THERMODYNAMICS AND TRANSPORT LABORATORY

CONVECTIVE HEAT TRANSFER PRELAB

Ch En 385 – Knotts

Lab Learning Objectives

1. Students will be able to calculate convective heat transfer coefficients from experiments.
2. Students will be able to explain how flowrate affects the convective heat transfer coefficient.
3. Students will be able to explain the difference between free and forced convection.

Introduction and Theoretical Background (Linking to and Expanding upon Previous Knowledge)

Convection of heat occurs when a moving fluid (liquid or gas) at one temperature flows past an object at another temperature. For a fluid at T_∞ and an object with a surface temperature of T_s, the total heat transfer rate (q) between the fluid and the object is given by Newton's Law of Cooling

$$q = hA(T_s - T_\infty) \tag{1}$$

where A is the area available to heat transfer and h is the convective heat transfer coefficient. In Ch En 374 and 376 you learned (or will learn) about the concept of boundary layers and how the heat flux at the surface by conduction (with fluid thermal conductivity k_f, is equal to the convective heat flux at the surface. Mathematically, this gives the definition of the convective heat transfer coefficient.

$$q'' = h(T_s - T_\infty) = -k_f \left(\frac{\partial T}{\partial y}\right)\bigg|_{y=0} \Rightarrow h \equiv \frac{-k_f \left(\frac{\partial T}{\partial y}\right)\big|_{y=0}}{(T_s - T_\infty)} \tag{2}$$

The last equality indicates that h could be determined if the gradient of the temperature is known at the surface. Obtaining the gradient requires solving the energy balance for the boundary layer. The first step in this is make the balance dimensionless which introduces the multiple dimensionless numbers—Nusselt Number (Nu), Reynold's Number (Re), and Prandtl number (Pr). The Nusselt Number is a dimensionless h defined as

$$Nu \equiv \frac{hL}{k} \tag{3}$$

where L is the characteristic length of the system. Because h is related to the temperature gradient in the boundary layer, Nu can also be thought of as a dimensionless temperature gradient. Making the energy balance dimensionless, and subsequent analysis, leads to the conclusion that Nu (and thus h) is a function of Re, Pr, and the geometry of the system.

Solving for Nu (the temperature gradient) is analytically impossible for all but the simplest of cases. One of these is laminar flow of a fluid over a flat plate. The solution to this situation is

$$Nu = 0.644 Re^{\frac{1}{2}} Pr^{\frac{1}{3}} \tag{4}$$

Though this solution is only applicable to a single geometry and limited range of conditions, it indicates the *form* of the solution for other cases. Over the years, researchers have obtained "solutions" to other geometries by doing experiments to calculate h for a variety of conditions and then fitting the data to an equation like similar in form to Equation 4. These "solutions" are called "correlations."

In this lab, you will do experiments to calculate h's for different geometries and conditions. Equation 1 will be the main workhorse to transform your experimental data into h's. Specifically, the experiments are designed to heat an object with a constant q and allow you to measure T_s and T_∞. But don't let this mathematical easiness mask the fundamental physics. Remember that h is related to the temperature gradient in the boundary layer and the Nu correlations are empirical relationships that are trying to describe this boundary layers. In other words, remember that anything that changes the boundary layer will change h. Thinking about boundary layers will also help you understand how to use the correlations. For example, remembering that the boundary layer is produced by the *fluid* will help you remember to use *fluid* properties when evaluating Nu correlations and not the properties of the solid phase over which the fluid is flowing. Using the incorrect properties is a common problem with students when they don't try to see past the numbers and remember the physics the numbers are trying to describe.

Prepare for a Safe Experiment

Task 1: Read and Commit to Follow the General Lab Safety Rules

1. No food or drink is allowed in the laboratory.
2. All personnel in the laboratory area are required to wear safety glasses, long pants, and covered shoes (no sandals or flip-flops).
3. Experimental work should be completed during the regular class periods. If additional time is needed in the laboratory, you must clear it with your instructor and make an appointment to use the laboratory with a TA. At least two students must be present during those additional hours. (No one is permitted to work in the lab alone).
4. At least two students from each team must be physically in the lab when running experiments. These students should be monitoring the experiment so that emergency procedures can be enacted if problems occur.
5. Students who operate *any* equipment in *any* unsafe manner or in a manner that damages the equipment or results in a user-preventable accident will incur a *significant* grade penalty. This includes not knowing how to run the equipment or shut it down as per instructions provided. *All team members are required to know how to safely run the equipment as instructed.*

Task 2: Review the Following Lab-specific Safety Statements and Procedures

A. This lab uses electrically heated objects. Do not touch the objects during operations.
B. This lab does not involve chemicals other than air.

Task 3: Learn about the Lab Equipment

Figure 1 is a picture of the experimental apparatus. It is from the manufacturer Gunt and is model WL 440. It consists of a metal base, a vertical piece of square duct, a fan, thermocouples, and an electrically heated object such as a flat plate or a cylinder. View ports are placed in the duct for observation.

Figure 1 Experimental apparatus for measuring convective heat transfer coefficients.

The duct sits on top of a grated foundation on the base. The fan sits on top of the duct and draws air through the grate in the bottom and ejects it out the top. The electrically heated object is suspended in the middle of the duct for experiments for forced convection. The object can be fixed to the outside of the unit for experiments for free convection.

The apparatus is controlled with software which will be running when you arrive at the lab. The software allows you to control the following.

1. Fan speed
2. Heat rate to the object (Q)

The interface displays the following during the experiment.

1. Heat rate (Q)
2. Air velocity (v)
3. Surface temperature of object (T_s)
4. Air temperature before the object (T_∞)
5. Air temperature after the object

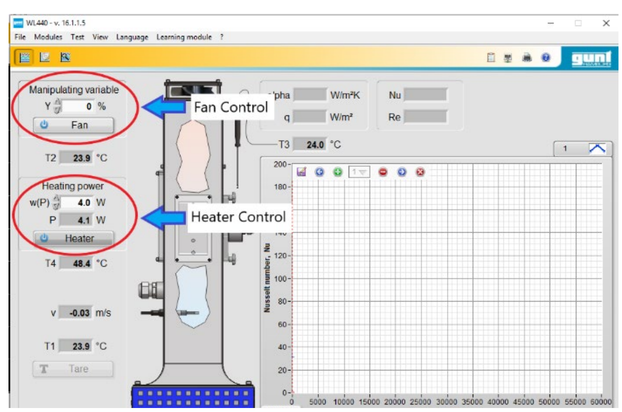


Figure 2 Control interface showing location of fan and heater controls

Four different units will be in operation and at steady state when you arrive at the lab. One will be set up to measure free convection for a flat plate. Another will be arranged to investigate forced convection for a flat plate. Two will be set up to measure forced convection over a cylinder—each at different fan speeds.

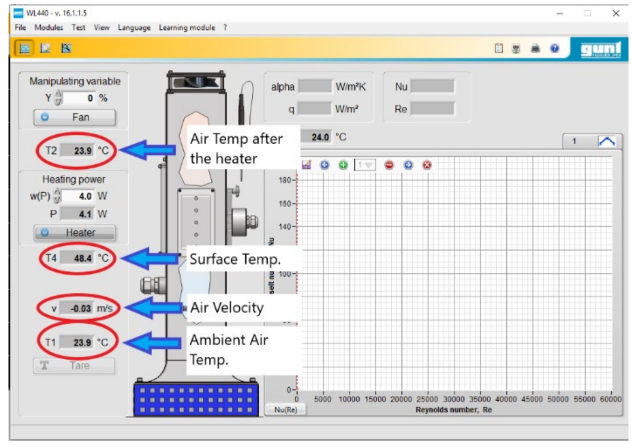


Figure 3 Where to read data on the control interface

Task 4: Know how to read steady state

The apparatus will have achieved steady state when the heater temperature ceases to change over time. The control interface has a built-in module that will display the change over time, called the chart recorder. As shown in Figure 5, you will be able to observe the steady state in the chart recorder as a flat region in the temperature over time. Once steady state behavior is observed, you will record the data and input a new set point. Data from the chart recorder may be output for analysis in Excel or saved as an image to include in your lab worksheet.

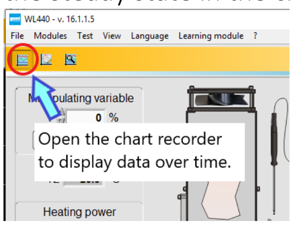
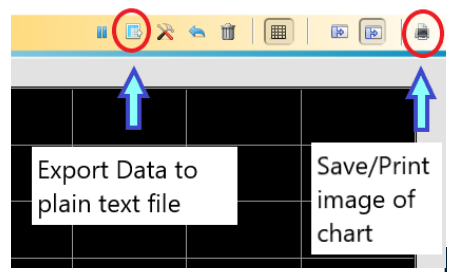


Figure 4 Where to open the chart recorder



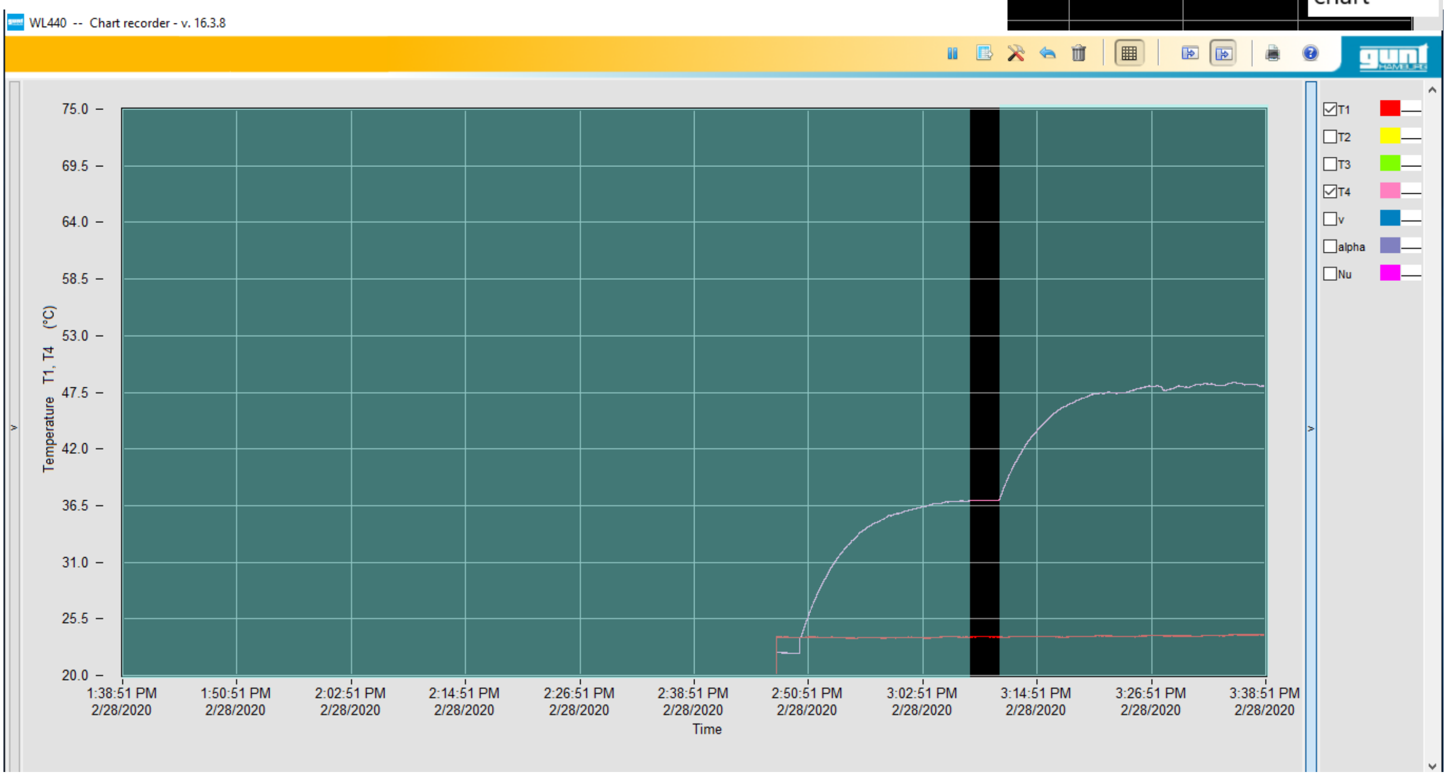


Figure 5 Chart recorder with steady state between two transitions highlighted