Worksheet: Reverse osmosis

Name(s)_____

A reverse osmosis (RO) membrane separates a saltwater solution into a permeate stream (purified water) and a retentate stream (higher salt concentration solution). Reverse osmosis uses a high pressure on the feed side (salt water) of a semi-permeable membrane to overcome the osmotic pressure. The experiment examines the effects of feed pressure and salt concentration on permeate flow rate and salt rejection. Reverse osmosis is used on a large scale to convert sea water to fresh water.

Student Learning objectives

1. Be able to explain the operational principles of reverse osmosis.
2. Be able to calculate permeate flux and salt rejection for a RO membrane.
3. Observe the effects of pressure and feed concentration on permeate flow rate and salt rejection.

Equipment

- A feed tank containing a 1-3% NaCl solution.
- A high-pressure pump with a pressure gauge to measure the pressure applied to the RO unit.
- A lab-scale RO system with a feed inlet, a semi-permeable membrane (10 cm^2 surface area), and permeate and retentate outlets.
- A back-pressure regulator to control the feed side pressure.
- Beakers to collect the permeate and retentate streams.
- A conductivity meter to measure the salt concentrations in the feed, permeate, and retentate streams.

Put drawing of equipment here with inlet and outlet streams labeled

Questions to answer before starting experiment

Do you expect the percent of salt rejected to increase or decrease as the salt feed concentration increases?

Do you expect the percentage of salt rejected to increase or decrease as the feed pressure increases?

Start up

Calibrate the conductivity meter by measuring the conductivity of several solutions of different concentrations.

NaCl concentration (%)	Conductivity (mS/cm)
0.5	
1.0	
1.5	
2.0	
2.5	
3.0	
3.5	

Fill the feed tank with deionized water and flush the system to remove any contaminants or residual salt from previous experiments.

Experiments

Fill the feed tank with a 1.0% salt solution. Measure and record the conductivity of the feed solution.

Salt concentration _____

Conductivity _____

Measure the feed solution temperature.

Temperature _____

Start the pump and adjust the back-pressure regulator to increase the pressure to 15 bar.

Allow the system to reach steady state (typically 5-10 minutes in a physical experiment).

Start collecting the permeate and retentate solutions in beakers and start a timer.

After collecting sufficient amounts of the two solutions, record their volumes and the time and calculate the permeate and retentate flow rates. Record the data in the Table below.

Measure conductivities of the two solutions and use your calibration to convert conductivities to concentrations and record in the Table.

Raise the feed pressure to 22 bar and repeat the measurements and record the data in the Table.

Raise the feed pressure to 28 bar and repeat the measurements and record the data in the Table.

Repeat measurements at the three pressures for a 3.0% feed and record data in the Table.

Table 1										
Feed pressure (bar)	Feed conc. %	Time (s)	Permeate volume (cm^3)	Retentate volume (cm^3)	Permeate flow rate (cm^3/s)	Retentate flow rate (cm^3/s)	Permeate cond. mS	Retentate cond. mS	Permeate conc. %	Retentate conc. %
15	1.0									
22	1.0									
28	1.0									
15	3.0									
22	3.0									
28	3.0									

Analysis

Do mass balances for each experiment and record in Table 2 the percent of salt and water in the feed that appears in the system effluent.

Calculate the salt rejection for each experiment and record in Table 2.

$$salt\ rejection\ (\%) = \left(1 - \frac{permeate\ conc}{feed\ conc}\right) x100$$

Calculate the permeate flux (J) and record in Table 2.

$J = \frac{F_{permeate}}{A}$ where $F_{permeate}$ is the permeate flow rate (cm^3/s) and A is the membrane area (cm^2)

Table 2					
Feed pressure (bar)	Feed conc. %	Salt effluent/salt feed %	Water effluent/salt feed %	Salt rejection	Permeate flux ($cm^3/(s\ cm^2)$)
15	1.0				
22	1.0				
28	1.0				
15	3.0				
22	3.0				
28	3.0				

Plot the permeate flux and salt rejection against the applied pressure. Discuss how increasing pressure impacts water flux and salt rejection.

Question to answer

How does a higher salt concentration affect the permeate flux and salt rejection?