Worksheet: Reverse osmosis

Name(s)____

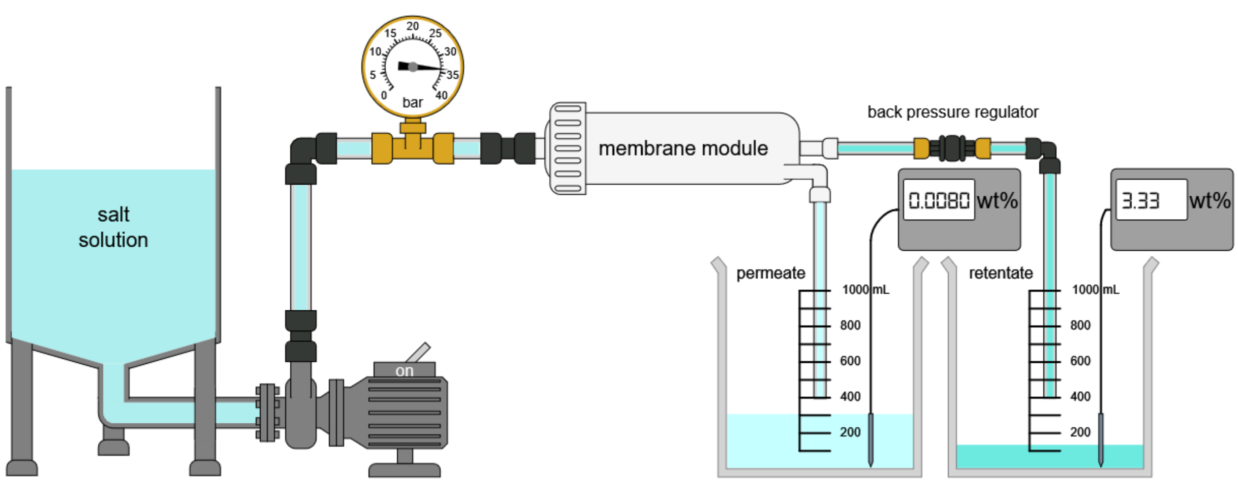
A reverse osmosis (RO) membrane separates a saltwater solution into a permeate stream (purified water) and a retentate stream (higher salt concentration solution). Reverse osmosis uses a high pressure on the feed side (salt water) of a semi-permeable membrane to overcome the osmotic pressure. The experiment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

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.
4. Apply mass balances to a reverse osmosis system.

Equipment

- A feed tank containing a 0.5-3.5% NaCl solution.
- A high-pressure pump and a pressure gauge to measure the pressure applied to the feed side of the RO unit.
- A lab-scale RO system with a feed inlet, a semi-permeable membrane (0.50 m^2 surface area), and permeate and retentate outlets.
- A back-pressure regulator at the exit of the retentate stream from the module controls the pressure on the feed side.
- Beakers to collect the permeate and retentate streams.
- Conductivity meters measure salt concentrations in the permeate and retentate streams.



Questions to answer before starting experiment

Do you expect the percentage 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?

For a NaCl feed concentration of 3.0%, is there a minimum feed pressure to collect permeate? Why?

Experiments

1. Select a feed temperature of 15°C.
2. Select a salt feed concentration of 0.5% NaCl.
3. Select a feed pressure of 15 bar.
4. Turn on the pump and allow the system to pressurize and reach steady state.
5. After collecting measurable amounts of liquid in the permeate and retentate beakers, record the volumes and start a timer. You may want to zoom with the scroll wheel to measure the liquid volumes more accurately.
6. After collecting enough of each solution, record their volumes and the elapsed time. Record the data in Table 1.
7. Record the permeate and retentate concentrations in Table 1.
8. Reset the system and repeat these measurements at 25, 35, and 40 bar feed pressure and record in Table 1.
9. Reset the system, change the salt feed concentration to 2.5 %, and make measurements at 25, 35, and 40 bar and record in Table 1. Why is the suggested lowest pressure 25 bar instead of 15 bar when the feed concentration is 2.5%?
10. Reset the system, set a feed temperature of 50°C, and make measurements for a feed concentration of 0.5% and feed pressures of 15, 25, 35, and 40 bar, and record the results in Table 2.

11. Calculate the permeate and retentate flow rates from all measurements and record these values in Tables 1 and 2.

Table 1 Measurements at 15ºC

Feed pressure (bar)	Feed conc. %	Time (s)	Permeate starting volume (cm^3)	Permeate final volume (cm^3)	Retentate starting volume (cm^3)	Retentate final volume (cm^3)	Permeate flow rate (cm^3/s)	Retentate flow rate (cm^3/s)	Permeate conc. %	Retentate conc. %
15	0.5									
25	0.5									
35	0.5									
40	0.5									
25	2.5									
35	2.5									
40	2.5									

Table 2 Measurements at 50ºC

Feed pressure (bar)	Feed conc. %	Time (s)	Permeate starting volume (cm^3)	Permeate final volume (cm^3)	Retentate starting volume (cm^3)	Retentate final volume (cm^3)	Permeate flow rate (cm^3/s)	Retentate flow rate (cm^3/s)	Permeate conc. %	Retentate conc. %
15	0.5									
25	0.5									
35	0.5									
40	0.5									

Analysis

Calculate the average salt concentration in the two beakers and enter the values in Table 3. How much do these values differ from the feed concentration?

Average salt concentration $= \dfrac{permeate\ volume * permeate\ conc + retentate\ volume * retentate\ conc}{permeate\ volume + retentate\ volume}$

Calculate the salt rejection for each experiment and record in Table 3.

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

Calculate the permeate flux (J) for each experiment and record in Table 3.

$J = \frac{F_{permeate}}{A}$ where $F_{permeate}$ is the permeate flow rate (cm^3/s) and A is the membrane area ($5.0 \times 10^3\ cm^2$)

Table 3

Feed pressure (bar), temperature (^oC)	Feed conc. %	Average salt concentration %	Salt rejection	Permeate flux ($cm^3/(s\ cm^2)$)
15, 15^oC	0.5			
25, 15^oC	0.5			
35, 15^oC	0.5			
40, 15^oC	0.5			
25, 15^oC	2.5			
35, 15^oC	2.5			
40, 15^oC	2.5			
15, 50^oC	0.5			
25, 50^oC	0.5			
35, 50^oC	0.5			
40, 50^oC	0.5			

Plot the permeate flux and salt rejection versus the pressure difference across the membrane for the two salt feed concentrations at 15^oC. Discuss how increasing pressure impacts water flux and salt rejection.

Plot the permeate flux versus (pressure difference – osmotic pressure) for the two salt concentrations at15ºC. What do you observe?

Compare the measurements at 15ºC and 50ºC. What changed as the temperature increased?

Questions to answer

How do higher salt concentrations affect the permeate flux and salt rejection?

What safety precautions would you take to carry out this experiment in the laboratory?

What other factors should be considered to carry out this process on a large scale?