Separation Processes, ChE 4M3, 2013

Assignment 4

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Objectives: Understanding membrane separation processes and some practice with liquid-liquid extraction systems.

Question 1 [5]

An microfiltration membrane operating with pure feed of water produces a flux of 0.05 $\text{kg.s}^{-1}.\text{m}^{-2}$ when operated with an applied pressure different of 25 kPa.

1. What is the resistance component due to the membrane? Specify the units.
2. If operated with a protein-water mixture at a 22 kPa pressure difference, a flux of $242 \times 10^{-6}\,\text{kg.s}^{-1}.\text{m}^{-2}$ is measured at steady state. What is the resistance due to cake build-up? Specify the units.

Question 2 [25]

An ultrafiltration membrane is to be used to separate paint from a liquid stream, and to achieve a more concentrated paint-water mixture. You plan to use several Zeeweed 1500 membrane modules (download the fact sheet and watch the video). The supplier has given you the performance equation, based on some joint test work on their experimental system:

$$J_v = 0.042 \ln \left(\frac{27}{C} \right)$$

where the bulk concentration C has units of kg.m^{-3} and flux is measured in $\text{m}^3.\text{hour}^{-1}.\text{m}^{-2}$.

The feed waste stream arrives at a flow rate of 5.1 $\text{m}^3.\text{hour}^{-1}$ with concentration of 0.6 kg.m^{-3}. The aim is to achieve a paint-water concentration leaving the membrane of 20 kg.m^{-3}, so that it can be reused.

1. What is the flow rate of the cleaned water from the system? (We might be able to use it elsewhere in our process)
2. What number of modules would we have to purchase if operated in a single-stage feed-and-bleed configuration?
3. We could consider two membrane systems in series, where each system can have a different area. How many modules should you use in system 1 and how many modules in system 2, so that the total number of modules you buy are at a minimum?
4. For this 2 systems in series arrangement, what will be the total flow of cleaned water (*hint*: think carefully!)
5. What are your thoughts on putting four stages in series?

Please note: it is in your interest to solve this problem as if it were in a test or exam; i.e. don't use computer software. Solve part 3 on a computer after you've done some guess-and-check by hand.

Question 3 [15]

We are testing a RO membrane at 25°C. The feed contains 0.5 wt% NaCl at a flow rate of 1250 L/hour. The retentate is at 1.4 wt% NaCl and the permeate at 0.012 wt%. The pressure drop applied is 15 atmosphere. When using pure water, the permeate flow is 1000 L/hour at the same pressure drop.

Note: the osmostic pressure difference can be approximated from the difference between the *retentate* and permeate concentrations (initially we used the feed minus permeate concentrations when we didn't have the retentate concentration). The reality is the osmostic pressure difference should be calculated from values between the feed and retentate concentrations, integrated as it changes along the the membrane area.

1. Find the outlet flow rates of the permeate and the retentate.
2. What is the numerical value of the "cut"?
3. What is the separation factor's value for this system?

Question 4 [15 = 2 + 2 + 2 + 4 + 2 + 1 + 2]

Final exam, 2012

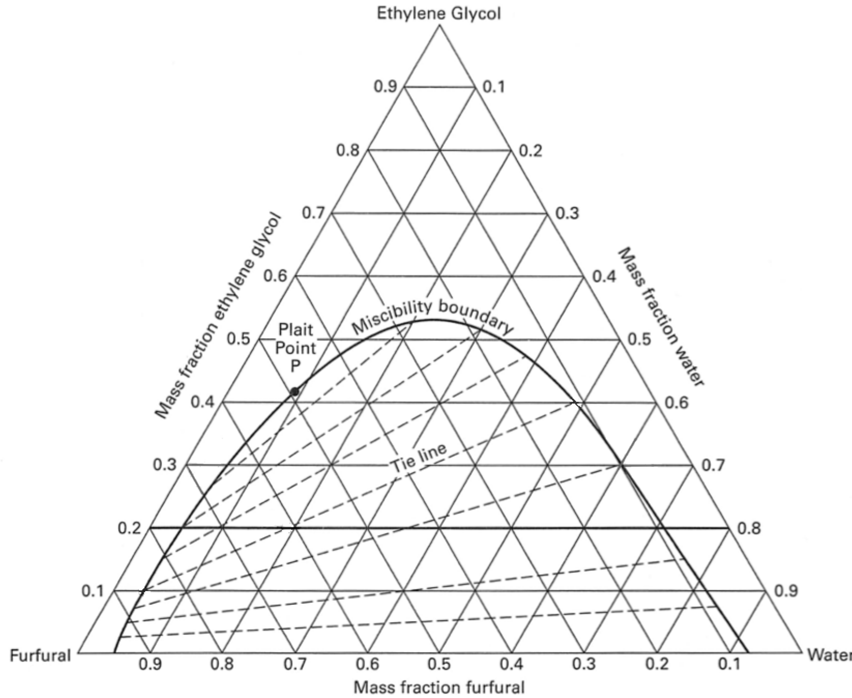
Reverse osmosis of a $50\,\text{g.L}^{-1}$ sucrose-water solution is being experimentally investigated. The osmotic pressure in a sucrose-water system is approximated by $\pi = 0.054m$, where m is the sucrose concentration in g.L^{-1}, and π has units of atmospheres. The membrane is operated so the cut is 40%, with a feed rate of $0.25\,\text{m}^3.\text{hr}^{-1}$. Using a pressure difference of 30 atm, the permeance of the membrane with respect to the solvent is $5.4 \times 10^{-4}\text{kg.s}^{-1}.\text{m}^{-2}.\text{atm}^{-1}$. For reference, the molar mass of water is $18\,\text{g.mol}^{-1}$, and for sucrose it is $342\,\text{g.mol}^{-1}$.

If the retentate concentration leaving the system is measured as $81.8\,\text{g.L}^{-1}$ of sucrose, calculate the following other quantities:

1. The retentate flow rate leaving the membrane. **[2]**
2. The permeate concentration in g.L^{-1}. **[2]**
3. The osmotic pressure difference across the membrane. **[2]**
4. The solvent (water) flux expressed in LMH. **[4]**
5. The solute (sucrose) **mass** flux expressed on an hourly basis. **[2]**
6. The rejection coefficient. **[1]**
7. The separation factor. **[2]**

Question 5 [20]

The aim is to recover ethylene glycol from water using furfural as solvent (the ternary diagram for furfural, ethylene glycol and water at the unit's operating temperature is provided).



1. Calculate the equilibrium compositions leaving a single mixer-settler unit operated at:
   - the recycled solvent stream: $120\,\text{kg.hr}^{-1}$ with a composition of 80% furfural, and unrecovered ethylene glycol at 5%, with the rest being water.
   - the feed stream contains 40% ethylene glycol and 60% water at a rate of $200\,\text{kg.hr}^{-1}$.
2. Calculate the flow rates of the extract and raffinate streams.
3. What is the distribution (partition) coefficient, D_A, for A = ethylene glycol (see course notes for definition)?
4. What is the distribution (partition) coefficient, D_C, for C = water, using this same definition?
5. What is the separation factor for i = ethylene glycol from j = water in the 1=extract and 2=raffinate streams? Also show the relationship between the separation factor and the previous two distribution coefficients.

END