# HEAT EXCHANGER BASICS PRELAB

Ch En 385

## Lab Learning Objectives

1. Understand how heat exchangers facilitate the transfer of energy from one fluid stream to another.
2. Understand how flowrate affects the operating conditions of heat exchangers.
3. Identify the differences between flat plate and shell & tube heat exchangers.

## Introduction

Heat and cooling of process streams is ubiquitous in chemical (and mechanical) engineering. Moving (transferring) heat (energy)—whether to prevent runaway reactions, heat a building, cool a dairy refrigerator, etc.—occurs constantly in the world around, and engineers are tasked with doing so efficiently to ensure economic feasibility. Heating or cooling of process streams in a continuous process is done using a *heat exchanger*. These pieces of equipment are designed to bring two streams at different temperatures into close enough proximity to allow transfer of heat but do so without mixing the two streams. You will investigate two types of heat exchangers in this lab.

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

Conduction is the transfer of heat through a solid.[1] Convection is the transfer of heat by means of fluid (gas or liquid) flow. Both conduction and convection[2] occur when a temperature gradient (a change in temperature over some physical space) exists in a system. The larger the gradient, the larger the amount of heat (energy) moved. Heat exchangers bring a hot and cold fluid into close proximity to create a temperature gradient.

A plate heat exchanger, as shown in Figure 1, is a stack of metal plates. Each plate is separated from the next to create a series of small gaps. The "hot" and "cold" fluids flow in alternating gaps in the stack and exchange heat as they proceed along the length of the exchanger.

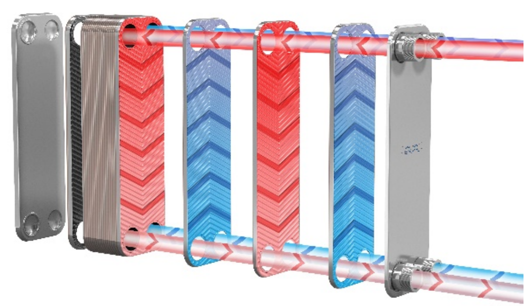

Figure 1 Function of plate heat exchanger. Courtesy of alfalaval.com.

A shell and tube heat exchanger, as shown in Figure 2, is composed of a bundle of tubes inside a hollow shell. One fluid flows *inside* the tubes and the other fluid flows across the *outside* of the tubes within the shell cavity. Heat is transferred from the hot to the cold fluid along the length of the exchanger.

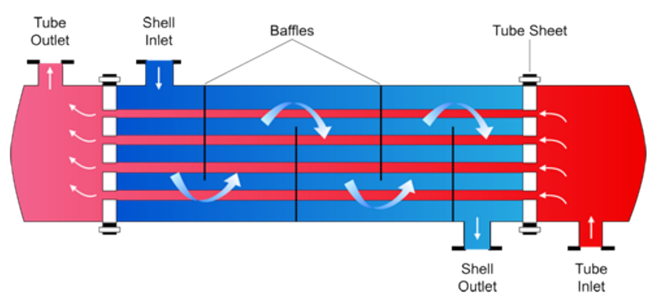


Figure 2 Function of a shell & tube heat exchanger. Courtesy of inciner8.com.

Thermodynamics (Ch En 273 and 373) explains that the total amount of heat transferred ($\dot{Q}$) to/from the fluid stream is related to the change in temperature experienced by the fluid. At steady state conditions, and assuming the fluid is incompressible, $\dot{Q}$ is given by

$$\dot{Q} = \dot{m} \int_{T_{in}}^{T_{out}} C_p dT$$

[1] Conduction can occur in liquids and gases under certain conditions, but these situations are rare in engineering practice.
[2] Radiative heat transfer can also occur, but such is not examined in this lab.

where $\dot{m}$ is the mass flowrate of the fluid, $C_p$ is the heat capacity of the fluid (the function for which can be obtained from DIPPR), $T_{in}$ is the temperature of the stream entering the exchanger and $T_{out}$ is the temperature of the stream exiting the exchanger.

Thermodynamics explains *how much* heat needs to be transferred to cause a given change in temperature, but it doesn't specify how this heat transfer is done. For example, instead of using a heat exchanger, you could put heat lamps on your fluid to increase the temperature. Designing the apparatus to induce the heat transfer is the subject of Ch En 376 Heat and Mass Transfer. The theory and math for this is beyond the scope of this lab and will be handled in a later one. For now, it is sufficient to know that surface area, flowrate, and geometry all affect heat transfer. You examine how in this lab.

Finally, you should remember that heat exchangers can be set up in *countercurrent flow* or *parallel (cocurrent) flow*. As depicted in Figure 3, in countercurrent flow, the inlets of the hot and cold streams are on *opposite* sides. In *parallel/cocurrent* flow, the inlets enter the unit on the same side. (Can you tell which configuration is shown in Figure 2?)

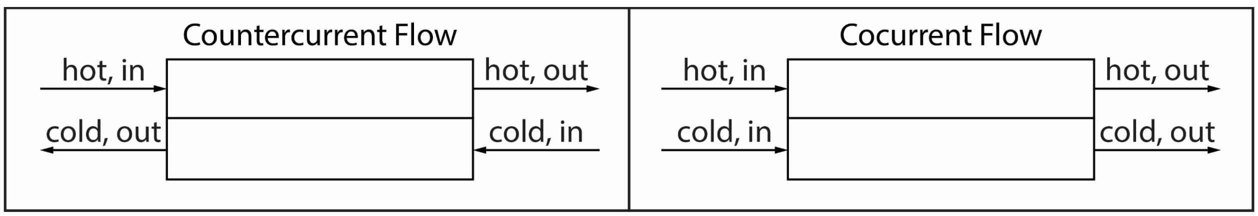


*Figure 3 Counter vs cocurrent heat exchanger flow.*

# Prepare for a Safe Experiment (Do This Before the Lab)

## Task 1: Read and Commit to Follow the General Lab Safety Rules (2 Minutes)

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: Become Informed about the Chemicals (10 Minutes)

One stream of the heat exchanger is *industrial water*. It is made by mixing the hot and cold tap water. It is labeled *industrial* to emphasize that you shouldn't drink it because it could be contaminated by equipment in the lab. (The CDC defines industrial water as water used in a process for creating products or cooling equipment. Industrial water in our lab is very clean, but such at a chemical plant may not be.)

The other stream in the lab uses cooling water from the central campus heating and cooling plant. It is water treated with a very small amount of phenolphthalein and PECO 8410. PECO 8410 is the brand name for a concentrated solution of sodium nitrate, sodium hydroxide, and sodium borate pentahydrate and is used to raise the pH to prevent corrosion and mineral deposits. The phenolphthalein is a pH indicator to ensure the pH remains sufficiently high and as a safety measure to alert the public to not drink the cooling water should it leak.

According to its SDS (available on Learning Suite), PECO 8410 is a hazardous substance. It is a strong oxidizer and can be absorbed through the skin. The NFPA Ratings are: Health – 2, Flammability – 0, Reactivity – 1, Other – NA. Each of these facts isfor PECO 8410 in its concentrated form; however, the heating plant dilutes this to 800-1200 ppm (0.08 - 0.12%), so the risk to health is significantly reduced. Moreover, during normal operation, students will not come into contact with this chemical as the TA handle moving the connections on the apparatus. Immediately wash any skin that contacts the chilled water with soap and water.

According to its SDS, pure phenolphthalein is flammable, is an irritant, and is carcinogenic. However, when used as an indicator at the concentration present in the chilled water line, the NFPA scale reports much lower hazards.

*Do the following.*

A. Download the SDS for phenolphthalein (your own search) and PECO 8410 (Learning Suite).
B. Review the SDS of each compound and identify potential hazards. Pay attention to the following:
    - Hazard Identification.
    - Precautionary Statements.
    - NFPA/HMIS Ratings.
    - First Aid Measures.
C. Commit to handle the compounds safely.

## Task 3: Review the Following Lab-specific Safety Statements and Procedures

A. Wear gloves if you are cleaning up spilled chilled water.
B. If the chilled water mixture spills on your skin, wash the affected area with soap and water.
C. Do not drink or eat the industrial water or chilled water mixture.
D. You may wear a lab coat to prevent staining of clothing by phenolphthalein.
E. Use caution with the hot water to avoid burns.

## Task 4: Learn about the Lab Equipment

Figure 3 is a picture of the apparatus. Notice the following.

1. Three rotameters are used to control the flow and are labelled: *Hot Water*, *Cold Water*, and *Chilled Water*.
2. The *Hot Water* and *Cold Water* combine before entering an exchanger in a Y-shaped connector. This gives you control over the *hot inlet* temperature to the exchanger.
3. The *Chilled Water* is supplied by the Central Heat Plant on campus. (This is the same water used to air condition the buildings in the summer.)
    a. It runs on a closed loop and returns to the heating plant.
    b. It is pink in color due to the phenolphthalein.
4. The hot-side outlet exits to a floor drain.
5. The inlets (*hot* and *cold*) to each heat exchanger are on the side closest to the rotameters (in the foreground of Figure 1.
6. The outlets (*hot* and *cold*) of each heat exchanger on the side farthest from the rotameter (in the background of Figure 1.
7. The *hot* and *cold* sides of the exchangers have different connections to ensure they cannot be connected incorrectly.
8. The Temperature Readings module displays the temperature of the streams in the system.
    a. T1: Hot-side Inlet Stream Temperature
    b. T2: Hot-side Outlet Stream Temperature

c. T3: Cold-side Inlet Stream Temperature
d. T4: Cold-side Outlet Stream Temperature

9. The connections have brass labels identifying each temperature (T1-T4).
10. Three heat exchangers are available.
    a. A “small” brazed-plate heat exchanger with 0.12 $m^2$ heat transfer surface area.
    b. A “large” brazed-plate heat exchanger with 0.24 $m^2$ heat transfer surface area.
    c. A shell & tube heat exchanger with 0.12 $m^2$ heat transfer surface area on the shell side.

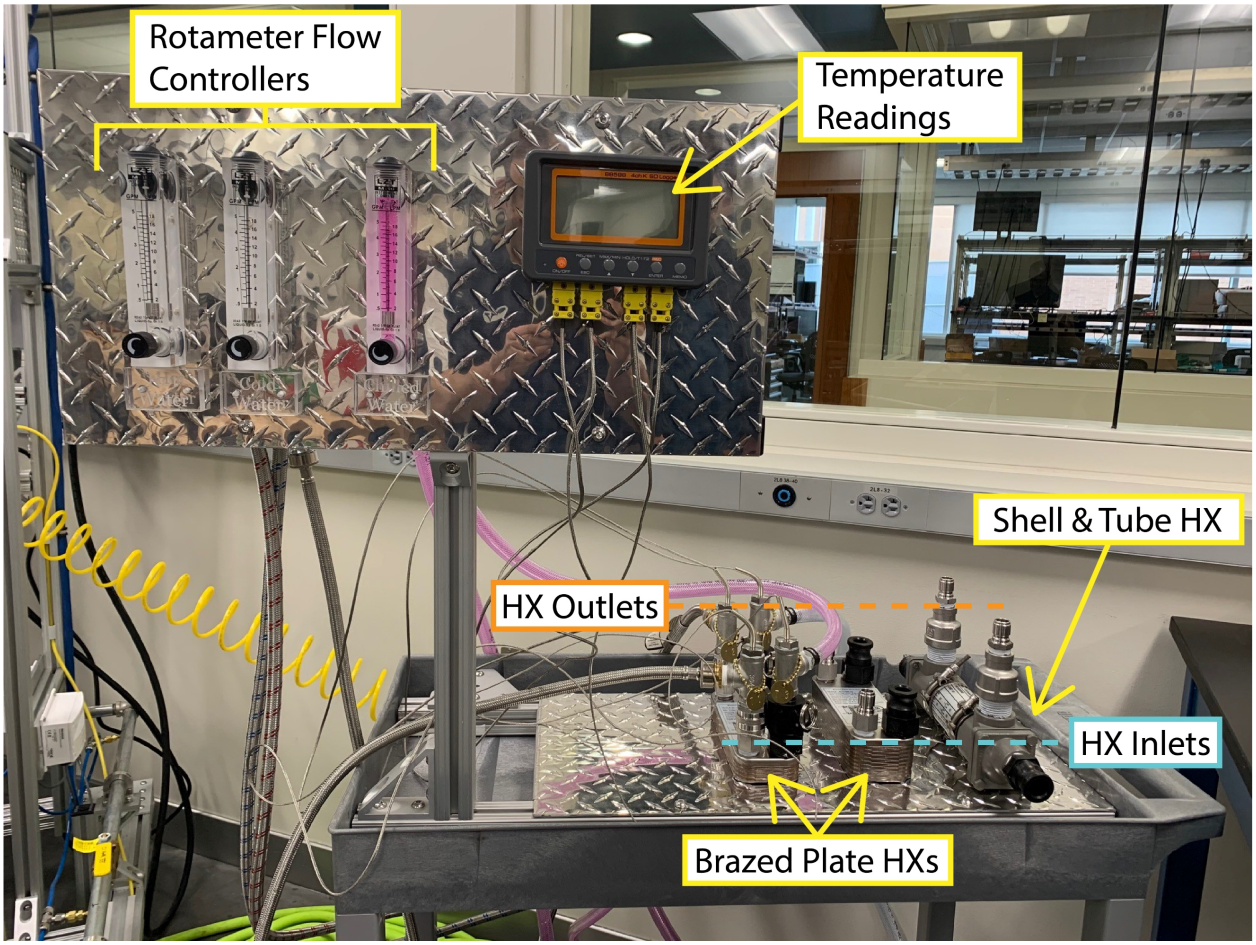


*Figure 4 Picture of experimental apparatus.*

The flowrate is measured using a rotameter. These are devices calibrate the position of a float within the flow stream to the flowrate. Gravity forces the float down while drag from the fluid forces it up. Many different shapes and types of floats are used, and a few are depicted in Figure 5. Notice that the reading on each type of float is different. The documentation for a specific model will indicate where to read the measurement. For convenience, the manufacturer of the rotameters used in the apparatus for this experiment printed the read location on the meter itself. If you inspect the flowmeters, you will see “READ TOP OF FLOAT” printed above the control knob. For accurate reading, make sure to look straight so the top of the float appears completely flat.

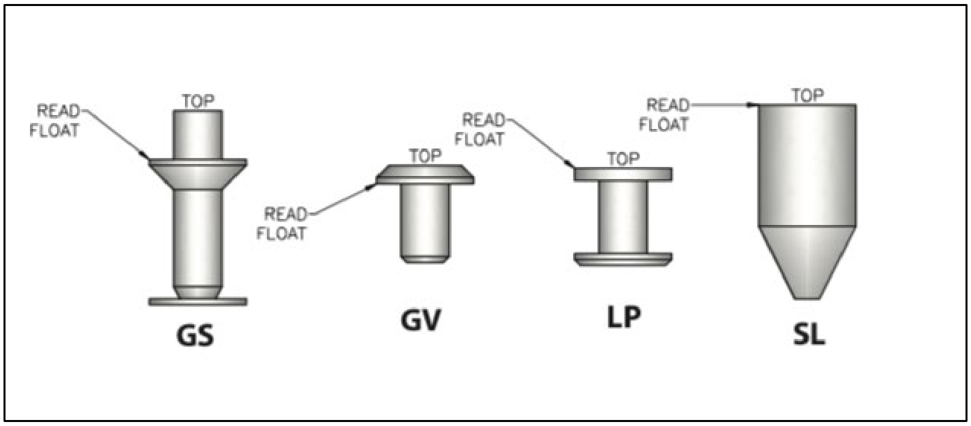


*Figure 5 Different types of floats and where to read each.*