MEEG346 Thermal Laboratory

Laboratory Problem X2 – Heat Exchangers - All Teams

Objectives

To observe and measure the heat transfer processes in a basic heat exchanger.

To observe and use the basic relation between thermal power, fluid flow, and temperature change in a fluid heating process.

<u>Design Objective</u>: Design of large computers requires thousands of chips and components jammed into increasingly smaller spaces. In recent years heat transfer has become a major issue in design. Fins and circulating air are not enough. Molded heat sinks take up space and have limited performance. Liquid cooling, once a no-no around electronics, is being used.

We are asked to study the characteristics of very small heat exchangers that could be incorporated into a design. Specifically, if a circuit board stack was generating 1 watt/cm^2 over 0.5 m^2 could <u>this</u> little heat exchanger work (located external to the board)? Assume hot side tubing is adhered in loops to the board undersides and cold side cooling is provided by utility water just as in the lab apparatus. Determine if <u>this</u> heat exchanger could remove the heat, given maximum limits on $T_{h,i}$ = 95 C, $T_{c,o}$ = 60 C, m_c= 2 l/min and $T_{c,i}$ cooling water availability =20 C. The cooling water limits derive from regulation on discharge to sewers. $T_{h,i}$, $T_{h,o}$, $T_{c,o}$ and m_h are variables: you can choose values within given limits.

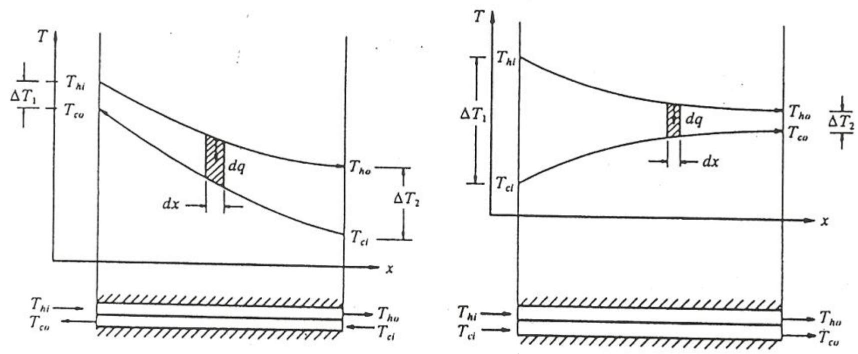
Theoretical Background

Your thermodynamics text book frequently illustrated systems where heat was moved from a high temperature source into the system, and removed to a low temperature sink. The thermo mechanical means to do this was generally not shown or discussed. A “heat exchanger” of some type is the answer and we will see several this semester.

You will learn a lot more about how to design heat exchangers later in the lecture course. Simple energy balances suffice to calculate the basic performance of a given heat exchanger.

Two-fluid heat exchangers are the workhorses of industries requiring significant heat transfer. They come in all sizes and shapes. The “radiator” in an automobile is one very common heat exchanger (the name is a misnomer left over from Henry Ford’s days. It radiates very little heat). They can be larger than railroad tank cars with thousands of tubes. The basic principles are the same for all, and these are what we will focus on.

Figure 1 below shows the fundamental configurations. Notice the only difference: in the parallel flow heat exchanger the cooling fluid and the hot fluid enter both enter and leave at the same end. In the counterflow exchanger, the cooling fluid enters at the end that the hot fluid exits. Study the diagram and the temperature profiles to understand how they differ.



<u>Counter flow</u> Fig. 1 <u>Parallel Flow</u>

These are called <u>shell-and-tube</u> heat exchangers, because mechanically one fluid flows through a tube(s) inside of a larger pipe called the shell. There can be multiple tubes in parallel. While not always true, the tubes usually contain the hotter fluid (minimizes energy loss to environment) or the fluid under higher pressure (small diameter tubes are less stressed by internal pressure). The whole assembly is often insulated for additional energy conservation.

In principle, the energy decrease in one fluid equals the energy increase in the other. We designate fluids as h and c, subscripts meaning hot and cold.
We use the additional subscripts 1 and 2 to indicate physical ends of the heat exchanger.
We use subscipts i and o to indicate inlet and outlet conditions for a fluid.

$$Q = m_h C_{ph} (T_{h,i} - T_{h,o}) = m_c C_{pc} (T_{c,o} - T_{c,i}) \qquad (1)$$

This expression is equally applicable to parallel and counter flow exchangers as long as you can keep the subscripts right. Compare the expression above to Figure 1 to understand the logic. (<u>Keeping subscripting right may be the biggest HX challenge</u>)!

The heat transfer rate through the tube walls is also important. This is controlled by the tube material conductivity k, and the convection heat transfer coefficients on the inner and outer tube surfaces. We know from fundamentals that

$$Q = U A \Delta T$$

where U is the overall heat transfer coefficient. But Figure 1 indicates that ΔT varies along the tube length. It can be shown that an equivalent $\Delta T_{;m}$ called the log mean temperature difference LMTD is

$$\Delta T_{lm} = (\Delta T_2 - \Delta T_1) / \ln(\Delta T_2/\Delta T_1) \quad (2)$$

so that $$Q = U A \Delta T_{lm} \quad (3)$$

Look at Figure 1 for ΔT definition. The subscript notation is the challenge. Get it right.

Finally, we need to refine the definitions of U and of the Area A. One can use as the area either the inner tube surface area A_i or the outer surface area A_o . Either works as long as you are consistent.

For this basic experiment, we are going to measure U, not try to calculate it.

Given a design, the problem reduces to solving for Q, mass rates, or temperature differences. Our task here is to observe and understand physically in a lab how these all work together. Later in the semester, classroom lectures and your textbook will elaborate on the theory. But we will be seeing heat exchangers frequently in lab and the power house. This lab gives you the basic insight.

Procedure

The lab equipment is a small shell and tube type heat exchanger, with water flowing in both the shell and the tubes. Flow rates and hot water temperatures are controlled from the computer display. The heat exchanger can be operated in either counter flow or parallel flow modes. Technical data is as follows.

Tube inside diameter	$d_i = 0.00515$ m
Tube outside diameter	$d_o = 0.00635$ m
Tube length	l = 0.144 m
Number of tubes	n = 7
Total heat transfer length=	n*l = 1.008 m
Tube material =	Stainless steel
Hot fluid flow rate =	Adjustable and shown on monitor, liters/min
Cold fluid flow rate =	Adjustable and shown on monitor, liters/min

UNLESS TA SAYS OTHERWISE, Teams A or B will take data with the unit in countercurrent mode. Teams AA or BB will take data with unit in Parallel flow. One report will include both sets of data. Directions below are the same for both.The report Discussion should compare the two.

1. Examine the equipment, identifying cold and hot fluid inlets and outlets. Cold fluid is taken from utility sink and discharged to sink drain. Hot water recirculates and a thermostat controls the heater element to set point temperature.
2. Examine the control computer monitor screen, and find where data is displayed, and how you can change temperature set point and fluid flow rates.

3. The equipment simply lists temperatures as T_1 , T_2 , T_3 , and T_4 . Sort out which is which and relate to the subscripting shown in Figure 1. You should draw a sketch of the heat exchanger showing the relation, for example T_1 is $T_{h,i}$. Set the hot water inlet temperature to 60 C and maintain it there.
4. Set the hot water flow rate to 3.0 liters/minute, and the cold water to 1.0 liters/minute (55%). The software includes a feedback flow control algorithm which may "hunt" around the set point.. Reasonably good settings have been found to be Proportional 100, Integral 2, Derivative 0.
5. When flows and temperatures are reasonably steady, record all.
6. Increase the cold water flow to its maximum (it is limited by an orifice on the inlet piping to prevent drain overflow). Decrease the hot water flow to equal the cold water flow. Maintain inlet hot water temperature at 60 C.
7. At steady state, record all temperatures and flows.
8. Stop the system flows, turn off the water heater.
9. Change the connections from Countercurrent to Parallel flow and repeat.

This completes the data acquisition. You each have two data sets, where the ratio of hot side flow to cold flow was varied. Heat transfer, inlet and outlet temperatures changed accordingly. Pause and review your data. Does it make sense, intuitively? Does energy in equal energy out? If not, where else could it go?

Analysis

1. Plot the data from your runs in a manner similar to Figure 1. The only data points are inlet and outlet temperatures; therefore simply draw a straight line in between. Draw an arrow head on each line to show flow direction,
2. Calculate and tabulate ΔT_{hot} and ΔT_{cold} for each data set.
3. Performance calculations and investigation.
   (a) Overall efficiency – this is a measure of heat loss to surroundings instead of being exchanged between fluids. C_h and C_c are called the *heat capacity rate* for each fluid.

$$Q_h = m_h c_{ph} (T_{h,i} - T_{h,o}) = C_h \Delta T_{hot}$$

$$Q_c = m_c c_{pc} (T_{c,o} - T_{c,i}) = C_c \Delta T_{cold}$$

Ideally, $Q_h = Q_c$ if there were no losses. The efficiency is defined as Q_{min}/Q_{max}. where Q_{min} is the lesser of (Q_h , Q_c) and Q_{max} is the greater. Calculate the overall efficiency for each run. Comment on significant differences, if any.

   (b) The U-Value for conduction through the tube walls between the fluids is an important design and performance parameter. With an existing heat exchanger such as we have here, if we measure its temperature performance and geometry then U can be estimated from the data using eqns (2) and (3).

For each run calculate the log mean temperature difference ΔT_{lm} using eqn (2). Then calculate $U = Q_h /(A^* \Delta T_{lm})$. For area A use the tube mean diameter $(d_i+d_o)/2$ so that that $A = n \pi d_m L$. (Don't forget- there are (n) seven tubes) For Q, use the lower value (Q_{min}). Comment on differences in U-values, if any. (Look at eqns (4) and ask yourself: What changed in the different runs?). Generally, heat exchanger analysis assumes a constant U value over the length of the tubes.

Important: Each team will do the analysis. Answer this: Which configuration, counter flow or parallel, is more efficient?

Design Objective:

Use the performance data of this heat exchanger to study and answer the Design Objective question. The question is, will this heat exchanger as is remove the higher heat load required?

Note that the cold side flow and temperatures are fixed. You can vary the hot side flow and temperatures. You know a U and A. There are specified limits on m_c, $T_{h,I}$ and $T_{c,o}$. Can you find a combination of variables that will work? The answer will be a parameter set that transfers (Q_{actual}) at least the required power. Or, you may find that there is no such set. Not just any combination will work; all energy equations must be satisfied.

(Hint: Test hot side parameters (Yes/No). Test cold side parameters (Yes/No). Test Conduction through the tube walls (Yes/No). If any are No, it will not do the task).

Error Analysis. In this experiment, Eqn (1) is repeatedly used for calculating results. You may have noted that the parameters being measured fluctuated, even when nominally the apparatus was in steady state. Some or all of this may be consequence of the computer control system constantly "hunting" for the set point. Whatever the source, these are delta uncertainties in the recorded values.

Perform a Propagation of Errors analysis of the hot stream part of eqn (1).

Summary

Write a short letter to the client with the answer, given the restraints imposed. What factor(s) is limiting? (e.g., shell side flow rate? Tube side? Heat transfer area between them? Offer to continue research and development.

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