Homework Set 7

Due: Thursday, October 27 (sections 001, 003, and 004) / Friday, October 28 (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. (**3 pts**) First, review the sections of the course syllabus on "Individual effort assessments for team homework" and "Team Policies and Expectations." On a single sheet of paper, put your names and list the rules and expectations you agree as a team to adopt. You should deal with any or all aspects of the responsibilities outlined above: preparation for and attendance at group meetings, making sure everyone understands all the solutions, cooperating with the team effort, communicating frankly but with respect when conflicts arise, etc. Each team member should sign the sheet, indicating acceptance of these expectations and intention to fulfill them. *These expectations are for your use and benefit: we won't grade them or even comment on them unless you ask us to.* Note, however, that if you make the list fairly thorough without being unrealistic, you'll be giving yourselves the best chance. For example, "We will each solve every problem in every assignment completely before we get together" or "We will get 100 on every assignment" or "We will never miss a meeting" are probably unrealistic, but "We will try to set up the problems individually before meeting" and "We will make sure that anyone who misses a meeting for good cause gets caught up on the work" are reasonable.

2. (**12 pts**) A vapor mixture containing 30 mole% benzene and 70% toluene at 1 atm is cooled isobarically in a closed container from an initial temperature of 115°C. Use the *Txy* diagram of Figure 6.4-1 to answer the following questions.
   (a) At what temperature does the first drop of condensate form? What is its composition?
   (b) At one point during the process the system temperature is 100°C. Determine the mole fractions of benzene in the vapor and liquid phases and the ratio (total moles in vapor/total moles in liquid) at this point.
   (c) At what temperature does the last bubble of vapor condense? What is its composition?

3. (**12 pts**) Three gram-moles of benzene and 7 gram-moles of toluene are placed in a closed cylinder equipped with a piston. The cylinder is immersed in a bath of boiling water that maintains the temperature at 100°C. The force exerted on the piston can be varied to adjust the cylinder pressure to any desired value. The pressure is initially 1000mm Hg and is gradually lowered to 600mm Hg. Use the *Pxy* diagram of Figure 6.4-1 to convince yourself that the cylinder initially contains only liquid benzene and toluene and to answer the following questions.
   (a) At what pressure does the first vapor bubble form? What is its composition?

(b) At what pressure does the last droplet of liquid evaporate? What is its composition?

(c) What are the liquid and vapor compositions in equilibrium with each other when the pressure is 750mm Hg? What is the ratio (moles vapor/mole liquid) at this point?

(d) Estimate the volume of the cylinder contents when the pressure is (i) 1000mm Hg, (ii) 750mm Hg, and (iii) 600mm Hg.

4. (**20 pts**) In this problem you will use a spreadsheet to create a *Txy* diagram for the benzene-chloroform system at 1 atm. Once the spreadsheet has been created, it can be used as a template for vapor–liquid equilibrium calculations for other species. The calculations will be based on Raoult's law(i.e., $y_iP . x_ip^*_i$), although we recognize that this relationship may not produce accurate results for benzene-chloroform mixtures.

   (a) Begin by establishing bounds on the system behavior. Look up the normal boiling points of chloroform and benzene and, without performing any calculations, sketch the expected shape of a *Txy* diagram for these two species at 1 atm.

   (b) Using APEx or Table B.4, estimate the normal boiling points of the two species and compare them to the results in Part (a).

   (c) Prepare a spreadsheet that has a title row "*Txy* Diagram for Ideal Binary Solution of Chloroform and Benzene." In the first cell of Row 2, place the label "*P* (mm Hg) =" and in the adjacent cell enter the system pressure, which for this case is 760. In Row 3 place headings for columns: xC, xB,T, p*C, p*B, P, yC, yB, and yC+yB. Not all of these columns are essential, but when filled, they will give a complete picture of the system and a final check of the calculations. Carry out the following procedures in each subsequent row:

   - Enter values for the mole fraction of chloroform (the first entry should be 1.000 and the last should be 0.000).
   - Calculate the mole fraction of benzene by subtracting the value in the previous cell from 1.000.
   - Enter an estimate of the equilibrium temperature that is between the two pure-component boiling points.
   - Use APEx or Table B.4 to estimate *p**C and *p**B from the estimated temperature.
   - Calculate *p*C and *p*B from Raoult's law.
   - Calculate *P* = *p*C + *p*B and apply the GoalSeek tool to adjust the value of *T* until *P* = 760 mm Hg.
   - Calculate *y*C and *y*B from the partial pressures and *P*.
   - Sum *y*C and *y*B to be sure they equal 1.000.

   Once you have completed a row for the first value of *x*C, you should be able to copy formulas into subsequent rows. When the calculation has been completed for all rows (i.e., *x*C = 0.0, 0.2, 0.4, 0.5, 0.6, 0.8, 1.0), draw the *Txy* diagram.

(d) Explain what you did in the bulleted sequence of steps in Part (c) giving relevant relationships among system variables. The phrase "bubble point" should appear in your explanation.

(e) The following vapor–liquid equilibrium data have been obtained for mixtures of chloroform (C) and benzene (B) at 1 atm.

T(°C)	80.6	79.8	79.0	77.3	75.3	71.9	68.9	61.4
x_C	0.00	0.08	0.15	0.29	0.44	0.66	0.79	1.00
y_C	0.00	0.10	0.20	0.40	0.60	0.80	0.90	1.00

Plot these data on the graph generated in Part (c). Estimate the percentage errors in the Raoult's law values of the bubble-point temperature and vapor mole fraction for xC = 0.44, taking the tabulated values to be correct. Why does Raoult's law give poor estimates for this system? <u>Each group should upload ONE Excel file to Moodle for part (c) as well as include a hard copy printout of the spreadsheet with the submitted HW.</u> Any individual in the homework group can submit the Excel file. Please name the file with the *number* of your homework group, i.e. HW 7_Group 46.xlsx. <u>The hard copy should be submitted as part of the homework set with Problem 4 – do not staple the sheet out of order to the back.</u> *Review the syllabus instructions about academic integrity related to spreadsheets.*

5. (**18 pts**) This problem deals with two-phase mixtures of benzene and toluene at equilibrium. The vapor phase may be assumed ideal, and Raoult's law can be used for all system compositions. Use APEx and Solver (<u>and not Figure 6.4-1</u>) for the requested calculations, and write out the equations you used to solve each part.

(a) Use the Gibbs phase rule to show that there are two degrees of freedom for the system.

(b) For T = 25°C and P = 50 mm Hg, estimate the liquid and vapor compositions.

(c) For T = 25°C and $x_B = 0.500$, estimate the pressure and vapor composition.

(d) For P = 100 mm Hg and $x_B = 0.500$, estimate the temperature and vapor composition.

(e) For P = 100 mm Hg and $y_B = 0.500$, estimate the temperature and liquid composition.

(f) For $x_B = 0.55$ and $y_B = 0.8$, estimate the temperature and pressure.

(**35 pts**) The remainder of the assignment (4 problems) will be completed online using WileyPLUS. <u>You can work with your team members to solve these problems</u>, although 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.

Challenge Problem: FR&B 5.3