Homework Set 9

Due: Thursday, November 10 (sections 001, 003, and 004)/Friday, November 11 (section 002)

This assignment is to be completed in assigned homework groups. Be sure to include the group number as well as first and last names of all contributing group members in addition to the assignment number and instructor name on the submitted homework. The assignment must be in one person's handwriting. If you use an equation solving tool (calculator, APEx, Solver, MATLAB), write out the equation(s) and note the tool that you used; otherwise, show all hand calculations in equation solving.

1. **(5 pts)** Based on the results of the CATME survey (complete by Saturday Nov.5 at midnight, results released on Sunday, Nov.6), talk about what changes you plan to make, as a team and as individuals, on the last two group homework sets. Note that this early survey does not affect your grade, but it can provide useful feedback on what is going well and what might need to be changed. Another CATME survey will be administered after HW 10 that will be included in your grades for group HW 7-10.

2. **(10 pts)** Your roommate has learned that burning approximately 3,500 food calories (The food calorie is a quantity equal to a kilocalorie, kcal) results in a weight loss of 1 lbm, and he gets the bright idea of losing weight rapidly by eating ice. His theory is that the energy expended by the body in melting the ice and raising the resulting liquid water to body temperature will do the trick. You burst the poor boy's bubble by telling him the amount of ice he would have to consume. How much ice would be required per pound of weight lost?

3. **(10 pts)** An adiabatic membrane separation unit is used to dry (remove water vapor from) a gas mixture containing 10.0 mole% $H_2O(v)$, 10.0 mole% CO, and the balance CO_2. The gas enters the unit at 30°C and flows past a semipermeable membrane. Water vapor permeates through the membrane into an air stream. The dried gas leaves the separator at 30°C containing 2.0 mole% $H_2O(v)$ and the balance CO and CO_2. Air enters the separator at 50°C with an absolute humidity of 0.002 kg H2O/kg dry air and leaves at 48°C. Negligible quantities of CO, CO_2, O_2, and N_2 permeate through the membrane. All gas streams are at approximately 1 atm.

   (a) Draw and label a flowchart of the process and carry out a degree-of-freedom analysis to verify that you can determine all unknown quantities on the chart.

   (b) Calculate (i) the ratio of entering air to entering gas (kg humid air/mol gas) and (ii) the relative humidity of the exiting air.

   (c) List several desirable properties of the membrane. (Think about more than just what it allows and does not allow to permeate.)

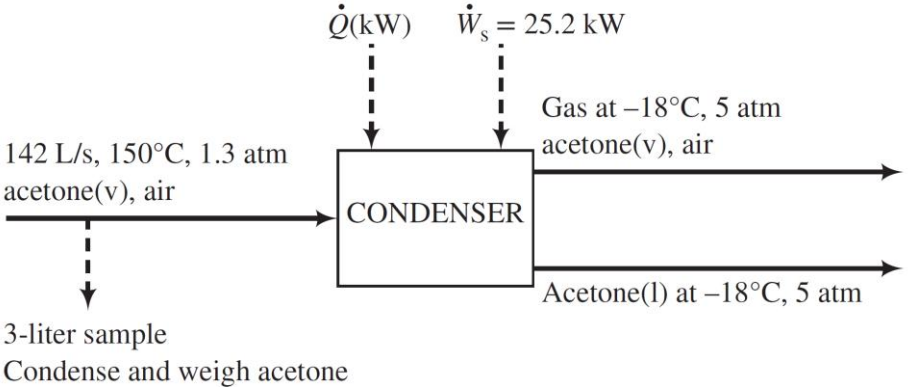
4. **(10 pts)** An adult human being at rest produces roughly 0.40mJ/h of thermal energy through metabolic activity. Use that fact to solve the following problems.

   (a) A college student who weighs 128 pounds put off a major assignment until the day before it was due and worked for eight hours to complete it. If she is modeled as a closed adiabatic system at constant pressure, her heat capacity and molecular weight are approximately the same as that of liquid water, and her temperature was normal when she began to work, what would her temperature have been by the time the assignment was finished?

(b) Now model the student as an open system and assume that evaporation of perspiration (evaporative cooling) is the only mechanism for heat loss. How much weight would she have lost through evaporation if she maintained a constant body temperature?

(c) Are either of the models in Parts (a) and (b) reasonable? Explain. What is the most likely explanation of what happened to the metabolic energy produced in her body?

5. (15 pts) A gas stream containing acetone in air flows from a solvent recovery unit at a rate of 142 L/s at 150°C and 1.3 atm. The stream flows into a condenser which condenses most of the acetone, and the liquid and gas outlet streams are in equilibrium at -18°C and 5.0 atm. Shaft work is delivered to the system at a rate of 25.2kW to achieve the compression from 1.3 atm to 5.0 atm. To determine the condenser feed stream composition, a 3.00-liter sample of the gas is taken and cooled to a temperature at which essentially all the acetone in the sample is recovered as a liquid. The liquid is poured into an empty flask with a mass of 4.017 g. The flask containing the liquid acetone is weighed and found to have a mass of 4.973 g.



(a) Carry out a degree-of-freedom analysis to show that enough information is available to determine the compositions of all streams and the required heat transfer rate.

(b) Write out a complete set of equations for the molar flow rates of all streams, the mole fractions of acetone in the feed and product gas streams, and the rate (kW) at which heat must be removed in the condenser. Do no calculations.

(c) Solve the equations of Part (b) by hand.

(d) Solve the equations of Part (b) using APEx.

6. (15 pts) The off-gas from a reactor in a process plant in the heart of Freedonia has been condensing and plugging up the vent line, causing a dangerous pressure buildup in the reactor. Plans have been made to send the gas directly from the reactor into a cooling condenser in which the gas and liquid condensate will be brought to 25°C.

(a) You have been called in as a consultant to aid in the design of this unit. Unfortunately, the chief (and only) plant engineer has disappeared and nobody else in the plant can tell you what the off gas is (or what anything else is, for that matter). However, a job is a job, and you set out to do what you can. You find an elemental analysis in the engineer's notebook indicating that the gas formula is $C_5H_{12}O$. On another page of the notebook, the off-gas flow rate is given as 235m3/h at 116°C and 1 atm. You take a sample of the gas and cool it to 25°C, where it proves to be a solid.

You then heat the solidified sample at 1 atm and note that it melts at 52°C and boils at 113°C. Finally, you make several assumptions and estimate the heat removal rate in kW required to bring the off-gas from 116°C to 25°C. What is your result?

(b) If you had the right equipment, what might you have done to get a better estimate of the cooling rate?

7. (15 pts) A sheet of cellulose acetate film containing 5.00 wt% liquid acetone enters an adiabatic dryer where 90% of the acetone evaporates into a stream of dry air flowing over the film. The film enters the dryer at T_{f1} - 35°C and leaves at T_{f2}(°C). The air enters the dryer at T_{a1}(°C) and 1.01 atm and exits the dryer at T_{a2} - 49°C and 1 atm with a relative saturation of 40%. C_p may be taken to be 1.33 kJ/(kg °C) for dry film and 0.129 kJ/(mol °C) for liquid acetone. Make a reasonable assumption regarding the heat capacity of dry air. The heat of vaporization of acetone may be considered independent of temperature. Take a basis of 100 kg film fed to the dryer for the requested calculations.

(a) Estimate the feed ratio [liters dry air (STP)/kg dry film].

(b) Derive an expression for T_{a1} in terms of the film temperature change, (T_{f2} - 35), and use it to answer Parts (c) and (d).

(c) Calculate the film temperature change if the inlet air temperature is 120°C.

(d) Calculate the required value of T_{a1} if the film temperature falls to 34°C, and the value if it rises to 36°C.

(e) If you solved Parts (c) and (d) correctly, you found that even though the air temperature is consistently higher than the film temperature in the dryer, so that heat is always transferred from the air to the film, the film temperature can drop from the inlet to the outlet. How is this possible?

(20 pts) The remainder of the assignment (5 problems) will be completed online using WileyPLUS. You can work with your team members to solve these problems, although note that each person may have unique values for some variables. **Each person should submit their own solutions through their own WileyPLUS link.** *You do not have to turn in any paperwork with this portion of the assignment.* Use the link for your class on the Moodle site, and then you can access the Assignment within WileyPLUS. The due date for the WileyPLUS completion is the same as for the homework assignment – the beginning of your class period. Note that the WileyPLUS assignment cannot be submitted late. *You do not have to turn in any paperwork with this portion of the assignment.* Use the link for your class on the Moodle site, and then you can access the Assignment within WileyPLUS. The due date for the WileyPLUS completion is the same as for the homework assignment – the beginning of your class period. Note that the WileyPLUS assignment cannot be submitted late. (There are no Excel problems to be submitted in this assignment).

Challenge problem for Honors Contract: FR&B **8.46**