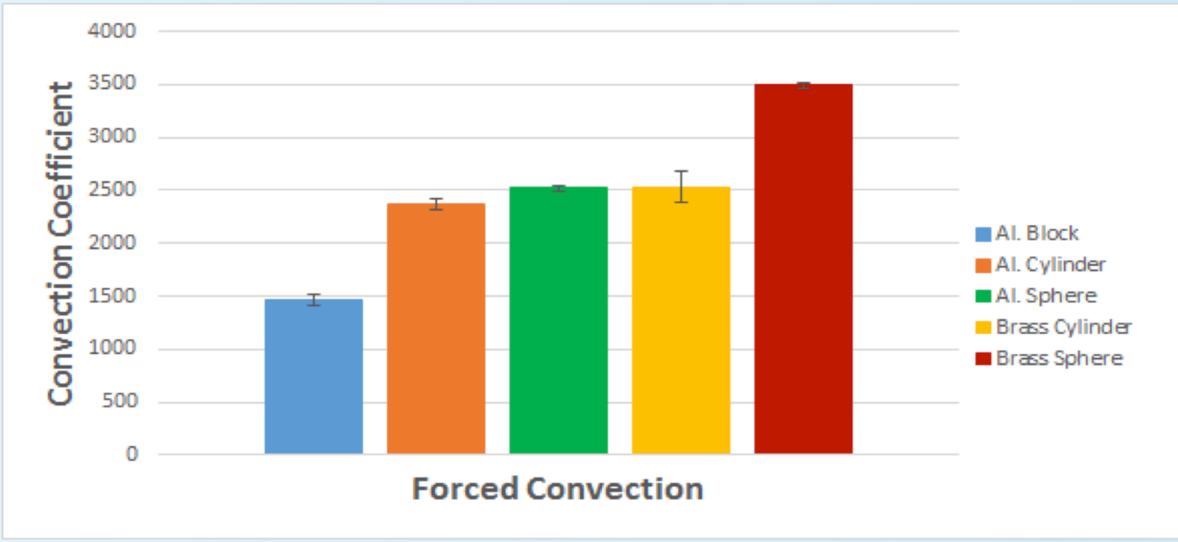
Results

- Objects were placed in heating bath (80 ℃) prior to being immersed in an ice bath (0 ℃) at constant temperature

Object	Free Convection Coefficient (W/m^2K)	Time to Steady State (sec)	Forced Convection Coefficient (W/m^2K)	Time to Steady State (sec)
Block (Aluminum)	540.87	200	1466.06	70
Cylinder (Aluminum)	875.76	200	2365.83	70
Sphere (Aluminum)	903.95	160	2517.74	50
Cylinder (Brass)	1420.79	100	2524.34	75
Sphere (Brass)	2378.66	50	3492.34	35

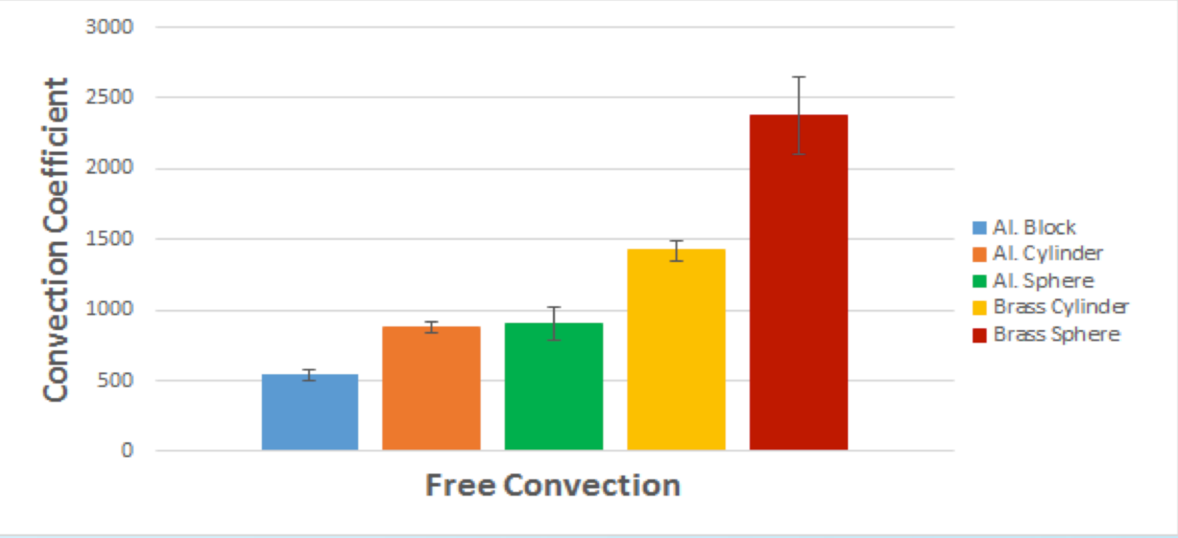


- The sphere saw the largest convection coefficient under both free and forced convection for their relative material. This was due to the sphere size being much smaller relative to the other objects, and allowed the object to come to steady state at a faster rate.

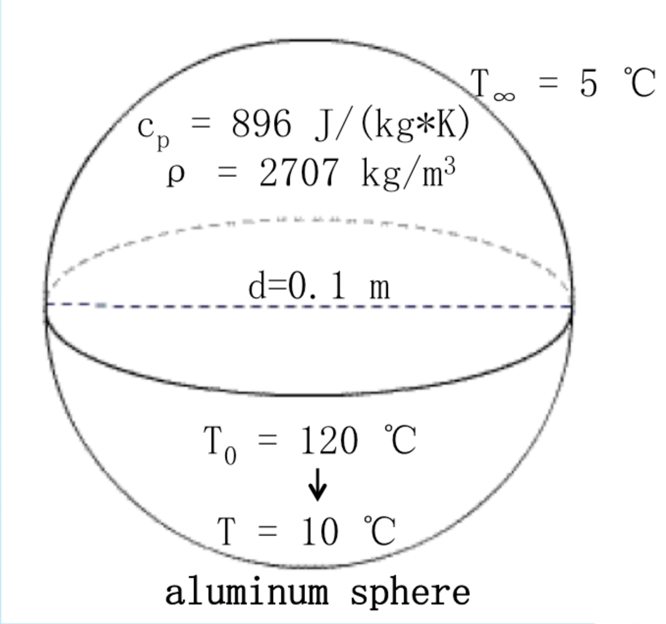


- Brass objects had much larger coefficient values compared to the corresponding aluminum objects also due to faster steady state times.

- Average convection coefficient values taken from 3 trials of each object geometry and material under free/forced convection. Standard error was calculated for the individual objects.



Design Problems



Basic calculation:

- $A = 4\pi r^2 = 4\pi(0.1)^2$
  $= 0.12566\ m^2$
- $V = 4\pi r^3/3$
  $= 4\pi(0.1)^3/3$
  $= 0.0041888$

Equation:

① $$\frac{h_{lab}D_{lab}}{k_{lab}} = \frac{h_{scal}D_{scal}}{k_{scal}}$$

② $$\ln\left(\frac{T-T_\infty}{T_0-T_\infty}\right) = -\left(\frac{hA}{c_p\rho V}\right)t$$ [3]

③ $$t = \ln\left(\frac{T-T_\infty}{T_0-T_\infty}\right)\left(\frac{-c_p\rho L_c}{h}\right)$$

Solution:

	h_{lab} (W/m2K)	h_{scal} (W/m2K)	**t (sec)**
Free Convection	903.95	413.29	**306.7**
Forced Convection	2517.74	1151.11	**110.11**

(① from h_{lab} to h_{scal}; ③ from h_{scal} to t)

Conclusions

- Convection coefficient was larger in the Brass objects than in the Aluminum objects.
- Decrease in time to steady state from free convection to forced convection for all objects, regardless of geometry or type of material.
- The Brass sphere had the largest convection coefficient, roughly 67% greater under free convection and 38% greater under forced convection.
- The Brass sphere came to steady state the quickest of any geometry or material during free and forced convection.
- The Aluminum block was the best at retaining heat, having the lowest convection coefficient value by roughly 62% in both free and forced convection.

References

[1] C. Reardon. (2013). *Passive cooling* [Online]. Available: http://www.yourhome.gov.au /passive-design/passive-coolin
[2] C. Polk and E. Postow, "Electric and Magnetic Fields for Bone and Soft Tissue Repair," *in Handbook of Biological Effects of Electromagnetic Fields*, 2nd ed. FL: Boca Raton, 1995, ch.5, pp.231-246
2nd ed. Boca Raton, FL, 1995.
[3] C. J. Geankoplis, "Principles of Unsteady-State Heat Transfer," in *Transport Processes and Separation Process Principles*, 4th ed. Upper Saddle River, NJ: Prentice Hall, 2003, ch.5, sec .1-2, pp.357-360

Acknowledgements

We thank Adam St. Jean and Lev Levintov for laboratory assistance. We thank Department of Chemical Engineering for funding of this experiment.