CE 370

Membrane Processes – Part 2

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Reverse osmosis - Defenition

- It is the process of forcing a solvent (like water) from a region of high solute (such as salts of Soudium, Potasium, etc…) concentration through a membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure.
- It is the reverse of the normal osmosis process, which is the natural movement of solvent from an area of low solute concentration, through a membrane, to an area of high solute concentration when no external pressure is applied.
- The membrane here is semipermeable, meaning it allows the passage of solvent but not of solute.

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Reverse osmosis – How it works

- Reverse osmosis occurs when the water is moved across the membrane against the concentration gradient, from lower concentration to higher concentration.
- To illustrate, imagine a semipermeable membrane with fresh water on one side and a concentrated aqueous solution on the other side. If normal osmosis takes place, the fresh water will cross the membrane to dilute the concentrated solution.
- In reverse osmosis, pressure is exerted on the side with the concentrated solution to force the water molecules across the membrane to the fresh water side.

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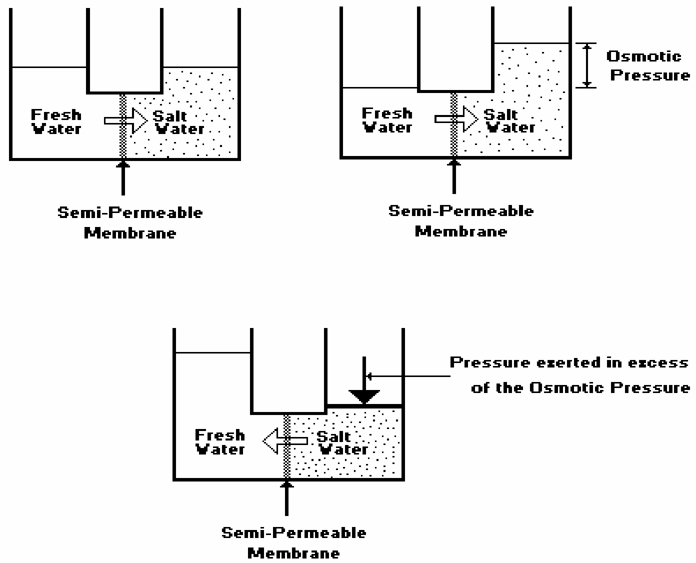
Reverse osmosis – How it works



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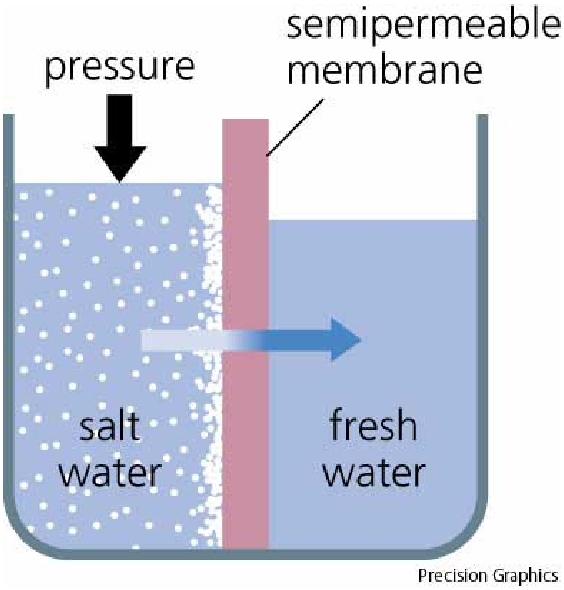

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Reverse osmosis – Osmotic Pressure

- The osmotic pressure of solutions of electrolytes may be determined by the following equation:

$$\pi = \phi \nu \frac{n}{V} RT$$

Where;

- π = osmotic pressure
- ϕ = osmotic coefficient
- ν = number of ions formed from one molecule of electrolyte
- n = number of moles of electrolyte
- V = volume of solvent
- R = universal gas constant
- T = absolute temperature

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Reverse osmosis – Osmotic Pressure

- The osmotic pressure for see water, which has 35,000 mg/l dissolved solids, is 397 psi (2740 kPa) at 25°C.
- It can be assumed that an increase of 1000 mg/l salt concentration results in an increase of approximately 11.3 psi (78 kPa) in osmotic pressure.
- For example, the osmotic pressure of a solution that has 23,000 mg/l of TDS is:

$$\pi = 23{,}000 \times \frac{11.3}{1000} = 260\ \text{psi}$$

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Reverse osmosis – Flux

- The main design parameter for a reverse osmosis unit are the production per unit area of membrane and water quality.
- The production is measured by the flux of water through the membrane (gal/day-ft^2 or *l*/day-m^2).
- The flux is related to the pressure by the following equation:

$$F_w = K(\Delta p - \Delta\pi)$$

Where

F_w = water flux (gal/day-ft^2 or l/day-m^2)

K = mass transfer coefficient (gal/d-ft^2-psi or l/d-m^2-kPa)

Δp = pressure difference between feed and product water (psi or kPa)

$\Delta\pi$ = osmotic pressure difference between feed and product water (psi or kPa)

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Reverse osmosis – Flux

- The membrane flux value furnished by manufacturer is usually for 25°C. Temperature variations causes the flux to vary. Therefore, membrane area correction (A_T/A_{25}) should be considered as the following:
  - For 10°C,1.58; 15°C, 1.34; 20°C, 1.15; 25°C, 1.00; 30°C, 0.84
- The term (A_T/A_{25}) is the ratio of the areas required for temperatures of T°C and 25°C.

Reverse osmosis – Flux

- The flux value will gradually decrease during the lifetime of a membrane which occurs in all membranes and is permanent.
- The membrane must be replaced when the flux has reached the minimum acceptable level set by the membrane manufacturers.
- Usually, the life span of a membrane is from few months to several years.
- Pre-treatment of the raw water is essential to make sure that the membrane serves its design lifetime.
- Pre-treatment includes removal of turbidity and other impurities, adjusting the pH, removal of chlorine for some types of membrane materials, adjusting temperature, etc…

Types of Reverse Osmosis Membranes

- The most common membrane materials are polyamide thin film composites (TFC) or cellulose-type **membranes**.
- TFC membranes are:
  - More costly, but have greater strength and durability than cellulose-**types**
  - They have higher total dissolved solids (TDS) rejection rates
  - Are more resistant to microbial attack and are more tolerant of high pH
  - Deteriorate in chlorinated water.
- Cellulose type membranes are:
  - less costly than TCF membranes
  - Can tolerate chlorine which is commonly used for disinfection of drinking water.
- Another type of membrane is a sulfonated polysulfone (SPS) membrane.
  - tolerant of chlorine and can withstand higher pH levels
  - are more costly than cellulose-types and less effective than TFC membranes
  - SPS membranes can be used in RO systems when the water is soft and pH is high

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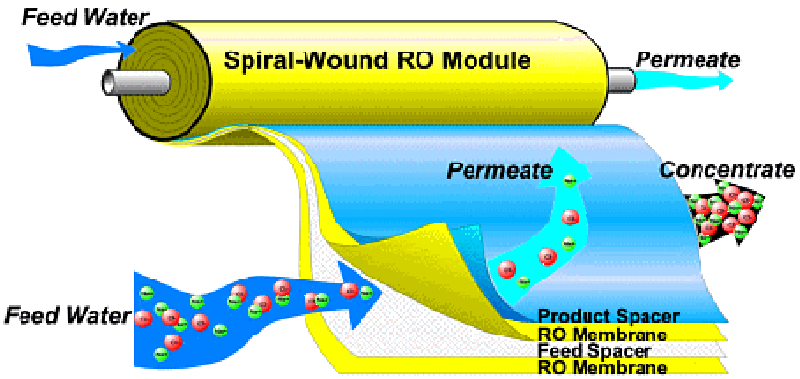
Types of Reverse Osmosis Membranes

- Spiral wound (like a rolled up newspaper):



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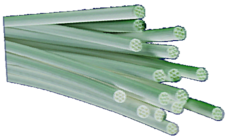
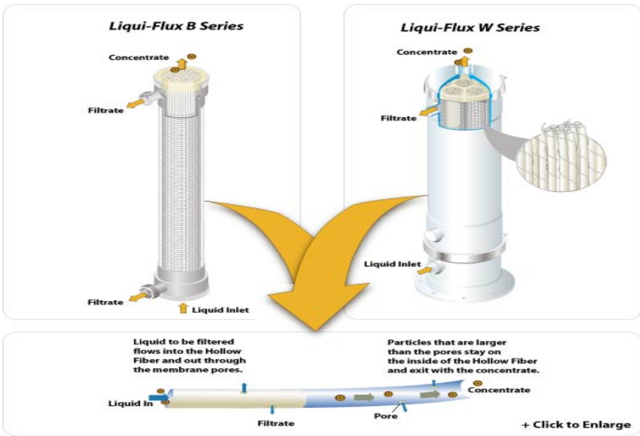
Types of Reverse Osmosis Membranes

- Hollow fibers: can be bundled together. This provides a very large surface area for water treatment within a compact tube element.





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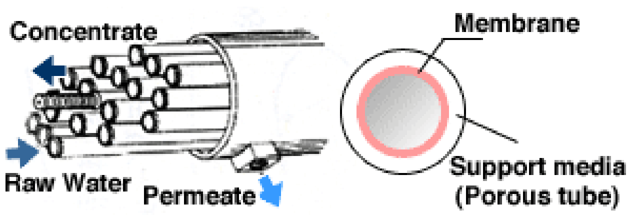
Types of Reverse Osmosis Membranes

- Hollow fibers.



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Reverse Osmosis - Example

Example 14.2 page 406:

A reverse osmosis unit is to demineralize 760,000 l/d of tertiary treated effluent. Pertinent data are as follows: mass transfer coefficient = 0.2068 l/(d-m^2)(kPa) at 25^{o}C, pressure between the feed and product water = 2400 kPa, osmotic pressure difference between the feed and product water = 310 kPa, lowest operating temperature = 10^{o}C, and A_{10C} = 1.58 A_{25C}. Determine the membrane area required.

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Reverse Osmosis - Example

Solution:

The water flux is given by equation (14.6):

$$F_w = K(\Delta p - \Delta \pi)$$

F_w = [0.2068 l/(d-m^2)(kPa)]×(2400 kPa – 310 kPa)
= 432.21 l/(d-m^2) at 25^{o}C

The area is given by:
A = (760,000 l/d)/(432.21 l/(d-m^2) = 1758.4 m^2 at 25^{o}C

The area at 10^{o}C is given by:
A_T/A_{25} = 1.58, therefore:
A (at T=10^{o}C) = $A_{25\ C}$ × 1.58 = 1758.4 × 1.58 = 2780 m^2

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Reverse Osmosis - Application

- RO finds extensive applications in the following:
  - Producing potable water from sea or brackish water.
  - Ultrapure water for food processing and electronic industries
  - Pharmaceutical grade water
  - Water for chemical, pulp & paper industry
  - Waste treatment etc.

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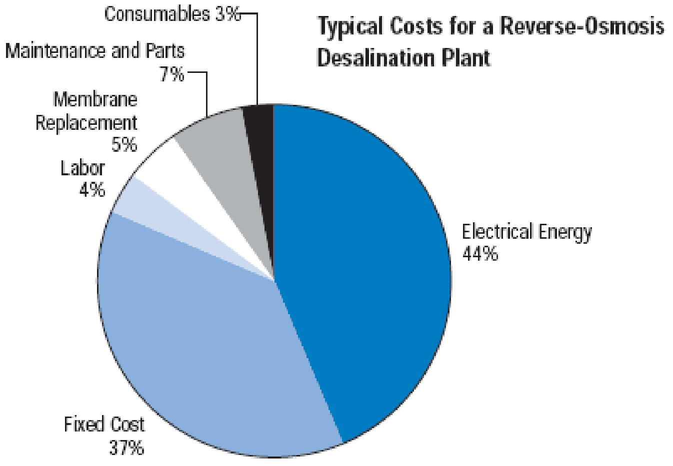
Reverse Osmosis - Cost



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Membrane Installations

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Reverse Osmosis Process Schematic…