CM3215 ChemE Transport Lab:

Overall Heat Transfer Coefficient for Double-Pipe Heat Exchanger

Pre-laboratory Assignment

Review the following: concept of the double-pipe heat exchanger, the overall heat transfer coefficient, logarithmic mean temperature difference (ΔT_{lm}), macroscopic energy balances, enthalpy, and the purpose and operation of steam traps.

Calculate the heat transfer area (m^2) of the double pipe heat exchanger in the lab. Dimensions of the heat exchanger are in the Equipment Schedule. Base your calculation on the *outside* area of the *inside* pipe. Look up and fit the latent heat of vaporization of steam $(\Delta \widehat{H}_{vap})$ as a function of saturation temperature to an appropriate function and record the result and the plot in your lab notebook (include the reference). We are interested in temperatures near the atmospheric boiling point.

Calculate the rotameter setting for the desired water-side flow rate; write in your lab notebook.

Answer this question in your lab notebook: If $T_2 - T_1 = 76^oC$, what is ΔT in units of K? Be prepared also to make and share calculations of Q and U during the lab (on the white board).

Prepare a safety section in your laboratory notebook detailing all safety issues associated with this laboratory.

Introduction

You will be investigating the heat-exchange performance of the lab double-pipe heat exchangers. We will measure the heat transferred by the exchanger in two ways:

water-side and steam-side measurements. The performance of the heat exchanger will be expressed in terms of its overall heat transfer coefficient U $(W/m^2K) = Q/A\Delta T_{lm}$. Our calculation will be based on the outer area of the inner pipe.

We have a limited amount of time for the lab; therefore, we operate at a fixed water flow rate (1.5 gpm) and investigate the effect on the heat exchanger's performance of varying the steam flow rate. We will be consolidating the data from all of the heat exchangers. The measurement of the steam condensate flow rate will be by pail-and-scale (triplicates). We are also going to be investigating whether the heat exchangers are adiabatic. We need, as always, to consider the degree of uncertainty in our measurements and calculations.

Each lab group will take data triplicates of steam condensate flow rate at a minimum of two steady state steam flow rates. It takes a long time to get to true steady state when varying the steam flow rate. Due to the small number of data points we have time to take, we will share and combine all the data taken. We collect the data on a Google Form.

The steam mass flow rate will be varied by varying the position of the pneumatic valve on the steam line SV06. The rate that steam flows through the valve is determined by the valve position, but it depends both on the upstream steam pressure (out of our control; depends on the building demand for steam, outside temperature and other factors), the downstream pressure (the pressure, in the heat exchanger), and on the steam valve setting. We will set the operating conditions by setting the steam valve position with the pneumatic air line; we subsequently measure the mass flow rate of steam by using the pail-and-scale method on the steam

condensate line. Note that setting SV06 to the same setting twice may not result in the same steam mass flow rate due to changes in upstream and downstream pressures that are out of our control. Thus, two data points with the same steam valve setting are not replicates (may not result in the same steam mass flow rate).

Note on obtaining accurate temperatures: Note that we measure temperature using thermowells (www.temperatures.com/twells.html). When the thermocouples are placed into the thermowells, they must be securely pressed against the bottom of the well. Only when the thermocouple is firmly pressed against the bottom of the well will an accurate temperature be recorded. Please plan your procedure so that you get the most accurate temperatures possible.

As we learned in our error analysis discussions, the uncertainty in temperature measurements is high. To roughly calibrate the thermocouples in the lab, a 40^oC water bath and a 60^oC water bath will be set up to allow you to do a two-point calibration of the thermocouples that you use. For each thermocouple you use, label the thermocouple and measure the temperatures of the water in the baths. Take your temperature data as usual; when performing your data analysis, however, shift all subsequent temperature measurements from that thermocouple according to the two-point calibration. Be sure to label your thermocouples and record the label in your lab notebooks to make sure you can apply the correct calibration to each thermocouple you use.

Theory: See lecture.

Overall Objectives and Strategy: Measure appropriate data to allow you to determine the steady-state amount of heat transferred in your lab-station heat exchanger at various steam flow rates. Quantitatively verify and demonstrate in your report that you achieved steady state. Work at a fixed water flow rate (1.5 gpm) and vary the steam flow rates. Determine the overall heat-transfer coefficient for each operating condition (shared data). Determine if the heat exchanger is operating adiabatically. Address all other objectives as discussed in **Data Analysis** below. Using error analysis appropriately is an essential part of this lab. To obtain more data points, share results with the other groups.

Experimental Procedure

CAUTION: Always wear insulated gloves when adjusting the steam valves, when touching uninsulated piping or when handling condensate. Note: The equipment may be hot at the beginning of lab.

Overall procedure:
1. Steam left over from the most recent operation of the heat exchanger at your lab station has condensed in the lines and must be drained before we operate. The TA will prepare the steam lines of your lab station by draining condensate from the lines.
2. Set the water flow rate on the inside of the heat exchanger to the desired flow rate with the water flowing from Tank 2 to Tank 1 to the drain. Note: do not recirculate warm water back to Tank 2.
3. Prepare the heat exchanger for steam flow (see Procedure A in the appendix).
4. Set the steam flow rate to the assigned level (Dr. Morrison will provide each group with a steam

valve setting in terms of fraction open).

5. Data acquisition strategy: allow the station to come to steady state (10 minutes at a minimum; steady state is achieved when the heat exchanger pressure has stabilized and the outlet water temperature does not vary for at least 5 minutes.); measure steady state values of the variables needed to meet your objectives. Use a pail and scale procedure to determine the steam flow rate (see Procedure C in the appendix). Be prepared to justify in your report that you operated at steady state.

6. Record the %open setting of the pneumatic control valve and the air pressure need to achieve that setting; include these data in your raw data appendix.

7. When all data acquisition is completed, wait for the signal from Dr. Morrison and then adjust the steam valve position to your second assigned value and repeat the data acquisition steps. <u>Do not move before instructed</u>; we are minimizing the disturbances on the steam side by moving our steam valve positions in unison.

8. Shut down the station when instructed to do so (see Shut Down Procedure). <u>Do not shut down early</u>; your diminished use of steam may affect your classmates' data.

9. Submit your data to the Google form; this form is shared with the entireclass.

Data Analysis

1. In your report, use all class raw data that applies to the heat exchanger you studied. Each operating point will include a triplicate on steam mass flow rate (pail and scale).

Determine the effect of steam flow rate on the measured overall heat transfer coefficient. Perform error propagation calculations on U (calculated both ways).

2. There are two ways of calculating Q from the data we have taken. For both methods, calculate and report overall heat-transfer coefficient U for each steam flow rate investigated. How do the two numbers compare? Which method is more accurate? Justify your answer with appropriate error analysis calculations. Be sure to use the appropriate number of significant figures when you report your answers. Appropriately and numerically express your uncertainty in reported values (error bars are to be included on appropriate plots).

3. We usually assume that the heat exchanger is adiabatic. To test this assumption, we can calculate the heat given up by the steam and the heat taken in by the water and compare them. They should be the same if the heat exchanger is adiabatic. According to your calculations, is the heat exchanger adiabatic? Note that you must take into account the uncertainty in your measurements to answer this question. Present graphics (plots, tables, schematics) to support your arguments.

4. Attach raw data tables and tables with your calculations as an appendix (do not include raw data tables in the main body of the report). Do not put necessary plots in the appendix; put those in the report.

Appendix: Procedures and Assigned Operating Conditions

Shut Down Procedure
1. Set the FV-06 air pressure regulator to 0 psig. Note that pressure regulator valves are "left-hand-rule" meaning that turning the handle in a right-hand sense increases the flow in through the regulator.
2. Close the main air supply valve AV-1.
3. Close main steam supply valve SV-1.
4. Return all drain hoses to the common drain.
5. Allow the cold water to circulate through the loop to cool the heat exchanger for at least 3 minutes. Stop the flow when the piping at the cold-water exit of the heat exchanger is cool to the touch. Check with Dr. Morrison or the TA before shutting of the cold water flow.
6. Close valves WV-1 and needle valve WV-5.
7. Turn off pump P-01.
8. Close main water valve WV-10.
9. Position three-way valve WV-9 to direct flow to Tank T-02.
10. Drain all tanks.
11. Dry off any wet surfaces with paper towels. Turn off all the electronic devices and properly store them.

Procedure A: Prepare the heat exchanger for steam flow:
1. Set up the station so that cold water is flowing through the inside of the heat exchanger at your desired water flow rate (no less than 1 gpm).
2. Verify that the TA has cleared condensate from the lines at your lab station.
3. Position three-way valve SV-3 to direct flow through the Swagelok steam trap.
4. Perform a one-point calibration of your thermocouples; label appropriately.
5. Install thermocouples in the appropriate thermowells.
6. Open the main steam valve SV-1.

Procedure B: Set the pneumatic steam valve.

Note that air pressure regulator valves are "left-hand-rule" meaning that turning the handle in a right-hand sense increases the flow in through the regulator.

1. Open main air valve AV-1.
2. Set the control valve FV-06 to your assigned valve-open position using the air regulator connected to FV-06. Note: it takes approximately $15\ psig$ on the air-pressure regulator to achieve a full-open valve; the minimum steam flow is achieved at approximately $11\ psig$. One team member should monitor the valve position while the other adjusts the air regulator. Follow the 3-points-of-contact ladder rule. All settings should be approached from below, that is, air should be *increased* (never decreased) until the setting is reached; if you overshoot the reading, reduce pressure by several *psi* and re-approach the desired setting from the lower settings.
3. Note the % open setting on the pneumatic control valve and the air pressure ($psig$) from the regulator needed to open the valve to that position.

4. Monitor the temperature at TW-05 at the exit of E-01 as the heat exchanger heats up (see warning about thermowells in introduction). **Do not allow the water-exit temperature to exceed 50ºC.).** If the outlet water temperature approaches 50ºC, temporarily increase the water flow rate with WV-5 and reduce the flow rate of steam by reducing the air pressure regulator to 10 psig or less.

consistent. This is an important measurement.

Procedure C: Pail and Scale the Steam Flow Rate:

1. Fill a Styrofoam bucket half-way with cold water from the sink.
2. Tare the counter-top scale with the water-containing bucket.
3. Empty the red rubber hose that is downstream of the Swagelok steam trap.
4. Using this hose, collect condensate in the Styrofoam bucket (place the hose under water to capture as much steam as possible; stabilize with gloved hands) for at least 5 minutes. When cutting off the steam flow, be sure to capture all the condensate from the line into the bucket. Some condensate may be trapped in a low section of the hose.
5. Weigh the bucket and calculate the mass flow rate of the steam condensate.
6. Without changing any valve positions, perform three replicates on the pail-and-scale measurement of the condensate mass flow rate.
7. Perform additional pail-and-scale replicates if the data are not

Operating Conditions Spring 2016

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station	setting 1	setting 2
2	5/8ths	7/8ths
4	6/8ths	8/8ths
6	5.5/8ths	5/8ths
7	6/8ths	6/8ths
8	6.5/8ths	5.5/8ths
9	7/8ths	6/8ths
10	8/8ths	6.5/8ths
Note: using the same valve setting does not produce a replicate (this is because the actual flow rate of steam will depend on the house steam pressure).		