Separation Processes, ChE 4M3, 2012

Assignment 4

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Objectives: Understanding membrane separation processes.

Question 1 [5; already answered as pop-quiz in class; do not re-submit a solution]

A microfiltration membrane operating with pure feed of water produces a flux of 0.06 kg.s^{-1}.m^{-2} when operated with a TMP of 30 kPa.

1. What is the resistance due to the membrane? Specify the units.
2. If operated with a protein-water mixture at a 20 kPa pressure difference, a flux of 216×10^{-6} kg.s^{-1}.m^{-2} is measured at steady state. What is the resistance due to cake build-up? Specify the units.

Question 2 [20; but please see the next paragraph though]

Please answer part A **or** part B. Part A was the class submission you handed in on 16 October. If you handed in at class, and want to keep that as your submission (i.e. less work for you in this assignment), then please indicate that in your assignment submission. If you prefer to do part B (i.e. because you feel you can do a better job than part A you handed in earlier) please submit the answer only to part B. We will either grade part A or part B, but not both. My suggestion is to do part B, mainly so you get practice on a different problem.

Part A

An asymmetric ultrafiltration membrane is used with the aim of separating dyes from a liquid stream and to achieve a more concentrated dye-water mixture. The feed waste stream arrives at a flow rate of 2.2 m^3.hour^{-1} with concentration of 1.2 kg.m^{-3}. The membrane's operating characteristic was calculated from various experiments:

$$J_v = 0.04 \ln \left(\frac{15}{C} \right)$$

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

If two membrane modules, each of area 25 m^2, are simply placed in series, give reasonable estimates of:

1. the dye concentration from the first membrane module?
2. the permeate flow rate from the first membrane module?
3. the dye concentration from the final membrane module?
4. the permeate flow rate from the final membrane module?
5. Then explain whether the above answers seem reasonable.

Please show all calculations, assumptions and relevant details.

Part B

An asymmetric ultrafiltration membrane is used with the aim of separating dyes from a liquid stream and to achieve a more concentrated dye-water mixture. The feed waste stream arrives at a flow rate of $3.0\,\mathrm{m}^3$.hour^{-1} with concentration of 0.5 kg.m^{-3}. The aim is to achieve a dye-water concentration leaving the membrane of 20 kg.m^{-3}, so that it can be reused to dye fabric. The membrane's operating characteristic was calculated from various experiments:

$$J_v = 0.04 \ln \left(\frac{25}{C} \right)$$

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

We have tubular membranes available from a supplier, but only as 30 m^2 modules. The modules are placed in parallel, so the effectively can be treated as one large membrane.

1. What is the flow rate of the cleaned water from the system (we can 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. What would be the *optimal* module arrangement if operated with two stages of feed-and-bleed in series? (*hint*: optimal should be taken to be the smallest number of modules per feed-and-bleed stage; each stage may have a different area).
4. For the optimal arrangement you choose: specify what will be the total flow of cleaned water (*hint*: think carefully!)
5. What are your thoughts on putting four feed-plus-bleed 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.

Question 3

At 25 °C in a lab membrane with area $A = 2 \times 10^{-3}\,\mathrm{m}^2$ we feed a solution of 10 kg NaCl per m^3 solution so well mixed that essentially it has the same strength leaving.

The permeate is measured as 0.39 kg NaCl per m^3 solution at a rate of $1.92 \times 10^{-8}\,\mathrm{m}^3.\mathrm{s}^{-1}$ when applying a constant pressure difference of 54.42 atm.

Calculate:

1. the permeance constants for the solvent
2. the permeance constants for salt (these type of constants are previously given, but this question shows how they may be calculated experimentally)
3. the rejection coefficient.

Question 4 [5]

Why did we not take osmotic pressure in account for microfiltration and ultrafiltration? Perform a representative calculation to prove your answer.

Question 5

Reverse osmosis with an NaCl-water feed, 2.5 wt% NaCl is being separated into a permeate and retentate stream using a TMP of 27.2 atm at 25 °C.

Through lab experiments (e.g. see a previous question in this assignment), the permeance of the membrane with respect to salt is 4.2×10^{-7} m.s^{-1} and solvent is 5.0×10^{-4} kg.s^{-1}.m^{-2}.atm^{-1}. The membrane is operated so the cut is unusually low, at 10%, producing a permeate stream of 0.38 m^3 per hour.

Calculate the permeate concentration, retentate concentration, rejection coefficient, and separation factor. It is not reasonable to assume that the feed and retentate concentration are the same in this problem: we require accurate estimates.

Question 6 [5]

Self-directed learning question : write no more than 0.5 page (i.e. 2 paragraphs) that answer **all** of the following questions in that space.

1. Where are membrane bioreactors used?
2. What do they separate?
3. What material(s) is/are they made from?
4. What is the advantage over the usual separation step that MBRs replace?
5. Who are the main manufacturers of MBRs?
6. What is the typical lifetime of an MBR unit?

For those in the class not familiar with self-directed learning: it is a valuable skill, that you will require in your future career, to be able to extend your existing knowledge into a new area and potentially apply that knowledge.

END