ENV 4417: WATER QUALITY & TREATMENT

Fall 2015	University of South Florida
Problem set #3	Civil & Environmental Eng.
Due Thursday, Oct. 1	Prof. J. A. Cunningham

1. (20 pts) Answer questions 11.70 and 11.71 in the text book (10 points each).

2. (20 pts) From: *Principles of Water Treatment*, Howe et al., 2012.
   An inside-out hollow-fiber-membrane system is operated with a cross-flow configuration. Each modeule contains 10,200 fibers that have an inside diameter of 0.9 mm and a length of 1.75 m. Calculate the following for one module:
   a. Feed flow necessary to achieve a cross-flow velocity of 1 m/s at the entrance to the module.
   b. Permeate flow rate if the system maintains an average permeate flux of 80 L/(m^2•hr).
   c. Cross-flow velocity at the exit to the module. (*Hint: it is less than 1 m/s because some of the influent water is collected as permeate.*)
   d. Ratio of the cross-flow velocity at the entrance of the module to the flow velocity toward (*i.e.*, *through*) the membrane surface. Given the magnitude of this ratio, what effect would you expect cross-flow velocity to have on fouling in cross-flow verus dead-end filtration?
   e. Ratio of permeate flow rate to feed flow rate (known as the single-pass recovery). What impact does this ratio have on operational costs in cross-flow versus dead-end filtration?

3. (15 pts) From: *Water and Wastewater Engineering: Design, Principles, and Practice*, Davis, 2011.
   The city of Yeehaw has a water demand of 2.75 mgd during the winter and 4.12 mgd during the summer. Yeehaw is installing a membrane filtration system to remove particles from the water during treatment. If the membrane filtration system is designed for the winter demand, can the system meet the summer demand with the same area of membrane? The winter and summer conditions are as follows:
   - maximum trans-membrane pressure = 152 kPa = 1.52 bar
   - operating trans-membrane pressure = 75% of maximum
   - membrane resistance coefficient = 2.94×10^{12} m^{-1}
   - winter water temperature = 4 °C
   - summer water temperature = 20 °C

   Hint #1: Look up the viscosity of water at these two temperatures.
   Hint #2: Find the membrane area required to meet the winter demand.

4. (5 pts) Consider a reverse-osmosis pressure vessel that contains seven spiral-wound RO elements. If the recovery of each element is 10%, what is the overall recovery of the pressure vessel? (These are all pretty realistic numbers.)

5. (30 pts) Reverse osmosis is being used to treat a stream of salty water, flow rate 1500 L/hr, that contains 1% NaCl by mass. The water is treated with a spiral-wound RO module that has a membrane surface area of 5.0 m^2. The water temperature is 15 °C and the applied trans-membrane pressure is 60 bar. At these conditions, the recovery of the RO system is 10% and the rejection is 98%. The osmotic coefficient of the feed is $\phi = 0.95$, and the osmotic coefficient of the permeate is something very close to 1.0.
   a. Esimtate/calculate the concentration of NaCl in both the feed and the permeate in units of mol/L and in units of mg/L.
   b. Estimate/calculate the osmotic pressure of both the feed and the permeate, in units of bar.
   c. Estimate/calculate the mass transfer coefficient, k_w, for the water flux throught he RO membrane, in units of L/(m^2•hr•bar). Hint: find the water flux, J_w, through the membrane.
   d. Estimate/calculate the mass transfer coefficient, k_s, for the salt flux through the RO membrane, in units of mg/(m^2•hr•bar). Hint: find the salt flux, J_s, through the membrane.
   e. Suppose the concentration of NaCl in the feed stream doubled to 2%. If the trans-membrane pressure is not changed, estimate the recovery and the rejection that you would expect for the new feed condition. You can assume that the osmotic coefficient is still $\phi = 0.95$ for the feed. Hint: use the mass-transfer coefficients that you found in parts (c) and (d), above.
   f. Comment briefly on the effect that the quality of the feed water has on the performance of reverse osmosis.

6. (10 pts) From: *Water and Wastewater Engineering: Design, Principles, and Practice*, Davis, 2011.
   Each pressure vessel in a proposed design for the softening of brackish groundwater is rated at 45% recovery at flow rates between 750 and 1000 m^3/d. Design an array system that will yield at least 4,000 m^3/d (*about 1 mgd*) of treated water for a town of 7,000 people at a permeate recovery of at least 80%.