UNIT OPERATIONS LABORATORY 1

SHELL & TUBE HEAT EXCHANGER LAB

ChEn 475 – Knotts

Introduction

Shell and tube heat exchangers are one of the most common pieces of equipment encountered by chemical and other engineers. They are used in many industries including oil and gas, pharmaceuticals, chemicals, and food processing. Students learn the theoretical basics of heat exchangers in courses, but there are many things to consider when designing real heat exchangers. The purpose of this lab is to give students experience with a real heat exchanger and help them understand the subtleties that must be taken into account when designing a shell and tube heat exchanger.

In this experiment, saturated steam enters the shell side of the heat exchanger and water enters the tube side. You can control the flowrate of the water and the steam pressure. The water is supplied from a 30 gallon tank. When running, cold water is added to the tank to prevent the system from overheating through constant recirculation through the heat exchanger. The exact details of the system are found on the UO lab website.

Task 1: Match theory to experiment

The equations that govern the heat transfer in heat exchangers involve convective heat transfer coefficients. A variety of correlations exist to predict the heat transfer coefficients for various situations based on dimensionless numbers, but the resulting values have errors anywhere from 10% to 50%. To force the theory to match the experiment, we often use the fouling factor. As heat exchangers age, accumulation of minerals and other material can occur on the heat transfer surfaces. The fouling factor quantifies how much this scaling reduces heat transfer.

1. *Learn about the heat exchangers found in the UO Lab.* Before performing design calculations, you must determine the design specifications of the heat exchanger. Two shell and tube heat exchangers are found in the UO lab. Each is model 03024 SSCF from Standard Xchange (http://www.standard-xchange.com) with a single tube pass. One of the heat exchangers has narrow baffle spacing and one has wide baffle spacing. Some of the information you need to design the heat exchanger is found on the website, but some had to be requested from the manufacturer. The information obtained from the manufacturer is found in a pdf on the UO lab website. You should also examine the entire process itself and determine what is measured, where the measurement devices are placed, etc.

After learning about the equipment, familiarize yourself with the startup, shutdown, and safety procedures by completing the "SHELL & TUBE SAFETY AND ETHICS TRAINING" pamphlet. (Note, you can start on Numbers 2 and 3 of Task 1 before you get the required signatures. Just don't go on to Task 2.)

2. *Research how to calculate a fouling factor.* One of the best ways to analyze a shell and tube heat exchanger is to calculate a fouling factor. This is actually a very involved process, but you should be able to figure out the *main* equations fairly quickly. Do this by reviewing the relevant sections in the Heat and Mass textbook.

3. Report your findings in a *short* email to the instructor. You are basically answering the question: "How do you calculate a fouling factor for the heat exchanger given the values you can measure in the experiment?" You are restricted to one paragraph of text and one attached PowerPoint Slide.

Task 2: Determine the factors that affect performance.

Good engineers seek to understand, as completely as possible, the systems and processes they oversee. This helps them troubleshoot problems and identify areas for optimization. Your second task is to perform experiments to gain a deeper understanding of the factors that affect performance. With the experimental setup available in the UO lab, you can basically change three factors: flow rate, steam pressure, and baffle spacing.

1. *Characterize steady state*. One of your first goals, once you start with the experiments, should be to determine how long it takes the system to reach steady state. Unless you want to model the unsteady-state behavior of the system (which requires solving differential equations and perhaps even finite difference methods), you only want to analyze the behavior at steady state. Make sure to perform initial experiments so that you can show the time-dependence of the system and demonstrate the system is at steady state. **You will want to include a graph of these results in your final report.** Also, you will want to think about how long it takes to reach steady state for small and large changes to the set points of the system.

2. *Perform experiments to determine how flow rate and steam pressure affect the performance of the system.* A big part of the reason for this experiment is to develop engineering intuition about heat transfer. At the end of the experiment you should be able to answer the following questions.
   a. What is the relationship between steam pressure and heat transfer rate? steam pressure and fouling factor? steam pressure and heat transfer coefficients?
   b. What is the relationship between flowrate[1] and heat transfer rate? flowrate and fouling factor? flowrate and heat transfer coefficients?
   c. What is the relationship between the temperature in the tank and the flowrate? the temperature of the tank and the heat transfer coefficients? the temperature of the tank and the steam pressure?
   d. What is the relationship between the change in the water temperature across the exchanger and the flowrate? the change in temperature across the exchanger and the temperature of the water in the tank?

   Part of your grade for this lab will be based on how much you learn about heat exchangers. Not only do you need to analyze all the questions found above, but you also need to tell me something else about the system or explain the physical phenomena. In other words, you can't just answer the questions above like you would an exam. You need to explain why things happen the way they do.

   This part of the lab is reported by completing the SHELL & TUBE TASK 2.2 HOMEWORK Sheet. For this assignment, the entire team may use the same graphs, but the explanations should be individual work.

[1] The term *flowrate* is used above, but you should use a more universal/helpful quantity when reporting your data.

Finally, you will need to do many experiments to accomplish what is required in this lab. Don't delay starting, and make use of time to do as many experiments as possible. You should be able to perform more than 25 experiments. If you are organized, you could do more and doing so will reflect well on your grade as it will improve your ability to answer the design problems and ensure statistically-significant data. If you do not make good use of time or do fewer experiments, you will not be able to achieve all of the goals of the lab.

3. *Calculate a fouling factor.* While performing the experiments, you should be analyzing the data to determine a fouling factor. This seems simple on the surface, but it is actually a complex calculation. ***The sooner you figure out how to do this calculation, the easier time you will have with the rest of the experiment.*** Therefore, for one of your first or second experimental runs, calculate the fouling factor and talk with me about the value you obtained.

   To obtain accurate fouling factors, you will need to make sure you use the most accurate correlations you can find. As you know, most correlations have errors around 25%, but there are some cases where errors of less than 10% may be found. You should use the best ones available to you. Also, you will need to pay attention to the exact conditions for which each correlation was developed and evaluate properties at the correct temperatures (T_{film}, T_{ave}, $T_{surface}$, etc.) This often becomes an iterative process, so I recommend using Mathcad for these calculations. (This also helps with the unit conversions.)

   When setting up the Mathcad sheet, you will want to do so in such a way that you can perform the calculation automatically for a series of different conditions including different sized heat exchangers and operating conditions. This will make it easier to analyze the system and scale up later (as you will do in a later task).

   Once you are done analyzing all of the experiments, send me an email with a spreadsheet containing all of the conditions and the values for fouling that you obtained. Make sure to send me all of the information that I need to calculate the fouling factors myself. I will use your experimental values and determine a fouling factor using my own calculations. You will receive a grade based on how accurate your value is. You may attach one slide if needed. Also, make sure the Excel sheet is easy to understand. (Only one email for the whole team is required. I am not grading the writing on this assignment, but make sure it is professional and has all the information needed.)

   I (Dr. Knotts) will help troubleshoot these calculations with you by asking questions, giving suggestions, and helping you get your Mathcad to converge. However, I won't tell you if your values are exactly correct unless requested. This request will cost you 20% of the grade for the calculation portion of the lab (20% of 25 points). You can think of this as a consulting fee. The purpose is to help you have confidence in your abilities to both solve the problem and assess the reasonableness of your solution and assumptions.

   Finally, I reemphasize that you should start on this calculation early. I would try to have it done by the second or third day of the lab period. By "done" I mean that you have coded into Mathcad everything that you think you need and tried to get value for fouling factor. This value may not be correct, but I can then help you figure out where the problems are to the level desired (see paragraph above).

4. *Determine how possible errors in relevant parameters, assumptions, theory, or measurements will affect performance.* Many things can affect the performance of the shell and tube heat exchanger. Some of these were discussed above, but there are countless more possibilities.

   Many of the factors you could identify are likely not significant. Dr. Solen used to say that engineers need to think about two things: "What is true" and "What is real." In other words, just how important are the various factors? Can you assume that the density of water is constant over your range of temperatures, or do you need to take into account temperature dependence? Technically, the density of liquid water changes with temperature, but the rate of change is slow and induces much less error than other sources. For example, what if your measurement devices are biased? Answering such questions helps you better understand the system, improves intuition about how things really work, improves prediction of the behavior of the equipment, and provides understanding of how out-of-spec performance could affect other operations.

   For your final report, you should identify at least three factors, other than errors in the water property values, which could affect your calculations. For these factors, perform a sensitivity analysis by changing the relevant parameters in your calculations by a certain percentage and determining how your final answers change.

Task 3: Select an appropriate heat exchanger for a larger installation.

When designing a new process, one of the ways to accurately predict performance of new equipment is to base it off the performance of existing equipment. In our case, we have a relatively small heat exchanger, but imagine that you needed to select a heat exchanger for a larger operation. Based on your analysis of our lab heat exchanger, determine which single-pass, heat exchanger from Standard Xchange that you would need to purchase to heat 200 gpm of water from 25 °C to 75 °C. Steam up to 300 psig is available in the plant. In your selection, remember that you will want to reduce capital equipment costs as much as possible and maintain safe operating conditions.

An important part of this task is to think about reasonable ranges of operation in relationship to the size of the available heat exchangers. Theoretically, any flowrate can be achieved for any sized pipe or tube. In practice, however, a given piece of equipment will be suitable for some finite operating range. What determines this? Another way to ask this is "What does the manufacturer do to change the recommended ranges given for the different heat exchangers on the website?" Also, what can you change to get more heat transfer or larger/smaller changes in temperature? As with Task 2, part of your grade will be based on how much understanding of heat exchangers that you share with me.

Task 4: Report Your Findings

You will document your findings to Parts 1 and 2 of Task 1, Parts 1, 3, and 4 of Task 2 and all of Task 3 in a report to your instructor. Each team member will turn in an individual report. The beginning of your report should be an introduction to remind the reader about the purpose of the memo and a discussion of your methods. This methods section includes the theory you used to analyze the problem, a description of the apparatus, and an outline of the actual experimental conditions you ran. You will then show the results along with your graphs/tables. The memo should end with a summative statement about what you did.

The main purpose of the report is to explain how to calculate fouling factors and how you used the fouling factors and other calculations to select the correct heat exchanger described in Task 3. It should also answer all of the questions proposed in Parts 1 and 4 of Task 2 as a demonstration of your understanding. *To help simulate the work environment, write your report in response to the memo found below.*

Summary of Deliverables

1. Theory email (with slide if needed) (Individual)
2. Email with data and calculated fouling factor (Team)
3. Shell & Tube Task 2.2 homework (Individual)
4. Written report (Individual)
5. Shell & Tube quiz (Individual)
6. Leadership report (Individual)

To: New Company Engineers

From: Thomas Knotts

Date: 5 January 2017

Subject: Sizing of New Shell-and-Tube Heat Exchanger

As part of your training as new engineers, you are going to be placed into a team with other recently-graduated engineers to solve a design project involving shell and tube heat exchangers. Specifically, a shell-and-tube heat exchanger is to be installed in our new plant that must heat 200 gpm of water from 25 °C to 75 °C. Steam at 300 pisg is available to use in the process. To maintain consistency in the plant, all of the heat exchangers are to be purchased from the same vendor—Standard Xchange.

Part of this training is to help you develop engineering intuition about shell and tube heat exchangers as they are used so often in the company. To this end, the pilot plant has set up a heat transfer system using a shell and tube heat exchanger from Standard Xchange. Specifically, the system uses model 03024 SSCF in two configurations: one with narrow baffles and one with wide baffles. This apparatus will be used for two aims. Aim 1 is to calculate a value for the fouling factor that can be expected from heat exchangers from Standard Xchange and use this value to select an appropriate heat exchanger for the application explained above. Aim 2 is to determine the factors that affect heat exchanger performance so that you understand how variables such as flow rate, steam pressure, temperature change, tank temperature, etc. are interrelated.

Your findings to Aim 1 are to be reported to me in written form. This report should explain how you used the apparatus and theory to determine a fouling factor, how you used the fouling factor to scale up to the larger installation, and your recommendation for the heat exchanger needed for the new plant. Make sure to explain how what you measured and calculated led to your conclusions. This is an important part of technical writing that new engineers often neglect. I need to see what you did, the outcomes, and how you interpreted the data. Your report should have several tables, charts, and graphs describing the data you took, the quantities you calculated, and the scale up to the larger heat exchanger. However, don't assume the reader knows why you are placing these in the report. Include enough description that the reader can know how you interpreted the data and why this interpretation is important.

Your findings to Aim 2 are reported in a separate document provided to you where you can paste graphs and write short answers explaining the behavior. This work does not need to be duplicated in your report for Aim 1, but you may find it useful to discuss some aspects in both.

I look forward to your report.