Homework Set 4

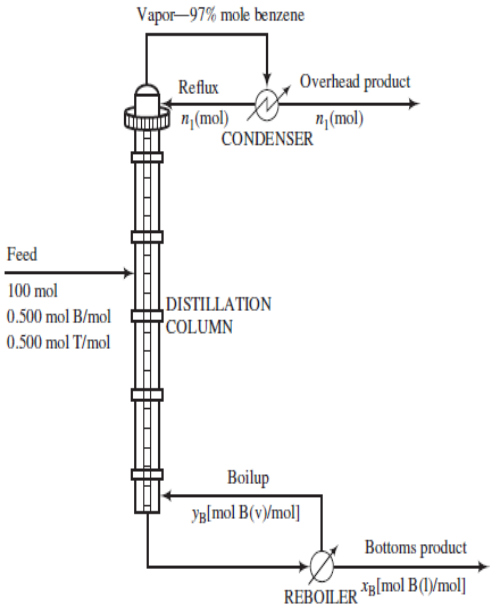
Due: Thursday, September 22 (sections 001, 003, 004)/Friday, September 23 (section 002)

This assignment is to be completed individually. The number in parentheses next to each problem shows how many points the problem is worth in the overall assignment. Please show all work and use correct significant figures to receive full credit. Be sure to follow the problem formatting instructions to avoid unnecessary deductions. 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 used to solve any equations.

1. **(5 pts)** Reflect on how you prepared for and took Test #1, why you missed what you missed, and what you can do to improve your performance next time.

2. (**20 pts**) A liquid mixture containing 30.0 mole% benzene (B), 25.0% toluene (T), and the balance xylene (X) is fed to a distillation column. The bottoms product contains 98.0% X and no B, and 96.0% of the X in the feed is recovered in this stream. The overhead product is fed to a second column. The overhead product from the second column contains 97.0% of the B in the feed to this stream. The composition of this stream is 94.0 mole% B and the balance T.
    a. Draw and label a flowsheet of this process and do the DOF analysis to prove that for an assumed basis of calculation, molar flow rates and compositions of all process streams can be calculated from the given information. Write in order the equations you would solve (if solving by hand) to calculate the unknown process variables. In each equation (or pair of simultaneous equations), circle the variable(s) for which you would solve. *Do not do the calculations.*
    b. Calculate (i) the percentage of the benzene in the process feed (i.e. the feed to the first column) that emerges in the overhead product from the second column and (ii) the percentage of toluene in the process feed that emerges in the bottom product from the second column.

3. (**20 pts**) An equimolar liquid mixture of benzene and toluene is separated into two product streams by distillation. A process flowchart and a somewhat oversimplified description of what happens in the process follow:



Inside the column a liquid stream flows downward and a vapor stream rises. At each point in the column some of the liquid vaporizes and some of the vapor condenses. The vapor leaving the top of the column, which contains 97 mole% benzene, is completely condensed and split into two equal fractions: one is taken off as the overhead product stream, and the other (the **reflux**) is recycled to the top of the column. The overhead product stream contains 89.2% of the benzene fed to the column. The liquid leaving the bottom of the column is fed to a partial reboiler in which 45% of it is vaporized. The vapor generated in the reboiler (the **boilup**) is recycled to become the rising vapor stream in the column, and the residual reboiler liquid is taken off as the bottom product stream. The compositions of the streams leaving the reboiler are governed by the relation

$$\frac{y_B / (1 - y_B)}{x_B / (1 - x_B)} = 2.25$$

where y_B and x_B are the mole fractions of benzene in the vapor and liquid streams, respectively.
(a) Take a basis of 100 mol fed to the column. Draw and completely label a flowchart, and for each of four systems (overall process, column, condenser, and reboiler), do the degree-of-freedom analysis and identify a system with which the process analysis might appropriately begin (one with zero degrees of freedom).
(b) Write in order the equations you would solve to determine all unknown variables on the flowchart, circling the variable for which you would solve in each equation. Do not do the calculations in this part.
(c) Calculate the molar amounts of the overhead and bottoms products, the mole fraction of benzene in the bottoms product, and the percentage recovery of toluene in the bottoms product (100 × moles toluene in bottoms/mole toluene in feed).

4. (**20 pts**) An evaporation–crystallization process of the type described in Example 4.5-2 is used to obtain solid potassium sulfate from an aqueous solution of this salt. The fresh feed to the process contains 19.6 wt% K_2SO_4. The wet filter cake consists of solid K_2SO_4 crystals and a 40.0 wt% K_2SO_4 solution, in a ratio 10 kg crystals/kg solution. The filtrate, also a 40.0% solution, is recycled to join the fresh feed. Of the water fed to the evaporator, 45.0% is evaporated. The evaporator has a maximum capacity of 175 kg water evaporated/s.
    a. Assume the process is operating at maximum capacity. Draw and label a flowchart and do the degree-of-freedom analysis for the overall system, the recycle–fresh feed mixing point, the evaporator, and the crystallizer. Then write in an efficient order (minimizing simultaneous equations) the equations you would solve to determine all unknown stream variables. In each equation, circle the variable for which you would solve, but don't do the calculations.
    b. Calculate the maximum production rate of solid K2SO4, the rate at which fresh feed must be supplied to achieve this production rate, and the ratio kg recycle/kg fresh feed.
    c. Calculate the composition and feed rate of the stream entering the crystallizer if the process is scaled to 75% of its maximum capacity.
    d. The wet filter cake is subjected to another operation after leaving the filter. Suggest what it might be. Also, list what you think the principal operating costs for this process might be.
    e. Use an equation-solving computer program to solve the equations derived in Part (a). Verify that you get the same solutions determined in Part (b).

(**35 pts**) The remainder of the assignment (3 problems) will be completed online using WileyPLUS. *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 4.54