Separation Processes, ChE 4M3, 2014

Assignment 5

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Objectives: We have been doing non-stop examples and problems in class. This assignment gives you a chance now to try some more problems related to liquid-liquid extraction, adsorption and drying; without my help and guidance.

All these questions are from prior exams and tests.

Question 1

The isotherm for benzene, at 25°C, on an activated carbon adsorbent is given as:

$$C_{\text{A,S}} = 32 C_{\text{A}}^{0.428}$$

where $C_{\text{A,S}}$ is in units of mg benzene per gram of carbon, and C_{A} is in units of mg benzene per litre of water-based solution.

You want to create your own adsorber packed bed from a piece of piping that has diameter of 24.5 cm.

The activated carbon supplier has given you the following specification sheet (and the isotherm information above):

- activated carbon mean diameter = 2 mm
- activated carbon size distribution range 0.4 mm to 3.8 mm
- activated carbon bulk density = 410 g/L
- activated carbon particle density = 520 g/L
- cost of activated carbon is $5.50 per kilogram.

You would like a breakthrough time of 4 hours when treating a feed stream containing 2.8 g of benzene per litre. You have to treat 30 L per minute of waste water.

1. What type of adsorption isotherm is this? **[1]**
2. How long should your packed bed be? Be clear with any simplifying assumptions you make. **[14]**

   Use the rule of thumb that if you cannot perform a lab experiment to calculate the MTZ, that your MTZ is 4ft, and assuming a symmetric wavefront, that the LUB $= 2 \times$ MTZ.
3. What will be the cost of the adsorbent you need to purchase? **[3]**

Question 2

A filter cake from a plate-and-frame press is to be dried by circulating warm, dry air over the solids. See this photo for a visual idea of what the material looks like. Trays are loaded with the solid, which is 3 cm high and an area of 2.0 m^2 per tray. Each tray contains 80 kg of wet filter cake, and the filtration press step leaves the solids with approximately 30 wt% moisture on a dry basis.

Air at 1 atmosphere, 70°C, and a relative humidity of 10% is used, at an approximate velocity of 4.2m.s^{-1}, in a direction that flows parallel to the solids.

1. Estimate the mass of water that would be evaporated from the cake after 4 hours. Be clear on all assumptions you make as you proceed. **[12]**
2. What is the moisture content of the cake after 4 hours, expressed on a dry basis? **[2]**
3. Name one method we can implement to reduce the drying time. **[1]**

Question 3

$140\,\text{kg.hr}^{-1}$ of a 40% acetone-in-water mixture are to be separated using trichloroethane as solvent.

1. Draw a flow diagram that illustrates the cross-current streams, having only 2 cross-current stages.
2. Draw a general flow diagram that illustrates the counter-current system, with two stages on one end, and two stages on the other end, and a general "Nth" stage in the middle.
3. If $80\,\text{kg.hr}^{-1}$ of pure solvent is fed into the first cross-current stage and $60\,\text{kg.hr}^{-1}$ into the second cross-current stage, what will be the acetone purity leaving in the raffinate from stage 1 and stage 2? Show all constructions and calculations on the ternary diagram (next page). Make sure all lines are clearly visible. *Hint*: you should achieve an acetone concentration in the raffinate of about 11%. **[8]**
4. What is the overall acetone recovery from such a 2-stage cross-current system? **[3]**
5. Now use a clean copy of the drawing (i.e. your assignment submission should have two ternary diagrams). In this second diagram start the construction for the counter-current system. The objective is to achieve the same (or better) raffinate concentration in terms of acetone as the cross-current system, but using $40\,\text{kg.hr}^{-1}$ of pure solvent.

   With a few basic lines on the drawing you should be able to find the values for these cross-current system:

   (a) the expected raffinate flow rate;

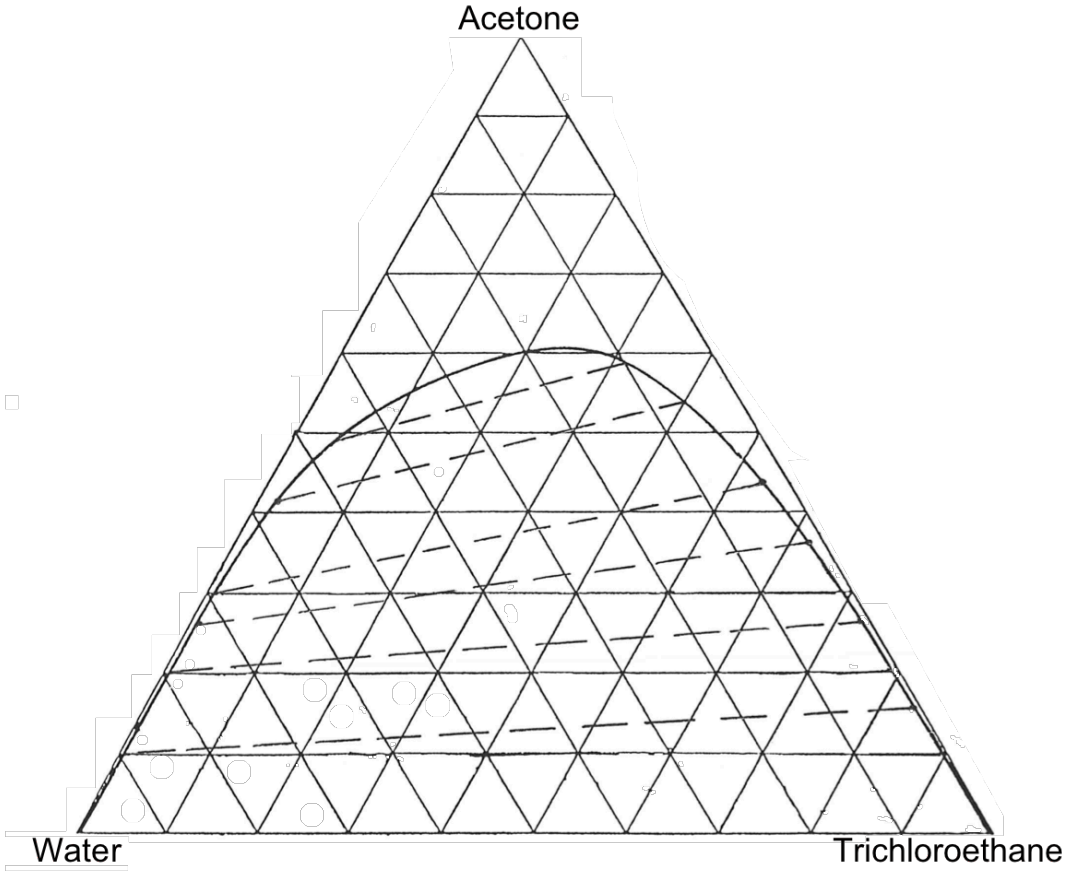
   (b) the expected extract flow rate;

   (c) the expected extract composition.
6. Now locate the operating point, P, and use this to calculate the number of stages required. Submit your ternary diagram showing these calculations.
7. Assume that the last stage is at the point you selected in part 5 of this problem (i.e. that it was at that desired 11% level for acetone). Calculate the recovery of acetone for the counter-current system.
8. Now compare **and contrast** the following parameters for the two configurations:

   - the extract concentration (for the cross-current system this is the blended concentrations of E_1 and E_2)
   - the extract flow rate
   - the recovery
   - the solvent use compared
   - *for extra credit*: the capital and operating costs compared between the two systems.

Student number: _____

*Question number:*_____



Feel free to use this page for calculations as well

Question 4 [0]

For practice.

A stream of acetic acid and water (also called diluent) is being fed in a counter current manner at 1000 kg/hour, in order to extract the acetic acid. The feed composition is 30 wt% acetic acid, and 70 wt% water.

The solvent is 99% pure IPE (isopropyl ether), and contains 1% acetic acid, at an inlet flow of 2500 kg/hour.

We desire the exiting raffinate stream to contain 5 wt% acetic acid.

1. Find the number of equilibrium stages to achieve this separation (show all calculations).
2. Calculate the exiting raffinate flow, and the exiting extract flow rate.

Unfortunately, we don't have the equilibrium data, however, various samples of the 3 species were made, mixed, and when they came to equilibrium they were found to have the following compositions (each row gives the aqueous and organic phase compositions):

Aqueous phase (weight %)			Organic phase (weight %)		
IPE	**Water**	**Acetic acid**	**IPE**	**Water**	**Acetic acid**
1.2	98.1	0.7	99.5	0.5	0
1.5	97.1	1.4	99.0	0.7	0.3
1.6	95.5	2.9	98.5	0.8	0.7
2.0	91.7	6.3	97	1	2
2.5	84.5	13	93	2	5
3	71	26	84	4	12
4	59	37	72	7	21
10	45	45	58	11	31
16	37	47	49	15	36

Feel free to download and use this empty ternary diagram. Electronic submissions that are based on photos are not acceptable, unless the photo is perpendicular to the page, and every detail is clear. If in doubt, submit your assignment in paper form.

Solution

See http://www.youtube.com/watch?v=N7MIH0_ELO0 for the full solution.

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