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Work In Progress: Enhancing Thermal and Fluids Laboratory Learning through the Integration of the Heat Exchanger Module (HEM)

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Abstract

This paper explores the integration of active learning in engineering education through a novel Heat Exchanger Module (HEM). The HEM enables students to experiment hands-on with heat transfer concepts using varying parameters and materials. The design incorporates versatility in flow direction and speed, inner tube material, and hot side temperature. The recent study has recently shown that the intervention improves students' understanding of the effect of the thermal conductivity of the heat exchanger separator material on heat transfer and the difference between internal energy and enthalpy.

Introduction

Active learning practices have become normative in modern engineering education. It has been found that the performance of recent engineering graduates can be significantly enhanced when traditional instructor-centered teaching and learning methods are supplemented through the use of these active learning methods as these graduates need to be able to handle more complex problems [1]. Accreditation boards, such as ABET, now recommend active learning components in engineering curricula [2]. Incorporating active learning, like discovery methods, have be proven to enhance students' performance in concept tests more than any other form of instruction [3]. This has encouraged further creative hands-on active learning solutions for the field of engineering education.

Hands-on learning modules have been developed and have been shown to engage interest, teach concepts, and improve knowledge retention for students [4, 5]. These modules make concrete what may have been abstract concepts, allowing students to connect theory with experience. This paper describes the concept, design, implementation and results of a novel Heat Exchanger Module (HEM) used in a junior-level thermal/fluids laboratory course.

Concept

The HEM is designed to enable students to experiment with, and to validate heat transfer concepts in a portable and cost-effective set of shell and tube heat exchangers. Students manipulate the controls and measure the outputs values provided by the module. The controllable input parameters include the operating temperature of the hot fluid, the mass flowrates of both shell and tube fluids, the direction of the tube fluid, and the material composition of the tube. Measurable values, specifically the temperature at the inlet and outlet of the shell and tube, allow students to analyze the change in temperature across the heat exchanger for both the shell and tube fluids. Several types of experiments can be done by the students, allowing for and encouraging curiosity, a KEEN Foundation pillar for entrepreneurial minded learning in engineering education [6].

Similar work has been done at Washington State University (WSU), with their Low-Cost Desktop Learning Module's (DLM) implementation in their Fluid Mechanics and Heat Transfer course [5] and we sought to achieve similar results using the HEM. In the WSU DLM, it was found that students using their cooperative, hands-on, active, problem-based learning approach were more confident and competent than their counterparts who did not interact with the DLM.

Two key differences between this work and the DLM are the ability to test and measure the heat exchange process across different HX tube materials and the ability to interface with the Chemical Engineering Education Reactor (CEER) that we have been developing [7]. By easily testing different materials, students are able to examine the effect of material on the conductive heat transfer term in a heat exchanger model. By allowing the fluid output to then be used in an external system like the CEER reactor system, the HEM will be able to deliver reactive fluids at a desired temperature to enable further work, such as examining the effect of temperature on reaction kinetics. This will also enable students to experience the need for temperature control when integrating a process.

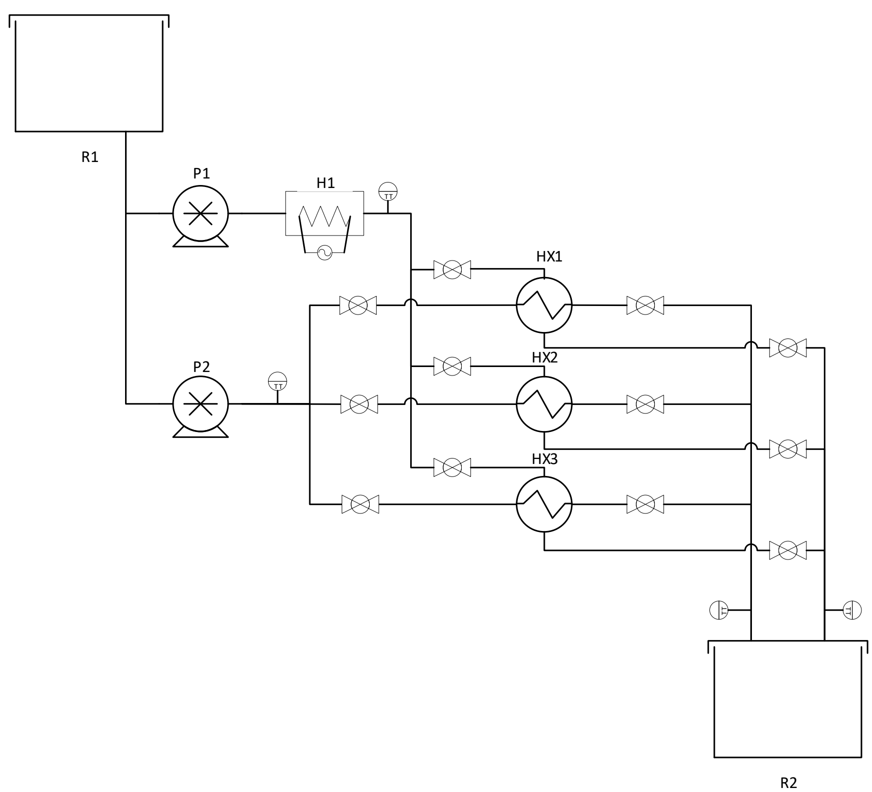

Figure 1. Process Flow Diagram of Heat Exchanger Module (HEM)

Figure 1 shows the Process Flow Diagram of the HEM, complete with fluid source (R1), fluid receptacle (R2), heater (H1), control valves, heat exchangers (HX1-HX3), and pumps (P1 and P2). The fluid flowing through the shell of the HXs is the hot fluid and the fluid flowing through the tube is the working fluid. The tube of each HX is composed of a different material, copper, stainless steel, and plastic. Only one HX will operate at a time, controlled by the shutting on and off the valves for each test. The temperature of the fluid warmed by H1 was controlled by a PID Temperature controller, reading the temperature from the thermocouple directly following the heater. In the case of this embodiment of the experiment, all the fluid is sourced from R1, but if desired, these can be different fluids based on the desired learning outcomes (e.g., examine the effect of heat capacity or preheat the fluid for a CEER experiment).

Design

Figure 2, Table 1, and Table 2 show the build, list of components, and operational ranges of the HEM laboratory intervention. The main thing to highlight here is the three different materials used in the HXs: plastic, copper, and stainless steel from top to bottom. The copper HX configuration is currently setup as can be seen with the moveable thermocouples and inlet and outlet tubes connected to the inlet and outlet of that copper tubing. As seen in Table 2, students have the ability to vary the set temperature for the PID Temperature controller and the volumetric flowrates of the pumps.

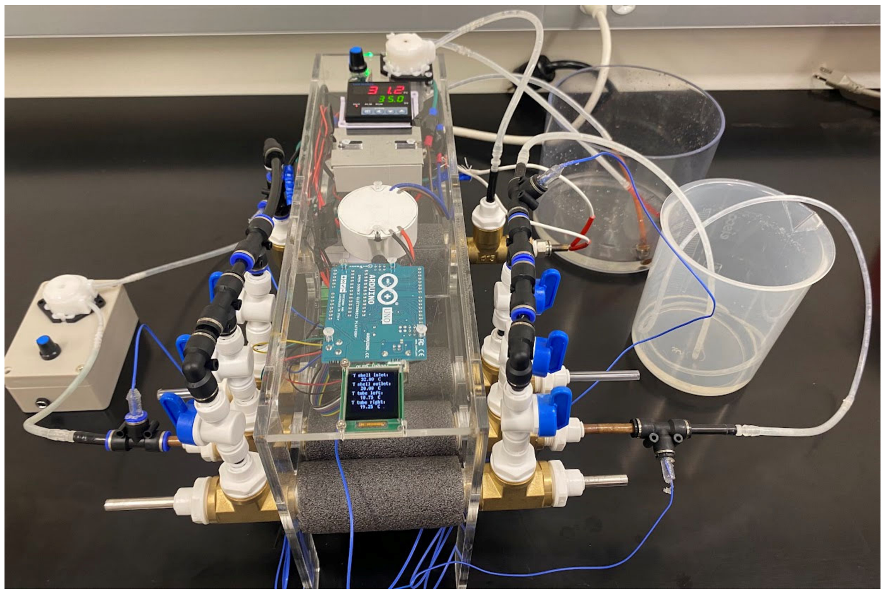

Figure 2. HEM Build used in the Thermal/Fluids Lab.

Table 1. List of components in the HEM

	Component	Description
Material	Module Structure	Laser-cut 1/4-inch Acrylic Pieces
	Shells of HXs and Heater	1/2-inch copper tubing with brass elbow and T-fittings
	Tubes of HXs	Plastic (Acrylic), Copper, and Stainless Steel 1/4-inch Tubes
	Valves	Plastic 1/4-inch to 1/4-inch shut-off valves
Electrical	Heater Controller	PID Temperature Controller with a Solid-State Relay
	Heater	110V 150W 6mm x 10mm Tubular Cartridge Heater
	Temperature Sensor	K-type Thermocouples
	Temperature Measurement System	MAX6675 Thermocouple Modules connected to Arduino Uno
	Pumps	12V DC Motors with Peristaltic Pump Attachments
	Pump Motor Controller	PWM DC Motor Speed Controllers

Table 2. Operations and ranges of controllable components of the HEM

Operation	Range
Influent Shell Fluid Temperature ($T_{Shell,in}$)	23°C - 50°C
Volumetric Flowrate ($\dot{V}$)	10 sccm - 100 sccm

Figure 3 shows temperature data obtained from the HEM operation. These measurements capture the temperatures at different points within the heat exchanger system across varying materials (copper, stainless steel, plastic) and are indicated on Table 3. Specifically, inlet (solid line) and outlet (dashed line) temperatures are shown in red for the shell side fluid and blue for the tube side fluid. This allows for observation and calculation of the important temperature changes across the shell and the tube, ΔT_{Shell} and ΔT_{Tube} respectively. Students can then easily notice the large oscillation in temperature for the shell fluid, given that the temperature is set by the cartridge heater controlled by the PID controller. For example, compare the ΔT_{Shell} and ΔT_{Tube} under the copper and plastic configurations. Copper, with the highest thermal conductivity of the 3 materials (k=400 W/(m K)), results in more effective transferring of heat, hence the greater ΔT_{Shell} and ΔT_{Tube}. Conversely, the plastic configuration, given its lower thermal conductivity (k=0.2 W/(m K)), corresponds to a smaller ΔT_{Shell} and ΔT_{Tube}, aligning with expected material properties.

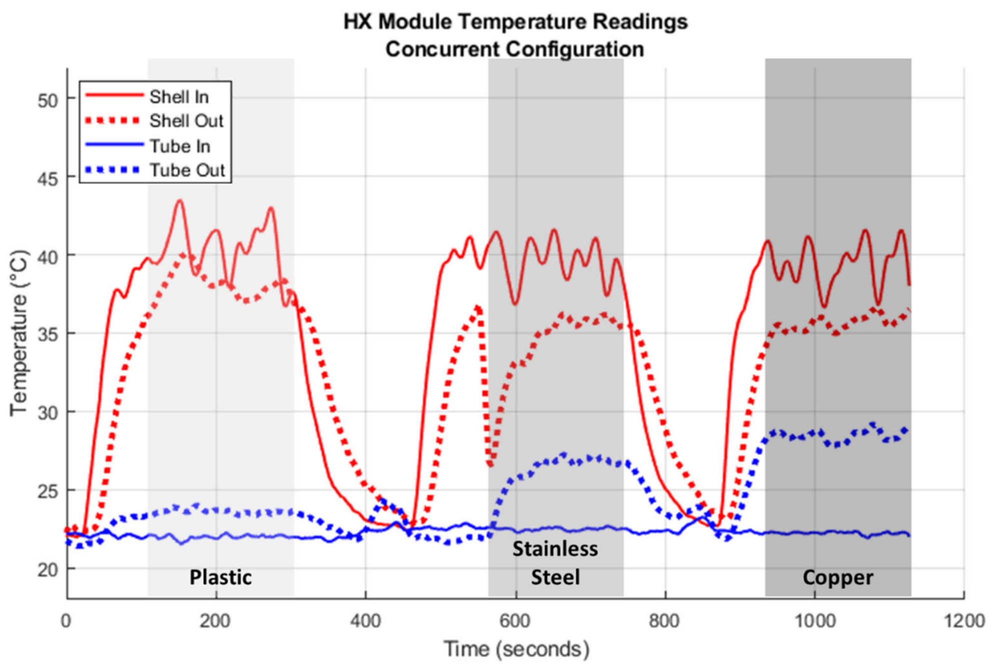

Figure 3. Sample of HEM temperature readings for each of the material options.

Table 3. Table of Measurements and properties in the system. Measures are from experiment shown in Figure 3 and material properties are from [8].

Tube Material	$k\ \left[\frac{W}{m\ K}\right]$	Shell Temperatures [°C]			Tube Temperatures [°C]		
		T_{in}	T_{out}	ΔT_{Shell}	T_{in}	T_{out}	ΔT_{Tube}
Plastic (Acrylic)	0.2	40	37	-3	22	24	2
Stainless Steel	14.4	40	36	-4	22	27	5
Copper	400	40	34	-4	22	29	7

Assessment

The HEM was implemented in a ME 3145 Thermal/Fluids Laboratory 75-minute class. The class had 14 students, with Juniors and Seniors, with all students having taken

Thermodynamics and some having taken Heat Transfer. The students read and followed the procedures shown in Appendix B.

The method by which the intervention was evaluated was a pre/post heat concept inventory, shown in Appendix A. The concept inventory comprised of 16 questions from the AIChE Concept Warehouse [9] with a follow-up companion question asking for the student's confidence in the answer they gave. The intervention took place during one lab session, with a pre-read before the pre-test and a post-analysis before the post-test.

Results and Discussion

Figure 4 shows a comparison of correct answers given with high or moderate confidence. As shown, most questions had minimal changes, with ±1 confident correct response change. The questions that indicate a significant increase in competence and confidence, highlighted in the figure, center around the concepts of thermal coefficients of materials and the difference between internal energy and enthalpy.

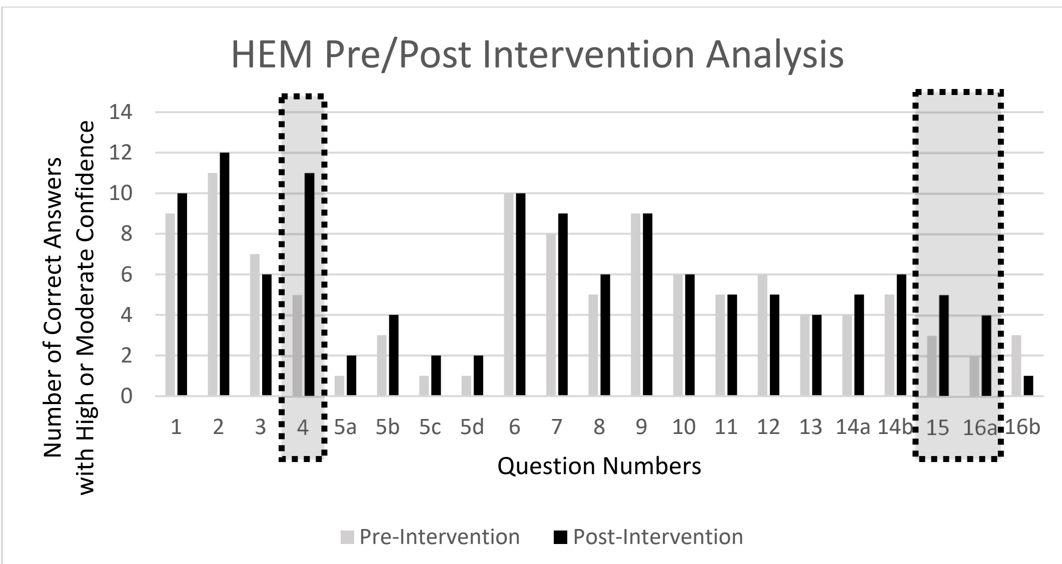

Figure 4. Combined quantitative and qualitative data from the pre- and post-intervention assessments, with Questions 4, 15, and 16a highlighted as significant.

In regard to thermal coefficients, this positive outcome can be attributed to the HEM's three different HXs with different inner tube materials. Figure 3 clearly shows how the material property affects the overall change in temperature, allowing students to observe those effects and connect the effect of the material property on the quantity of heat transferred. In addition, by enabling students to measure flow rates and temperatures for individual materials, calculate the heat exchange effectiveness, and compare their results with those of their peers, the module effectively conveyed the substantial impact of material properties on heat transfer dynamics.

Future Work

The positive, albeit limited, effects of the HEM intervention on some key concept areas encourage us to continue to develop activities to improve teaching activities employing the

HEM. Specifically, we intend develop activities to support teaching of heat and mass balances, and possibly other fields like fluid dynamics and the inclusion of Prandtl numbers in the description of heat exchanger models.

Some suggested improvements to the module are to incorporate the ability to evaluate the efficiency of the cartridge heater and incorporate two different fluids with different densities and specific heats. By incorporating measurements of the electrical power consumed by the heater and the heat transferred into the influent shell fluid, students will be able to analyze another energy balance system. By incorporating the use of 2 discrete fluids, like water and ethanol or propylene glycol, students will be able to analyze how the mass and energy balances are interacting with one another. In summary, we are encouraged to make these improvements and continue to implement this module in a variety of classes.

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Appendix A – HEM Pre- Post-Intervention Assessment

1. Heat can best be described as:
   a. Energy flow from one body to another.
   b. Friction from particles rubbing together.
   c. A reading on a thermometer.
   d. The absence of cold.
   e. A substance that makes objects feel warm.

   Indicate how confident you are in your responses for the previous question.
   a. Total Guess
   b. Low
   c. Moderate
   d. High

2. A block of copper is heated to 100°C. It is then left to cool down. Which of the following statements best describes the process of cooling down?
   a. The particles rubbing against each other over time will slow down creating less heat.
   b. The particles do not have room to vibrate in the solid and will slow down after the heating stops.
   c. There is a transfer of heat from the block to the surroundings.
   d. There is a transfer of temperature from the block to the surroundings.
   e. There is a transfer of cold from the surroundings to the block.

   Indicate how confident you are in your responses for the previous question.
   a. Total Guess
   b. Low
   c. Moderate
   d. High

3. They will freeze at the same time because they are in the same freezer at the same temperature.
   a. The plastic tray because it has a higher specific heat and attracts heat away from the water.
   b. The plastic tray because it insulates the cold into the water.
   c. The metal tray because it conducts cold quickly into the water.
   d. The metal tray because it conducts heat quickly away from the water.

   Indicate how confident you are in your responses for the previous question.
   a. Total Guess
   b. Low
   c. Moderate
   d. High

4. A bowl of soup and a metal spoon were at 70°C. Both cooled down to room temperature (25°C) Do they have the same heat change?
   a. Yes, heat and temperature are the same thing.
   b. Yes, they have the same heat change.
   c. No, they have different heat changes, but the same temperature change.
   d. No, they have different heat changes because heat easily leaves the spoon.
   e. No, they have different heat changes because they attract heat differently.

Indicate how confident you are in your responses for the previous question.
   a. Total Guess
   b. Low
   c. Moderate
   d. High

5a. You would like to melt ice which is at 0°C using hot blocks of metal as an energy source. One option is to use one metal block at a temperature of 200°C and a second option is to use two metal blocks each at a temperature of 100°C. Each individual metal block is made from the same material and has the same mass and surface area. Assume that the heat capacity is not a function of temperature.

If the blocks are placed in identical insulated containers filled with ice water, which option will ultimately melt more ice?
   a. Either Option with melt the same amount of ice
   b. The two 100°C blocks
   c. The one 200°C block

Indicate how confident you are in your responses for the previous question.
   a. Total Guess
   b. Low
   c. Moderate
   d. High

5b. Because…
   a. 2 blocks have twice as much surface area as 1 block so the energy transfer rate will be higher when more blocks are used
   b. Using a higher temperature block will melt the ice faster because the larger temperature difference will increase the rate of energy transfer
   c. The amount of energy transferred is proportional to the mass of blocks and the change in block temperature during the process
   d. The temperature of the hotter block will decrease faster as energy is transferred to the ice water

Indicate how confident you are in your responses for the previous question.
   a. Total Guess
   b. Low
   c. Moderate
   d. High

5c. Which option will melt the ice more quickly?

a. Either Option with melt ice at the same rate
b. The two 100°C blocks
c. The one 200°C block

Indicate how confident you are in your responses for the previous question.

a. Total Guess
b. Low
c. Moderate
d. High

5d. Because…

a. 2 blocks have twice as much surface area as 1 block so the energy transfer rate will be higher when more blocks are used
b. The higher temperature block creates a larger temperature gradient which will increase the rate of energy transfer
c. The temperature of the hotter block will decrease faster as energy is transferred to the ice water
d. The rate of heat transfer is proportional to the surface area of blocks and the temperature difference between the blocks and ice

Indicate how confident you are in your responses for the previous question.

a. Total Guess
b. Low
c. Moderate
d. High

6. A bar of copper is heated to 30°C and then placed into a Styrofoam cup of water. Thermal equilibrium between the copper bar and water is reached at 40°C. What was the temperature of the water before the copper bar was dropped into it? Why?

a. Less than 40°C because copper can hold more heat than water.
b. Less than 40°C because the copper bar heated the water.
c. Greater than 40°C because water can hold more heat than copper.
d. Greater than 40°C because the water heated the copper bar.
e. Greater than 40°C because the water and copper bar would cool down on their own without interacting with each other or anything else.

Indicate how confident you are in your responses for the previous question.

a. Total Guess
b. Low
c. Moderate
d. High

7. An engineering student walking barefoot (without shoes or socks) from a tile floor onto a carpeted floor notices that the tile feels cooler than the carpet.

   Which of the following explanations seems like the most plausible way to explain this observation?
   a. The carpet has a slightly higher temperature because air trapped in the carpet retains energy from the room better
   b. The rate of heat transfer into the room by convection (air movement) is different for tile and carpet surfaces
   c. The carpet has a slightly higher temperature because air trapped in the carpet slows down the rate of energy transfer through the carpet in the floor
   d. The tile conducts energy better than the carpet, so energy moves away from the student's foot faster on tile than carpet

Indicate how confident you are in your responses for the previous question.
a. Total Guess
b. Low
c. Moderate
d. High

8. Temperature is most accurately a measure of:
   a. The average kinetic energy of individual molecules in a substance
   b. The total kinetic energy of all molecules in a substance
   c. The average internal energy of individual molecules in a substance
   d. The total internal energy of all molecules in a substance
   e. The total energy of all molecules in a substance

Indicate how confident you are in your responses for the previous question.
a. Total Guess
b. Low
c. Moderate
d. High

9. If 25°C air feels warm on our skin, what is the *primary* reason that 25°C water feels cool when we swim in it?
   a. When water contacts human skin, it vaporizes at the surface, which causes the water to feel cooler than air
   b. Water holds energy better than air does, so it stays colder
   c. Water opens pores in human skin better than air does, so the heat transfer area is larger with water
   d. The heat transfer rate to water is faster than the rate to air because of differences in fluid physical properties

Indicate how confident you are in your responses for the previous question.
a. Total Guess
b. Low
c. Moderate
d. High

10. Two identical closed beakers contain equal masses of liquid at a temperature of 20°C as shown below. One beaker is filled with water and the other beaker is filled with ethanol (ethyl alcohol). The temperature of each liquid is increased from 20°C to 40°C using identical heaters immersed in the liquids. Each heater is set to the same power setting.

    It takes 2 minutes for the ethanol temperature to each 40°C and 3 minutes for the water to reach 40°C.

    Ignoring evaporation losses, to which liquid was more energy transferred during the heating process?
    a. Water because it is heated longer
    b. Alcohol because it heats up faster (temperature rises faster)
    c. Both liquids received the same amount of energy because they started at the same initial temperature and ended at the same final temperature
    d. Can't determine from the information given because heat transfer coefficients from the water and alcohol beaker surfaces are needed
    e. Can't determine from the information given because heat capacities of water and ethanol are needed

Indicate how confident you are in your responses for the previous question.
a. Total Guess
b. Low
c. Moderate
d. High

11. Rubbing alcohol feels cool when placed on your skin. This is primarily because:
    a. Alcohol remains cooler than room temperature even when stored for a long time
    b. Alcohol deadens the nerves in your skin
    c. Alcohol evaporates quickly
    d. Alcohol has a higher heat capacity than the surrounding air

Indicate how confident you are in your responses for the previous question.
a. Total Guess
b. Low
c. Moderate
d. High

12. A large bucket of boiling water poured over a deep layer of snow will melt more of the snow than a small bucket of boiling water poured on the same snow layer. This is *primarily* because:
    a. It covers more of the snow
    b. It stays hot longer
    c. It has more energy
    d. It stays in contact with the snow longer

Indicate how confident you are in your responses for the previous question.
a. Total Guess
b. Low
c. Moderate
d. High

13. Two thin, identical pizzas initially at room temperature are placed in separate pizza ovens, one for 5 minutes at 700°F and the other for 10 minutes at 350°F. If both pizzas are cooked to the precisely same degree of doneness when they are removed, to which pizza was more energy added?
   a. Not enough information provided
   b. The pizza cooked in the 700°F oven for 5 minutes had more energy transferred to it
   c. The pizza cooked in the 350°F oven for 10 minutes had more energy transferred to it
   d. Both pizzas had the same amount of energy

Indicate how confident you are in your responses for the previous question.
   a. Total Guess
   b. Low
   c. Moderate
   d. High

14a. Two copper cylinders, each at 75°C, are allowed to cool in a room where the air temperature is 25°C. As shown, cylinder 1 is twice as tall as cylinder 2 but both cylinders are the same diameter. The top and bottom of each cylinder are perfectly insulated so the only heat loss is through the sides of the cylinders. Laboratory observations show that the temperature for each cylinder falls at the same rate.

Which cylinder *loses energy* at a faster rate?
   a. Both cylinders lose energy at the same rate
   b. Cylinder 1
   c. Cylinder 2
   d. Not enough information given

Indicate how confident you are in your responses for the previous question.
   a. Total Guess
   b. Low
   c. Moderate
   d. High

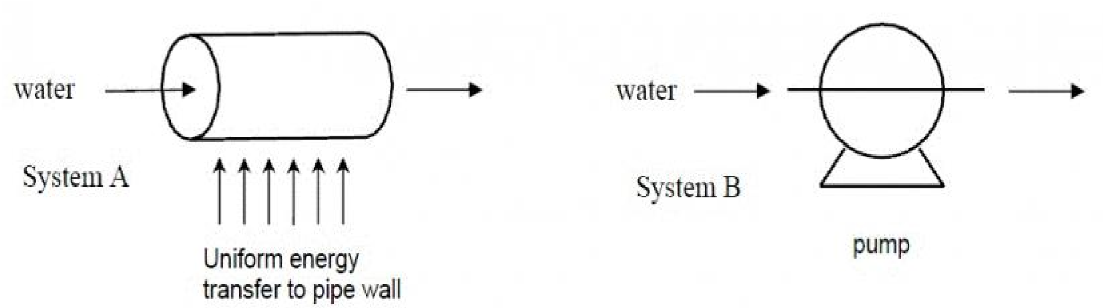
14b. Because…
   a. The surface area to volume ratio is the same for each cylinder
   b. The rate of energy loss equals the rate of change of temperature with time
   c. Energy loss is proportional to surface area
   d. A smaller area has a higher flux per area

Indicate how confident you are in your responses for the previous question.
   a. Total Guess
   b. Low
   c. Moderate
   d. High

15. You wish to cool a stream of mineral oil from 100°C to 90°C in a heat exchanger using identical volumetric flow rates of either 10°C air or 20°C water. Assume that the volumetric flow rates of both water and air are great enough that neither the water nor air temperature increases significantly through the process. Which stream is likely to transfer heat from the process stream more quickly?
    a. Water, primarily because it has a higher heat transfer coefficient
    b. Water, primarily because it has a higher heat capacity
    c. Air, primarily because it is colder
    d. Water, primarily because it will provide evaporative cooling
    e. Either will cool the oil equally quickly because of the high flow rates used

Indicate how confident you are in your responses for the previous question.

a. Total Guess
b. Low
c. Moderate
d. High



System A: temperature increases
pressure is constant (ignore very small frictional pressure drop in the pipe)

System B: pressure increases
temperature is constant (ignore very small frictional heating in the pump)

16a. As shown below, water flows steadily through two systems. In system A, thermal energy is transferred to the water through the pipe wall. In system B, a pump is installed which increases the pressure of the water.

Which of the following statements correctly describes how the pipe and pump change the enthalpy and internal energy of the flowing water?

a. systems A and B both increase enthalpy and internal energy
b. system A increases internal energy but not enthalpy; system B increases enthalpy but not internal energy
c. system A increases both enthalpy and internal energy; system B increases enthalpy but not internal energy
d. system A increases both enthalpy and internal energy; system B doesn't increase either internal energy or enthalpy

Indicate how confident you are in your responses for the previous question.

a. Total Guess
b. Low
c. Moderate
d. High

16b. because:

a. internal energy and enthalpy are closely related so that if one increases, so does the other
b. internal energy is a function of both temperature and pressure for liquids
c. enthalpy can increase with an increase in either temperature or pressure
d. no energy change occurs if the temperature remains constant

Indicate how confident you are in your responses for the previous question.

a. Total Guess
b. Low
c. Moderate
d. High

Appendix B – HEM Laboratory Exercise

Background

A heat exchanger is a device that is used to transfer heat between two nonmixing fluid steams. Heat exchangers are used in a variety of industries, including heating, ventilation, and air conditioning (HVAC), power generation, transportation, and chemical processing. One of the most common heat exchangers is known as a "shell and tube" heat exchanger, which can be described as an inner cylinder positioned inside an outer cylinder. In this lab, the "cold" stream flows through the outer annulus while the "hot" stream flows through the inner cylinder. Heat is exchanged between the hot and cold streams via thermal conduction across the walls of the inner cylinder. The rate heat lost, and gained, respectively, by the hot and cold streams can be analyzed using the 1st Law of Thermodynamics for steady state systems:

$$\dot{Q} = \dot{m}(h_{out} - h_{in})$$

Because both fluid streams are subcooled liquids, it can be assumed that

$$h_{out} - h_{in} = c(T_{out} - T_{in})$$

where c is the specific heat of water.

Objective

The purpose of this lab is to build an understanding of how heat exchangers work and how to measure the performance of a liquid-liquid heat exchanger. In order to do so, we will perform flowrate and temperature measurements on a tabletop heat exchanger testbench. Within the testbench, the "cold" water flow is pumped into the heat exchanger from a room-temperature reservoir. The "hot" water stream, meanwhile, is pumped from a reservoir into an inline heater, and then into the heat exchanger. We will investigate the effect of inner cylinder material (i.e., thermal conductivity) on heat exchanger performance by routing the streams through heat exchangers with varying inner cylinder material.

For each test, we will measure the volumetric flowrates of both the cold and hot streams as well as the inlet and exit temperatures of both streams. We will use this information to determine the rate of heat exchange between the streams. We will also calculate the effectiveness of the heat exchanger, which is defined as the ratio between the heat transfer rate and the maximum possible heat transfer rate.

Equipment and Materials

The equipment to be used will consist of:

- A heat exchanger testbench which consists of:
  - Reservoirs for the cold and hot fluid streams,
  - Two peristaltic pumps (one for each stream),
  - An inline heater,
  - Three shell-in-tube heat exchangers,

    - Four Type T thermocouples with a data acquisition board to measure the inlet and outlet temperature of both fluid streams,
- Graduated cylinders to measure volumetric flowrate via timed capture,

The only material used in this experiment will be tap water.

In-Lab Procedure

Each lab group will be tasked with collecting flowrate and temperature data for a single heat exchanger configuration. After all data is collected, we will share all of the collected data across all groups for subsequent analysis. Use the following procedure:

1. Wait until the heat exchanger has been appropriately configured and all temperatures have reached stable values.
2. Take five readings of the inlet and outlet temperatures of the hot and cold water streams.
3. Use the timed capture approach to measure the volumetric flowrate of the hot water stream:
    a. Start a stopwatch, and then direct the flow output to the graduated cylinder.
    b. Allow the water to fill a measurable volume, and record both the volume and fill time.
4. Repeat the timed capture approach to measure the volumetric flowrate of the cold water stream.

Analysis

For each heat exchanger configuration, perform the following analysis:

1. Calculate the average inlet and outlet temperature of each stream as well as the uncertainty of each temperature:

$$U_T = \sqrt{\left(U_{T,systematic}\right)^2 + \left(U_{T,random}\right)^2}$$

   where $U_{T,systematic}$ is the systematic uncertainty of the thermocouple data acquisition system and $U_{T,random}$ is the random uncertainty, calculated as:

$$U_{T,random} = t_{95\%,v} \frac{S_T}{\sqrt{N_T}}$$

   where S_T is the standard deviation of the temperature readings, N_T is the number of temperature readings taken, and $t_{95\%,v}$ is the Student's t-value with 95% confidence with $v = N_T - 1$ degrees of freedom.
2. Calculate the rate of heat gain of the cold fluid stream:

$$\dot{Q}_{cold} = \dot{m}_{cold} c\left(T_{cold,out} - T_{cold,in}\right)$$

3. Calculate the rate of heat loss from the hot fluid stream:

$$\dot{Q}_{hot} = \dot{m}_{hot} c\left(T_{hot,out} - T_{hot,in}\right)$$

4. Calculate the percent difference between the rate of heat loss/gained by the hot and cold streams.
5. Calculate the effectiveness of the heat exchanger:

$$\epsilon = \frac{\dot{Q}_{cold}}{\dot{m}_{hot} c\left(T_{hot,out} - T_{cold,in}\right)}$$

Compare the heat exchanger configurations by doing the following:

6. Generate a bar chart that compares the heat transfer rate $\dot{Q}_{cold}$ for each configuration.
7. Generate a bar chart that compare the heat exchanger effectiveness for each configuration.

Discussion Questions

Please answer the following questions within your worksheet:

- What is/are the reason(s) by which the heat loss from the hot stream would be different from the heat gained by the cold stream?
- In which configuration is the heat exchanger effectiveness maximized? Why would this be the case?

Experiment Data Sheet

Name: ____________________________ Date: ______________

Names of Lab Partners (for reference):

Environmental Conditions:

Barometric Pressure	Uncertainty of Barometric Pressure	Room Temperature	Uncertainty of Room Temperature

Heat Exchanger Configuration: ____

Hot Stream Inlet Temperature	Parameter	Uncertainty
Reading 1		
Reading 2		
Reading 3		
Reading 4		
Reading 5		

Hot Stream Outlet Temperature	Parameter	Uncertainty
Reading 1		
Reading 2		
Reading 3		
Reading 4		
Reading 5		

Cold Stream Inlet Temperature	Parameter	Uncertainty
Reading 1		
Reading 2		
Reading 3		
Reading 4		
Reading 5		

Cold Stream Outlet Temperature	Parameter	Uncertainty
Reading 1		
Reading 2		
Reading 3		
Reading 4		
Reading 5		

Hot Stream Flowrate (Timed Capture)	Parameter	Uncertainty
Fill Volume		
Fill Time		

Cold Stream Flowrate (Timed Capture)	Parameter	Uncertainty
Fill Volume		
Fill Time		

Instructor Signature: ________________________________