Objective:
The objective of this lab is to give students an opportunity to operate a double-effect evaporator using a pure water feed and to develop skills in evaluating process operation via a simple process model. The goal is to obtain heat transfer coefficients, steam efficiencies, and capacities for both effects, and study the effect of different operating conditions, including but not limited to, flow rates, forward vs. backward feed, natural vs. forced convection, and vacuum level in the second effect.

Major Topic Covered: Two-phase heat transfer, thermodynamics, equilibrium separations.

Theory:
See Geankoplis (the course text), chapter 8 for a discussion on the relevant theory for operation of the double effect evaporator.

Safety Precautions:

1. There are several process and steam valves that discharge directly into the room. Do not touch a valve until you know what you are doing! The tagged valves are particularly dangerous. Steam burns can be very serious.

2. If you overfeed the evaporator above the top view port, turn off the main steam immediately. There is a header valve on the steam next to the east wall (near the laboratory door).

3. When opening valves on the second floor, be careful that liquid is not discharged onto persons below. Always wear hard hats when working in the bay area.

4. Be sure that the condenser coolant is turned on before the steam and that coolant is not turned off until after boiling has stopped.

5. The pump seals are supposed to drip slowly. This lubricates the packing.

Available Variables: Feed flowrate, second effect vacuum, convection type (forced or natural), feed direction (forward or reverse)

Procedure: See Evaporator Operational Checklist.

Analysis:
Your analysis must include:

1. Mass and Energy balances. This means you must determine all of the appropriate flows
(e.g. feed, intermediate, outlet, for mass, condensate flows, etc. for energy) for each run that you do. Perform the balances from each effect individually and for the system as a whole. Making a checklist so that you do not have missing data during your calculations will be helpful.

2. Calculation of the steam economy (see Geankoplis for a discussion of steam economy).

3. Calculation of heat transfer coefficients for both effects. Note: this will require knowledge of effect geometry. Blueprints of the evaporator are available on the wall in the lab.

4. A multiple linear regression on steam economy as a function of all of your manipulated variables (i.e. feed rate, convection type, etc.) See Appendix 1 for performing multiple linear regressions using POLYMATH.

Report:
Describe the design of your experiment, the precautions you took to gather valid data, your results (including balances, heat transfer coefficients and error analysis), and your process model. Provide thoughtful and quantitative discussion of results, explain trends using physical principles and relate your results to theory or published values. Express any discrepancies between observed and predicted results in terms of quantified experimental uncertainties or model limitations.

Pro Tips:

1. Effect 1 and Effect 2 do not have the same heat transfer geometry.

2. Make sure that the drain lines for the effects are closed prior to attempting to fill the effects. Students have wasted many an hour by not checking this prior to starting.

3. Adjust the feeds to keep the level at approximately the center of the lower sight glass for each effect.

4. Steam, air, and water are shared between experiments – variations can occur with time as other experiments use resources, so monitoring is important.

5. As with the distillation column, cooling water should remain on for 30 minutes after the steam is shut off.

6. This is a large system – be patient while waiting for changes. Do your best to ensure you are at steady-state before taking data – monitor variables a reasonable intervals and take data when values are steady over several readings.
References:


Appendix 1: A Simple Process Model for the Evaporator

The objective of a model is to correlate and predict the performance of a system over a limited range of process variables. Ideally an operator can control these variables.

To develop the model, one first names all the controllable independent variables for which information is available. For example:

- $X_1 = $ vacuum level in mm Hg
- $X_2 = $ feed rate in gpm
- $X_3 = $ 1 if forward feed, 0 if backward.

The simplest model for this example would then be:

$$ Y = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 $$

(1)

where $Y$ could be the observed capacity of the evaporator, steam economy, etc. and $a_i$ are constants to be found by using the data, i.e., $Y$ vs. $X_i$. Other algebraic forms may be preferred, especially if suggested by theory or dimensional analysis. Note that the values of all $X_i$ must be recorded for each run, even if these are nominally held "constant." Also only one set (i.e., one value of $Y$ and one value each of $X_1$, $X_2$ and $X_3$) can be used from each independent run. If the run is a difficult one to control, take multiple sets of readings during the run, and average these; then use only the average in the model. Do not discard a set simply because an independent variable is not quite at the planned value; this set can be used. Sets that should be discarded include those resulting from grossly transient operation, or ones that feature seriously misread values of any variable.

To solve for the constants $a_i$ use any equation solver (e.g., Polymath) that can handle over-determined problems (called "regression," "fitting," etc.). An over-determined problem means that you have more data than constants. If this is not the case, then more data are needed. Most packages will also give you a measure of the significance of the constants. If the significance of a constant is low, then the corresponding term should be removed from the model and the problem solved again. Better yet, one should get more data that has lower error! As a measure of how well your experiment is going, it is very appropriate to keep fitting the model as the data come in.
Feed System
Steam System
Condensation Collection System
Double Effect Evaporator - Checklist

Rotometer Calibration

A. Shut valves 36, 37, and 38. These are the drains for effects 1 and 2.
B. Open valve 1. Check open valves 5 and 7. Check shut valve 6. Shut valve 8. This will line up the feed to calibrate the feed rotometer. Use valve 6 to throttle flow for calibration.
C. Once the feed rotometer is calibrated fill effect 1 by opening valve 8. Check shut valves 10 and 13. The effect should be filled to the middle of the middle sight glass.
D. Check open valve 9 and check shut valves 11, 12 and 15.
E. Calibrate the intermediate rotometer. Maintain level in the 1st effect during calibration.
F. Once the intermediate rotometer has been calibrated. Fill the 2nd effect by throttling flow with valve 11 until level is at the middle of the bottom sight glass.
G. Check open valve 14.
H. Calibrate the product rotometer by throttling flow with valve 15. Maintain level in the 1st and 2nd effects.
I. When the product rotometer is calibrated readjust level in both effects as needed then shut valves 6, 11, and 15.

Forward Feed

A. The evaporator is currently lined up for forward feed.
B. Line up the condensate collection system by checking open valves 22, 26, 28, 30 and 31. Check shut valves 21, 23, 25, 27, 29, 32, 33 and 34. This lines up drums 2 and 3 for condensate collection from effects one and two respectively.
C. Open valves 2 and 3. This provides cooling water to the condensers.
D. Line up steam to the 1st effect by opening valve 16. Throttle open valves 18 and 19 to blow out all condensate from the steam line prior to putting the regulator on service. Once all condensate is removed shut valves 18 and 19.
E. Slowly open valve 17 to introduce steam to the 1st effect. Monitor regulator pressure and ensure pressure is maintaining around 10 psig. If pressure is not steady repeat the condensate blow down from C. If the safety valve on the 1st effect opens. Shut valve 17 and repeat the condensate blow down from C wait a few minutes for the safety valve to cool down prior to repeating this step.
F. Control level of the condensate steam chests with valves 21 and 29. It is important that level is maintained in the sight glass to maintain the heat exchangers effective surface area. Sometimes during startup or if the sight glass goes out of sight it can become vapor locked. Level in the sight glass will not be correct during this condition. To correct this condition shut the lower valve of the sight glass until the liquid level starts to drain away then re-open this valve.
G. Throttle valves 6, 11, and 15 to maintain levels in the 1st and 2nd effects.

H. At the start of steam operation it is important to vent the heat exchangers of all non-condensable gasses. Once the water in the 1st effect is boiling and the pressure has risen to 1 – 3 psig, open valves 39 and 40 for approximately 1 minute to ensure all non-condensable gases are removed.

I. Turn on the pump for the 2nd effect to maintain product flow.

J. Open valve 20 to line up 120 psig steam to the air ejector. Open valve 41 to control steam flow to the air ejector. Maintain vacuum at or below 10 in Hg. Operation of vacuum above 10 in Hg can result in the condensate from the 2nd effect being drawn back into the 2nd effect steam condenser along with air causing the vacuum to become uncontrollable.

**Forced Circulation**

A. Turn on the pump for the 1st effect.

**Backwards Feed**

A. Operation in forward and backwards feed is similar, but requires some valve manipulation. To line up the system for backwards feed open valves 1, 4, and 5 and control flow to the 2nd effect with valve 6. Shut valves 7 and 8.


**Shutdown** (must be completed before lab notebook pages can be signed)

A. Shut off steam to air ejector by shutting valves 41 and 20.

B. Shut off steam to the 1st effect by shutting valves 16 and 17.

C. Shut appropriate throttle valves for feed, intermediate and product flow.

D. Shut off the pumps on the 1st and 2nd effects.

E. Open drains 36, 37, and 38.

F. Open valves 21 and 29 to drain the heat exchangers for the 1st and 2nd effects.

G. Let cooling water flow to the 2nd effect condenser and air ejector condenser for 5 minutes then shut valve 2. Check the air ejector condenser, if still hot or warm to touch allow water to flow for 1-2 more minutes. Once it is cool to the touch shut valve 3.

H. Ensure distillation column is shutdown prior to shutting valve 1.