# Lab 2e

# Thermal System Response and Effective Heat Transfer Coefficient

## OBJECTIVE

Warning: though the experiment has educational objectives (to learn about boiling heat transfer, etc.), these should not be included in your report.

- To study the transient cooling of a heated object in room temperature.
- To determine the apparent heat transfer coefficient assuming a lumped capacitance heat transfer model.

## EQUIPMENT

| *Name* | *Model* | *S/N* |
|---|---|---|
| Thermistor Standard | | |
| Calibrator | | |
| DAQ | | |
| Five Specimens | | |
| Test Stand | | |
| Thermocouples | | |
| Pyrometer | | |
| Tempbook or DBK19 | | |
| Computer | | |

The thermal system response and effective heat transfer coefficient experiment required the use of several pieces of equipment. Heat transfer is measured on an aluminum cube, an aluminum rod, a polished brass rod and a blackened brass rod. An Oven is used to heat the objects to slightly less than 200º Celsius. Five thermocouples are used to measure the temperature of each of the objects and ambient temperature. A Pyrometer is used to measure the heat transfer. A thermistor and calibrator are used to calibrate the thermocouples. A test stand holds each of the objects while they cooled at room temperature. Also, a NI data acquisition system is used to gather the data for the LabVIEW software application.

## REQUIRED READING

See reference [1], [2] and this write-up for theory and data reduction.

## PRELAB QUESTIONS

1- What is heat transfer coefficient?
2- What is Lumped Capacitance method?
3- What is dimensionless temperature in this experiment and why we use this parameter?
4- What is the Time Constant in this experiment?
5- What is the validity of the Lumped Capacitance Method?

## PROCEDURE

a. (Note: step b. is to be executed in conjunction with this step) Calibrate at least six TCs, and using the techniques you have learned in this class to determine their accuracy relative to a local standard. You will not need to use an ice point cell here. Also, you will not need to use the reference junction TC. Given the time you have in one lab period, determine the number of calibration points you will use (calibrator settings), starting from about 20 C higher that room temperature to the maximum temperature your standard can read (probably about 130 C). Calibrate at least six TCs; one for each of the five bodies, and one for the ambient temperature. You may want to calibrate one or two more TC in case one fails during the experiment. Determine the types of TCs you will use, the channels on the data acquisition system you will use, and the software setup (LabVIEW). You should set up a statistic module to give you random reading variations during the calibration.

b. Calibrate an infrared pyrometer sensor, starting from about 50 C to 150 C in increments of 25 C. The pyrometer calibrator (black-body calibrator) will be shared between groups if more than one workstation is running of this lab. Share the calibrator by putting it on an extension cord and passing it back and forth between the two groups. If you need help, the TA will help you setup the pyrometer and you will need a power supply for it. Connect 12 V DC to the red (+) and black (-) power wires, and the signal is read from the white (-) and blue (+) wires. The signal will be read using a voltage input channel on the data acquisition system. Determine repeatability error using one temperature setting on the pyrometer calibrator for the pyrometer.

c. Measure each specimen's mass, area, etc. You can use the accuracy information you determined in Lab 1 in your uncertainty calculations for micrometers or calipers used here.

d. Increase specimen's temperature as high as possible (maybe 200 C max) using the oven and use a thermocouple to measure the temperature of the specimen and the ambient air.

e. Remove the specimen from the oven using tongs or oven mits and start recording the temperature history of the specimen and the ambient air when the specimen is positioned on the stand. Record the temperature of the surface of the cube using the pyrometer.

f. Three different cases are to be studied:
   1. Polished and blackened Brass cylinders.
   2. Aluminum and Brass cylinders.
   3. Aluminum cylinder and cube (same surface area).

g. Discuss your observations of each object you use in the experiment, for example, on the decay of (dimensionless) temperature and the time constants of the decay. Compare (plot) the internal with the surface temperature of the body measured with the pyrometer. What does this tell you about the lumped thermal capacitance assumption?

h. See pages 60-61 of the lecture notes on the course website for the theoretical development of this dynamic system and the equations you will need for the analysis. Based on an appropriate physical model, obtain from the data an "apparent" heat transfer coefficient for each object, and compare the "apparent" heat transfer coefficients with the values calculated from theoretical considerations; discuss the results as appropriate. Determine the apparent heat transfer coefficient by finding the time constant through a curve fit of the data as shown in example 3.5 in your text. Compare this with the time constant found from the Temperature-Time plot.

i. Discuss uncertainty of measurements (uncertainty for the time constant is statistically found via the curve fit used in h. above). Also see the write-up that follows.

<u>Analysis</u>

**Temperature Response – Determination of Apparent Heat Transfer Coefficient**

Three different cases are to be studied for comparison:

1. Polished and blackened Brass cylinders.
2. Aluminum and Brass cylinders.
3. Aluminum cylinder and cube (same surface area).

1. Discuss your observations of each object you use in the experiment, for example, on the decay of (dimensionless) temperature and the time constants of the decay.

   - The dimensionless temperature is given in equation (1), where $T_s$ is the body, $T_i$ is the initial and $T\infty$ is the room temperature, respectively. See example plot below.

$$\Gamma = (\frac{T_s - T_\infty}{T_i - T_\infty}) \qquad (1)$$

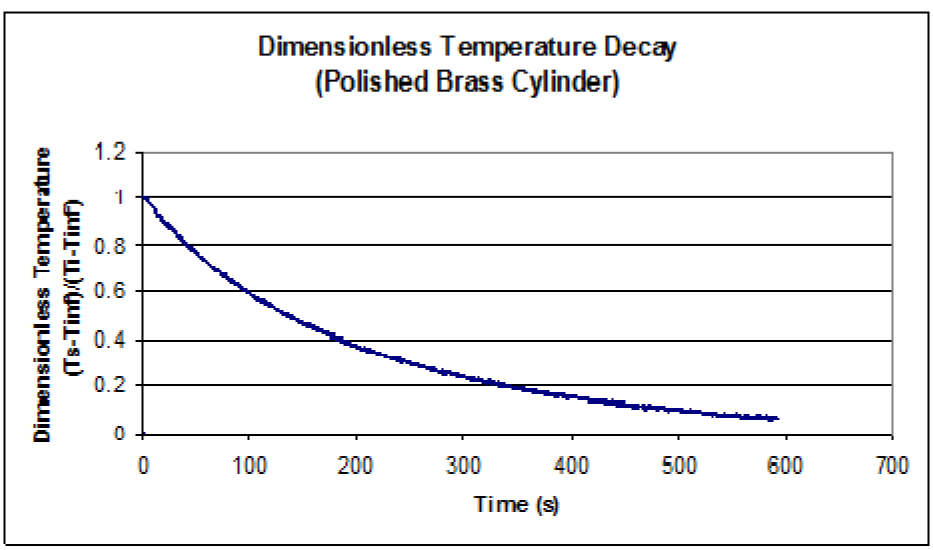


**Figure 1** Dimensionless Temperature Decay- Polished Brass Cylinder

- Compare (plot) the internal with the surface temperature of the body measured with the pyrometer. What does this tell you about the lumped thermal capacitance assumption? This should be straightforward.

2. Based on an appropriate physical model, obtain from the data an "apparent" heat transfer coefficient for each object, and compare the "apparent" heat transfer coefficients with the values calculated from theoretical considerations; discuss the results as appropriate.

   - A lumped thermal capacitance heat transfer model (body at uniform temperature) with a constant Newtonian heat transfer coefficient leads to a first-order system equation defined by the error fraction Γ in terms of temperatures, that decays exponentially with time according to a time constant τ

$$\Gamma(t) = \frac{T_s(t) - T\infty}{T_i - T_\infty} = e^{-t/\tau} \qquad (2)$$

   - Note: this error fraction is our "dimensionless temperature".
   - In this case the heat transfer coefficient is "apparent" since it will include convection and radiation, and will not be "perfectly" constant.

3. Determine the apparent heat transfer coefficient by finding the time constant through a curve fit of the data as shown in example 3.5 in your text. Compare this with the time constant found from the Temperature-Time plot.

   - Using the equation above, taking the natural log of both sides, one can put the temperature versus time data into a form such that linear regression can be used to determine the time constant and its uncertainty (standard error of the slope).

$$\ln(\Gamma(t)) = \ln\left(\frac{T_s(t) - T\infty}{T_i - T_\infty}\right) = \frac{-t}{\tau} \qquad (3)$$

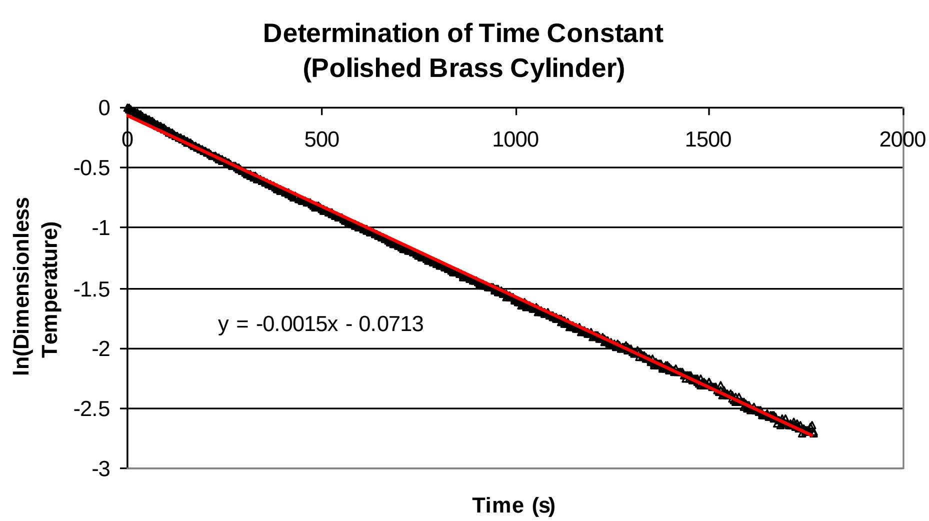


**Figure 2** Determination of Time Constant- Polished Brass Cylinder

An example plot and curve fit for the data shown earlier is given here. The time constant from the curve fit is 662 seconds. From the raw data (Temperature vs. Time plot) it is much less. Discuss any observations about this and its possible causes.

- The apparent heat transfer coefficient h is found from the time constant $\tau$, mass of specimen m, the specimen specific heat $c_v$ and the surface area of the specimen $A_s$:

$$\tau = \frac{mc_v}{hA_s} \tag{4}$$

4. If requested, determine and discuss the uncertainty of the measurements (hint: uncertainty for the time constant is statistically found via the curve fit used above, propagate the error to the results using uncertainties for mass of specimen m, and the surface area of the specimen $A_s$. You can neglect the uncertainty for the specimen specific heat $c_v$.).

- To determine the uncertainty in h you must use error propagation to that result using the equation for h.
- It is assumed you will perform similar calibration and uncertainty calculations for the thermocouples as required in the Lab 2 workstations.
- You will be graded on whether you perform these uncertainty calculations correctly and how thorough you perform them.

<u>REFERENCES</u>

1. Figliola, Richard S., and Donald E. Beasley. “Theory and Design for Mechanical Measurements” 5th ed., Wiley Inc., 2011.
2. Theodore L. Bergman, Frank P. Incropera, Adrienne S. Lavine, David P. DeWitt. “Fundamentals of Heat and Mass Transfer”, 6th ed., Wiley Inc., 2007, Chapter 5, Sections 5.1-5.3.