ME 105 – Mechanical Engineering Laboratory
Spring Quarter 2003

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2. INTRODUCTION TO TRANSIENT CONDUCTION AND CONVECTION

This set of experiments is designed to provide an introduction to unsteady conduction and to the effect of various types of convective boundary conditions on the cooling of a sphere. The primary type of measurement you will make is recording the center temperature of a sphere as a function of time. You will examine the difference between natural and forced convection in both liquids and gases, look at the effect of the thermal conductivity of the material and study the usefulness of the lumped capacitance method of analysis.

Note that you will work around big vats of boiling water. **Be very careful!**

Pre-Lab Reading

Read this handout carefully to determine what you will be doing during this session. Also read about lumped capacitance analysis and Heisler charts for unsteady conduction, and about the basics of convection, in particular about the convective heat transfer coefficient in natural and forced convection.

Pre-Lab Work

Prepare a clear and organized outline of data acquisition for the session that includes tables with blank boxes to be filled with raw data and processed temperatures as well as brief reminders about what you will be doing and in what order. Make sure to look up and include at the appropriate place any property values, formulae, etc., that you might need during the session. It would be an excellent idea to include comments or (educated) guesses about what you think will happen or about trends you anticipate in you measurements, so that you can spot any problems or unusual results as they occur. In addition, list the assumptions on which lumped capacitance analyses are based, list the assumptions on which the Heisler charts are based. Read about forced convection over a sphere in your ME151C text, and find a correlation for the Nusselt number to compare your results with. Prepare a sample calculation that allows you to determine the convection coefficient h from a quick look at experimental results (you may choose a more detailed analysis to use later). Note: **In this lab you will need to make calculations that will require additional measurements not explicitly given in the instructions. Be sure that you understand all of the analysis you will perform, so that you make all the necessary measurements! Failure to do this will result in an incomplete report.**

This pre-lab will be graded at the **beginning** of the session.

Required Equipment

- Instrumented aluminum and plexiglas spheres
- Fan
- Air speed meter
- Weight scale
- Caliper
- Themocouple probe (type K)
- Electronic temperature converters
- LabView chart recorder
- Water
- Hot plate, metal container
- Insulated containers

Experimental Work

The spheres you will work with have been instrumented by drilling a narrow radial channel to their center, and inserting a stainless steel sheathed, high thermal conductivity putty covered, type K themocouple such that it contacts the center of the sphere. The high thermal conductivity putty is used to improve the accuracy of the temperature measurement.

Preparation of Hardware

WARNING: Be careful of the boiling water and the steam being evolved from the boiling water. Severe burns can result from contact with your skin.

NOTE: Monitor the water in the stock pot and do not allow it to boil dry. Severe damage to the laboratory and equipment can result.

Prepare boiling water in the aluminum stock pot and fill one of the insulated containers with tap-water at the temperature of the tap. Make sure that you keep the water gently boiling throughout the experiments.

Experimental Procedures

1. Natural Convection in Water

A. Cooling of a plexiglas sphere. The TAs will start an experiment to measure the cooling of a plexiglas sphere from room temperature to the temperature of an ice-water bath without any agitation. The temperature of the center of the sphere and elapsed time will be measured with a thermocouple readout. The TA's will record these data and post them on the "white board" for your use in the write-up for this experiment. **Be sure to record the data that is posted for this part of the experiment.**

B. Cooling of an aluminum sphere.

a. You will use the LabView chart recorder available on the desktop to measure the transient temperature of an aluminum sphere. Connect the type K thermocouple in the aluminum sphere to an electronic temperature converter and plug the converter into Channel 0 of the I/O connector block interfacing your computer. You will need to determine what data collection rate is suitable for your measurement and what voltage scale is appropriate. You can accomplish this by transferring the sphere back and forth between the boiling water and the other bath while observing and adjusting the chart recorder scales.

b. Use a second type K thermocouple to measure the temperature of the tap-water and boiling water baths. Place the aluminum sphere in the boiling water bath and secure it to the labstand frame. Measure the temperature at the center of the sphere with its thermocouple and leave it in the bath until its temperature is the same as that of the bath.

c. Simultaneously start the chart recorder and remove the sphere from the boiling water. Immediately immerse the sphere delicately in the tap-water bath until it is about 2 inches below the surface, and record the temperature history of the sphere center and the tap-water bath using the chart recorder. Check the temperature of the tap-water bath. Repeat and record this part of the experiment a sufficient number of times to allow you to analyze the results statistically for your report. You may choose not to wait for the sphere to completely attain the bath temperature, but record long enough to determine the time constant. **To calculate the energy transfer to the bath, other measurements will be required here!**

2. Forced Convection in Water

NOTE: During this portion of the experiment you will be agitating the aluminum sphere in a bath of room temperature water. Please do not break the thermocouple leads and also please do not flood the lab.

A. Place the aluminum sphere in the boiling water bath and secure it to the labstand frame. Measure the temperature at the center of the sphere with its thermocouple and leave it in the bath until its temperature is the same as that of the bath.

B. While the sphere is in the boiling water bath, measure the temperature of the tap-temperature bath. Turn on the chart recorder and simultaneously transfer the sphere from the boiling water to the tap-water temperature bath, stirring gently by hand. **Violent agitation is not required.** Measure the temperature history of the center of the sphere and the water bath. Repeat and record this part of the experiment a sufficient number of times to allow you to analyze the results statistically for your report. You may choose not to wait for the sphere to completely attain the bath temperature, but record long enough to determine the time constant.

C. Compare the time it took to bring the temperature of the sphere center from that of the boiling water bath to that of the room temperature bath with and without stirring. Compute a ratio showing how much faster the cooling is in the case of forced convection, compared to the natural convection case.

3. Forced Convection in Air

A. Place the aluminum sphere in the boiling water bath and secure it to the labstand frame. Measure the temperature at the center of the sphere with its thermocouple and leave it in the bath until its temperature is the same as that of the bath.

B. Turn the fan on and measure the temperature of the air exiting the fan and the air speed. Turn on the chart recorder and simultaneously remove the sphere from the boiling water, quickly wipe it dry with a dry towel (why are you doing this?) and secure it over the mouth of the fan. Measure the temperature history of the sphere center in the moving air. Repeat and record this part of the experiment a sufficient number of times to allow you to analyze the results statistically for your report. You may choose not to wait for the sphere to completely attain the air temperature, but record long enough to determine the time constant.

C. Compare these results to those for forced convection in water.

4. Natural Convection in Air

A. Place the aluminum sphere in the boiling water bath and secure it to the labstand frame. Measure the temperature at the center of the sphere with its thermocouple and leave it in the bath until its temperature is the same as that of the bath.

B. Measure the temperature of still air in the lab. Turn on the chart recorder and simultaneously remove the sphere from the boiling water, quickly wipe it dry with a dry towel and secure it to your labstand away from the fan. Measure the temperature history of the sphere center.

Note: You will have time to perform some of the calculations and conversions required for your report while you are waiting for the sphere to cool.

C. Compare this result to that for natural convection in water and forced convection in air.

Report

Answer the following questions in your report:

1. For the forced convection experiments, determine the heat transfer coefficient h using lumped capacitance analysis.

2. Use the heat transfer coefficients obtained from experimental results to check the validity of the lumped capacitance analysis in each case.

3. Using the Heisler chart, determine the center temperature of the aluminum sphere after a time equal to the time constant for the forced convection in water case. How does this number differ from the temperature obtained by lumped capacitance analysis?

4. Calculated the energy transfer to the water in the forced convection experiments by consider both temperature change of the sphere and the water bath. Is energy conserved?

5. For the forced convection cooling in air, compute the Nusselt number and compare with an appropriate correlation from your heat transfer text. Does the agreement fall within experimental error?

6. For the forced convection cooling in air, compute the Nusselt number and compare with an appropriate correlation from your heat transfer text. Does the agreement fall within experimental error?

7. For the free convection experiments, check if the measured variation of temperature with time for the aluminum sphere agrees with the lumped capacitance analysis. (hint: there is a good reason why it should not)

Heissler Chart

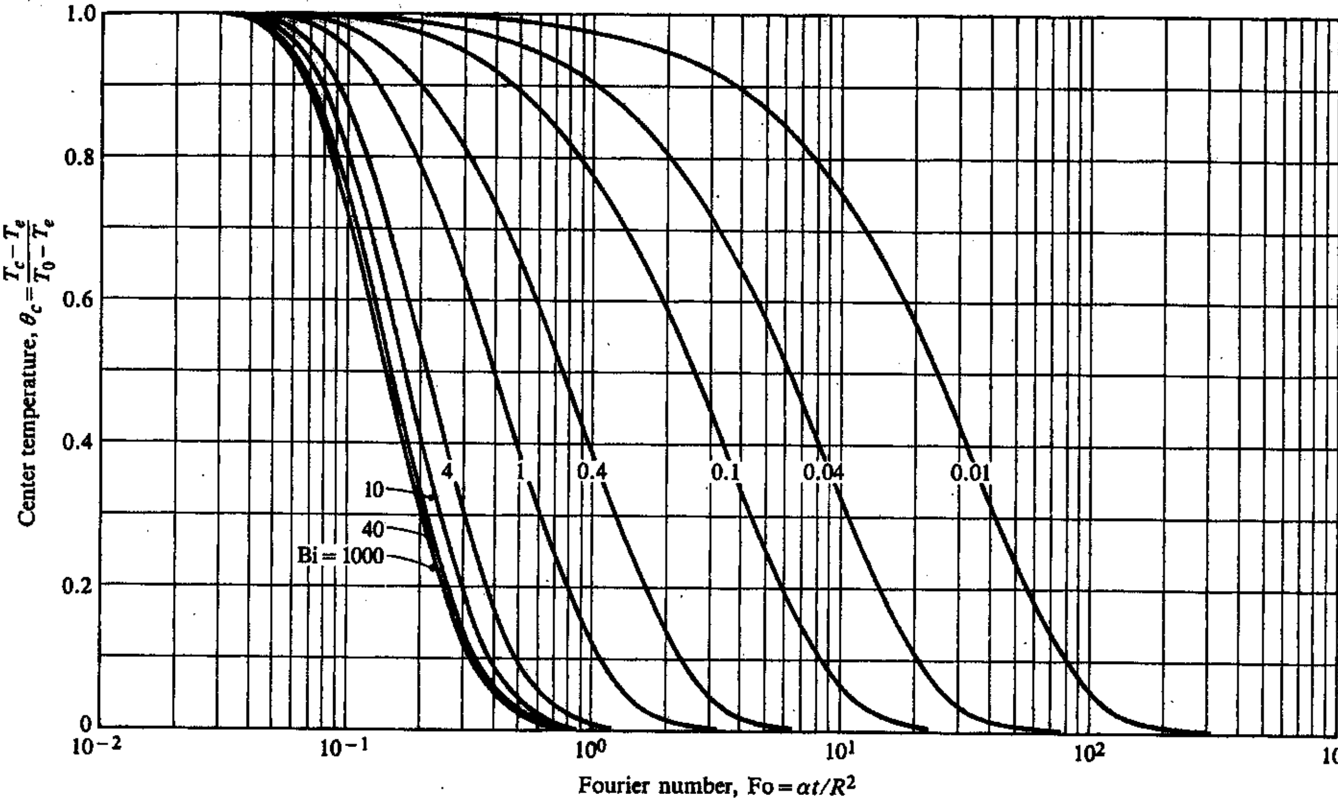

Figure C.1*c* Center temperature response for a convectively cooled sphere; Bi $= h_c R/k$.

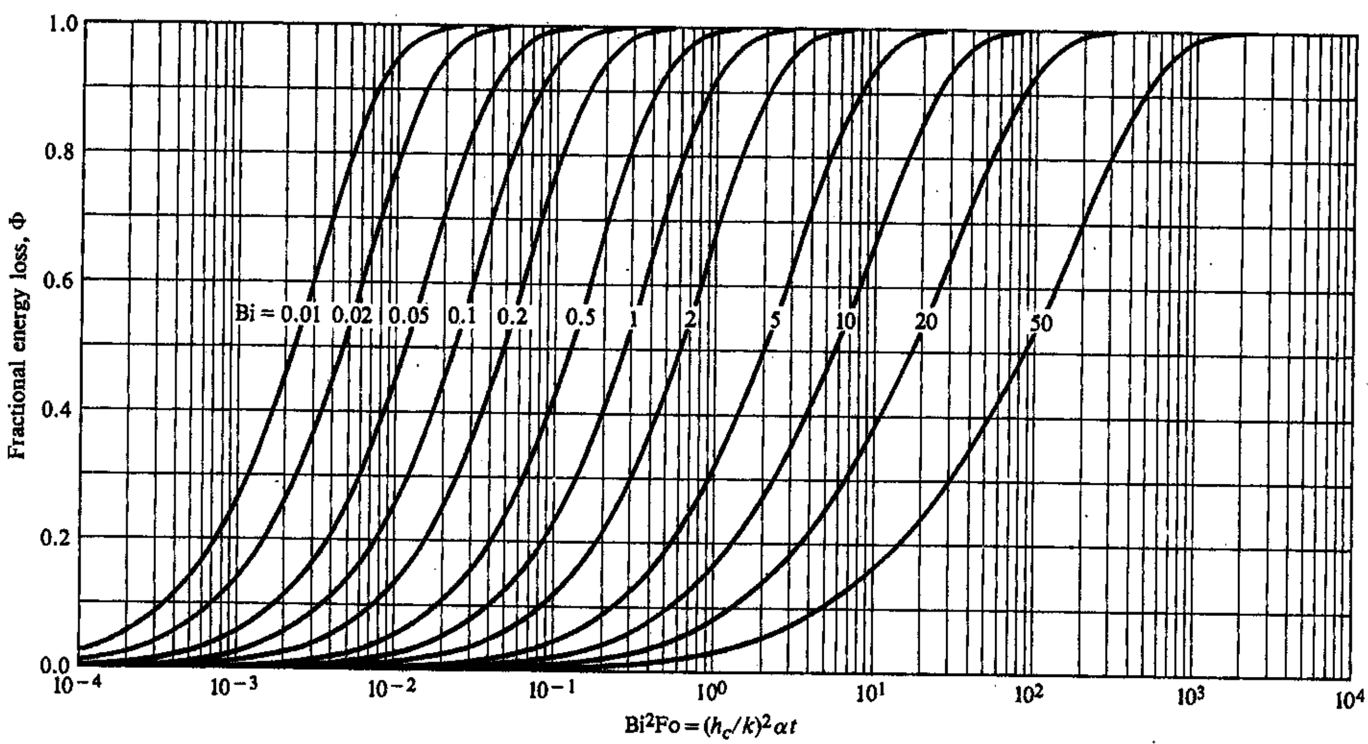

Figure C.2*c* Fractional energy loss for a convectively cooled sphere; Bi $= h_c R/k$.