Desalination of Seawater by Reverse Osmosis

April Youn
Fall 2010
Simon Fraser University
November 19, 2010

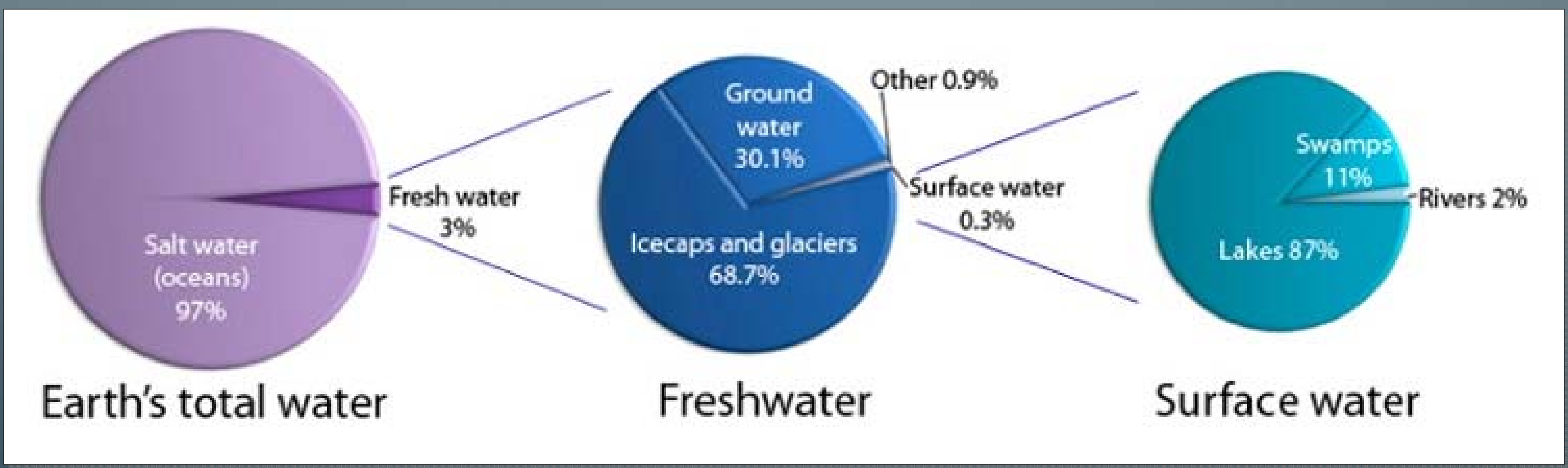
Presentation Outline

- Composition of seawater
- What is reverse osmosis
- Pre treatment of feed water
- Reverse osmosis membrane
- Post treatment of permeate
- Future aspects of reverse osmosis

Water

- 97.5% of the earths water is seawater and the remaining 2.5% is freshwater found in glaciers and underground

Figure 2: Illustration of water on Earth



Can We Drink Seawater

Figure 2: Clip of Homer trying to drink seawater

Simpsons season 5, episode 8: Boy Scoutz 'n the Hood

Composition of Seawater

- Total Dissolved Solids (TDS) are inorganic salts and small amounts of organic matter that are dissolved in water
- The TDS is seawater ranges 10,000 to 45,000ppm compared to fresh water that is 1500ppm

Chemical Ion	Concentration (ppm)
Chloride (Cl^-)	24975
Sodium (Na^+)	14239
Sulfate (SO_4^{2-})	3754
Magnesium (Mg^{2+})	1531
Calcium (Ca^{2+})	529
Potassium (K^+)	544
Bicarbonate (HCO_3^-)	141
Carbonate (CO_3^{2-})	0.11

Figure 3: Table of the chemical composition and its concentration of seawater

G Migliorini, et al., Desalination 165 (2004)289-298

Desalination

- The process of removing dissolved salts and other minerals from seawater to obtain water suitable for human and animal consumption, irrigation and other industrial uses
- Two desalination methods: by thermal process (multi stage flash) or by membrane (reverse osmosis)

Osmosis

- Osmosis is the spontaneous transport of solvent from a dilute solution to a concentrated solution across an ideal semi permeable membrane
- At a certain pressure, the osmotic pressure, equilibrium is reached and the amount of solvent which passes in each direction is equal

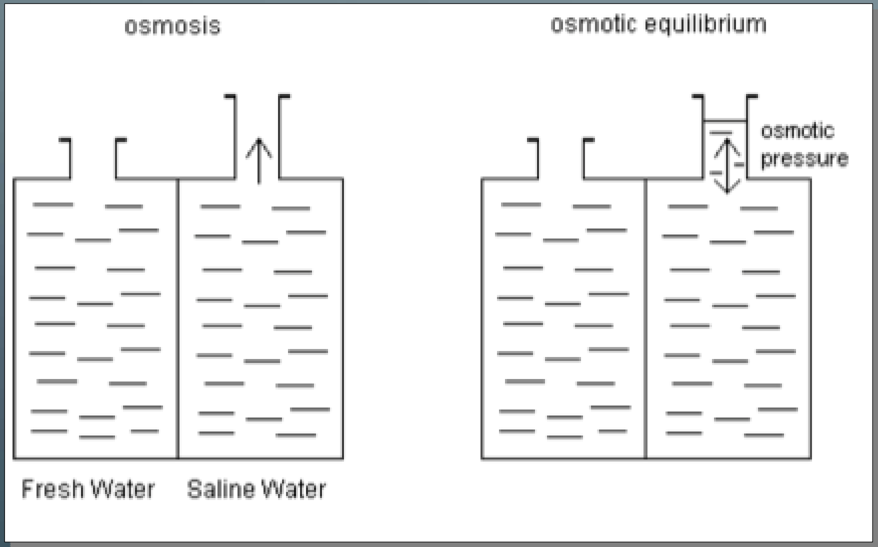
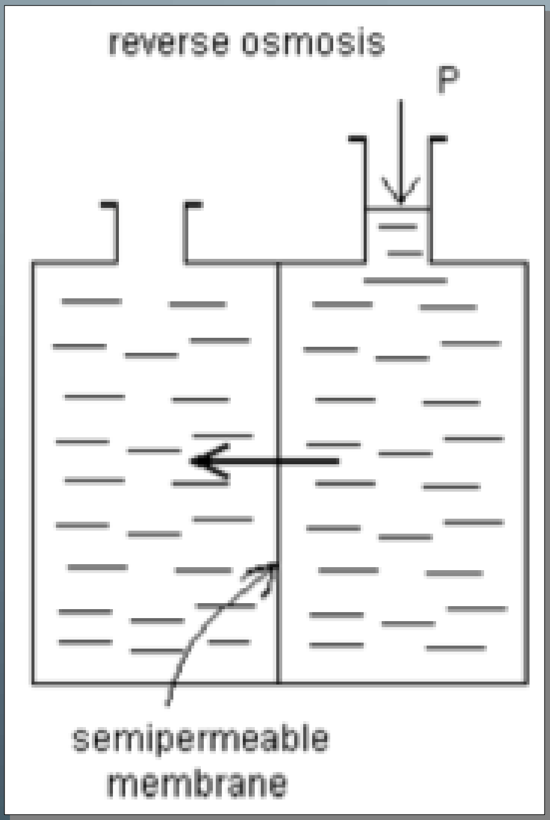


Figure 4: Illustration of osmosis and osmotic equilibrium

(N. Öztürk et al., Desalination 223 (2008) 1–9)

Reverse Osmosis

Figure 5: Illustration of RO



- If the pressure is increased above the osmotic pressure on the solution side of membrane, the flow is reversed and water flows from the concentrate to the dilute side, this is called reverse osmosis (RO)
- RO is based on two variables: high flux of water and high salt rejection
- Operates at pressures of 1 – 10MPa

(N. Öztürk et al., Desalination 223 (2008) 1–9)

Reverse Osmosis

Figure 6: Typical RO desalination plant

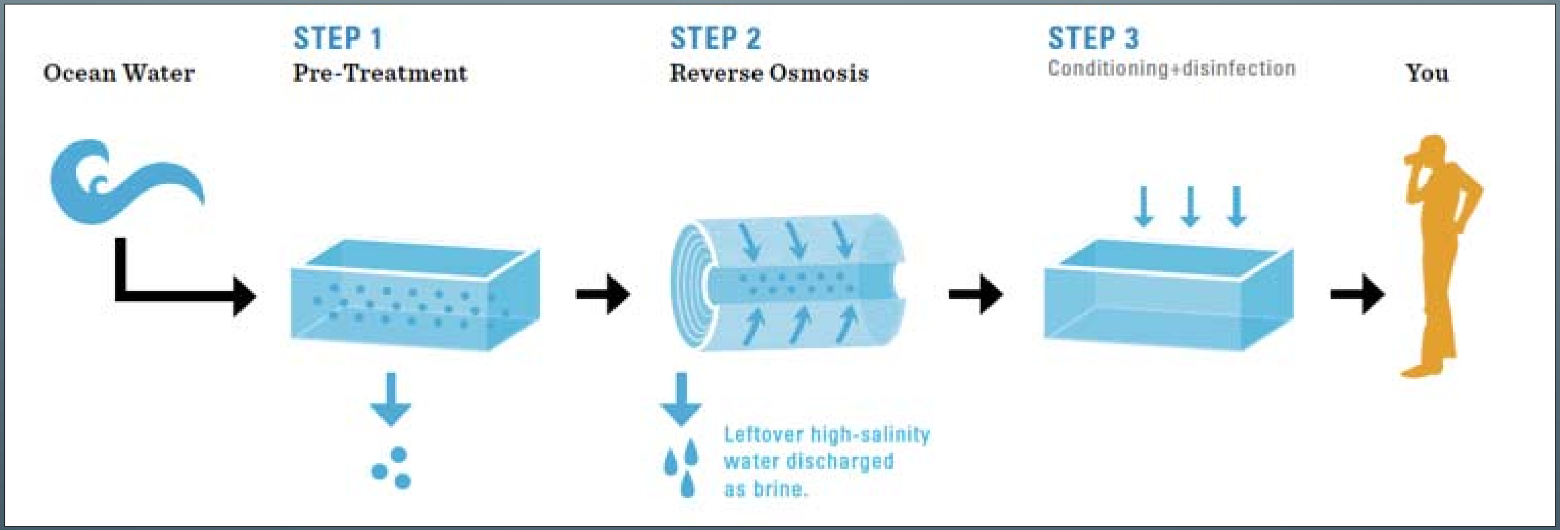
- It is one of the most efficient system based on the energy spent per m^3 of fresh water produced from seawater
- Reverse osmosis rejects nearly all dissolved compounds

Compton Engineering, Inc, (2007) City of Pascagoula Reverse Osmosis Water Plant, http://www.comptonengineering.com/pascagoula.html

Reverse Osmosis

- General schematic of reverse osmosis
- Water abstraction -> pre-treatment -> membrane separation unit -> post-treatment -> distribution

Figure 7: Illustration of RO



San Diego County Water Authority, Desalination, from:http://www.sdcwa.org/desalination

Water Abstraction

- Water can be abstracted through coast or beach wells or through open sea water intake systems
- Coast and beach wells provide better quality water due to low algae and TDS compared to open sea water

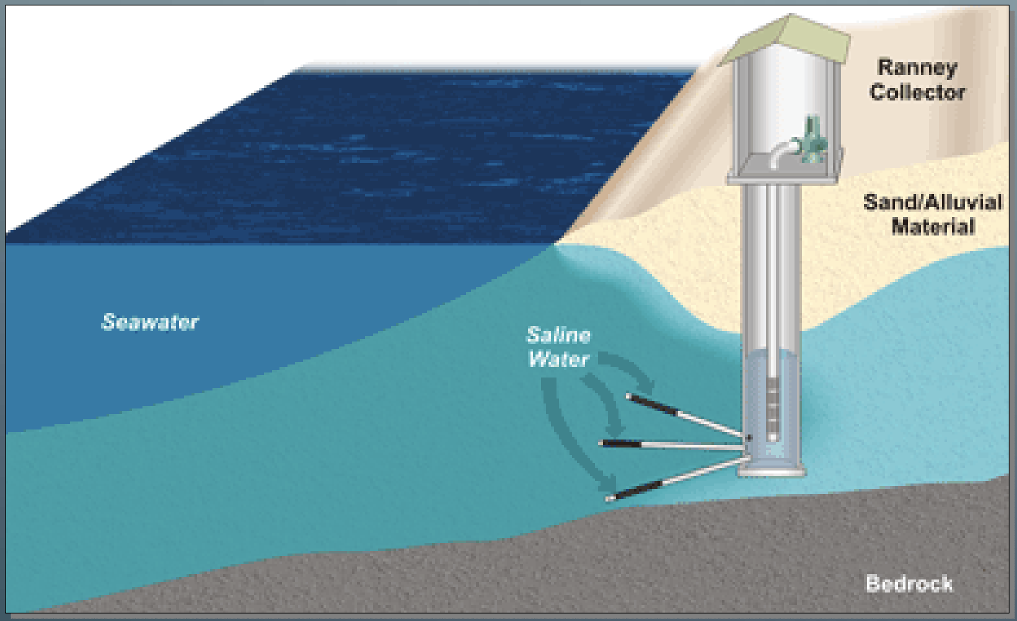


Figure 8: Illustration of water abstraction

scwd[2] (2008) *Intake Approaches*, Retrieved November 12, 2010 from: http://www.scwd2desal.org/Page-Project-Components_Intake-Approaches.php

Particulate Screening

- The screen gets rid of some of the organic matter such as algae and other particulates such as pebbles

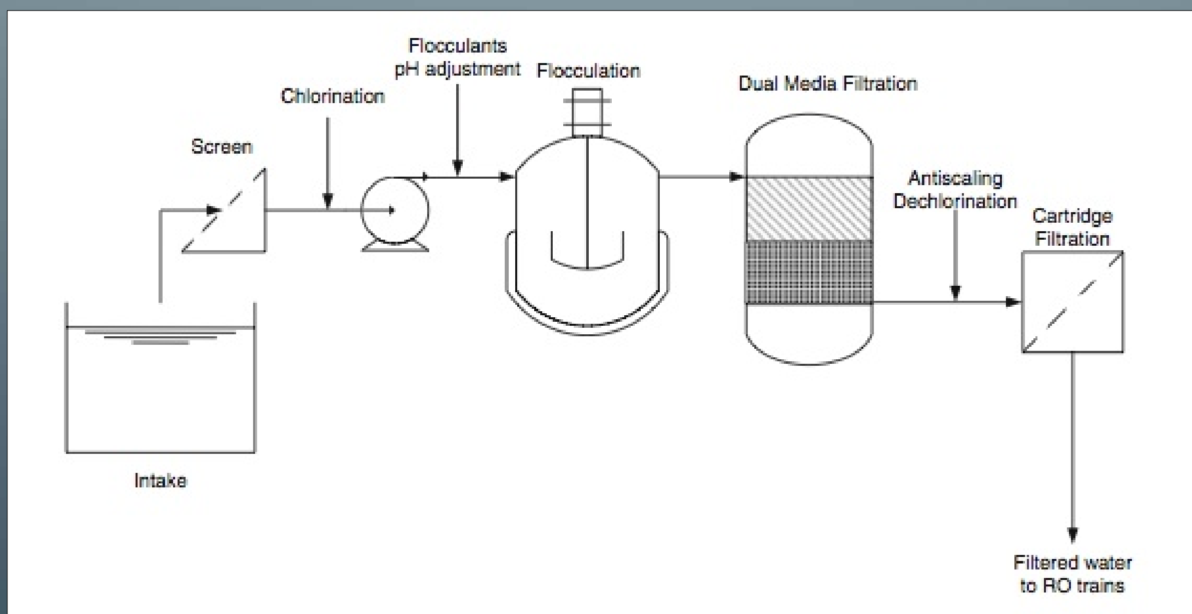
Figure 9: Illustration of a wire screen on a water intake

scwd[2] (2008) *Intake Approaches*, Retrieved November 12, 2010 from: http://www.scwd2desal.org/Page-Project-Components_Intake-Approaches.php

Pre-treatment

- Various contaminants can harm the membrane, leading to irreversible damage associated with reduced rejection capabilities and even destruction of the membrane

Figure 10: Illustration of the pre-treatment of seawater



*C. Fritzmann et al.,*Desalination 216 (2007) 1–76

Chlorination

- Prevents fouling of the membrane (biological and particulate) and acts as a disinfectant for bacteria and other biologics
- Chlorine is added to the raw water as sodium hypochlorite (NaOCl) or Chlorine gas, (Cl_2), water hydrolyzes to hypochlorous acid
  - $Cl_2 + H_2O$ -> HOCl + HCl
  - NaOCl + H_2O -> HOCl + NaOH

pH Adjustment

- Needs to be done to prevent scaling
- Scaling is caused by super saturation of inorganic compounds (when it exceeds their solubility level) concentrated on the feed side that precipitates on the membrane surface leaving a thin layer
- Acids used are HCl and H_2SO_4
- $Ca^{2+} + HCO_3^{-} <-> H^{+} + CaCO_3$
- As H^{+} increases, the equilibrium favors the left hand side

Addition of Coagulants and Flocculants

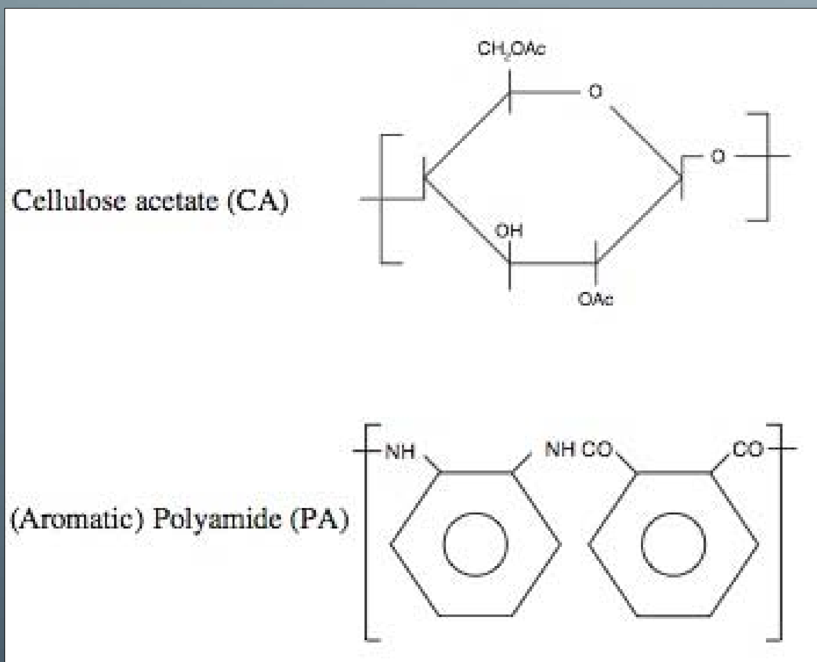
- Dissolved solids adsorb on hydroxides formed and colloidal matter to agglomerate (form in a mass group)
- Iron or Aluminum salts are used ($FeCl_3$, $Al_2(SO_4)_3$)
- $2FeCl_3 + 3Ca(HCO_3)_2 \leftrightarrow 2Fe(OH)_3 + 3CaCl_2 + 6CO_2$
- Sedimentation and sand filtration remove the agglomerates from the feed water

Dechloriniation

- Dechlorination is done prior to RO stage because residual chlorine in the feed water to the reverse osmosis element damages the membrane (poly amides)
- Sodium Metabisulfite ($Na_2S_2O_5$) is commonly used,
  - $Na_2S_2O_5 + H_2O \rightarrow 2NaHSO_3$
  - $2NaHSO_3 + 2HOCl \rightarrow H_2SO_4 + 2HCl + Na_2SO_4$

Reverse Osmosis Membrane

Figure 11: Polymers used for reverse osmosis



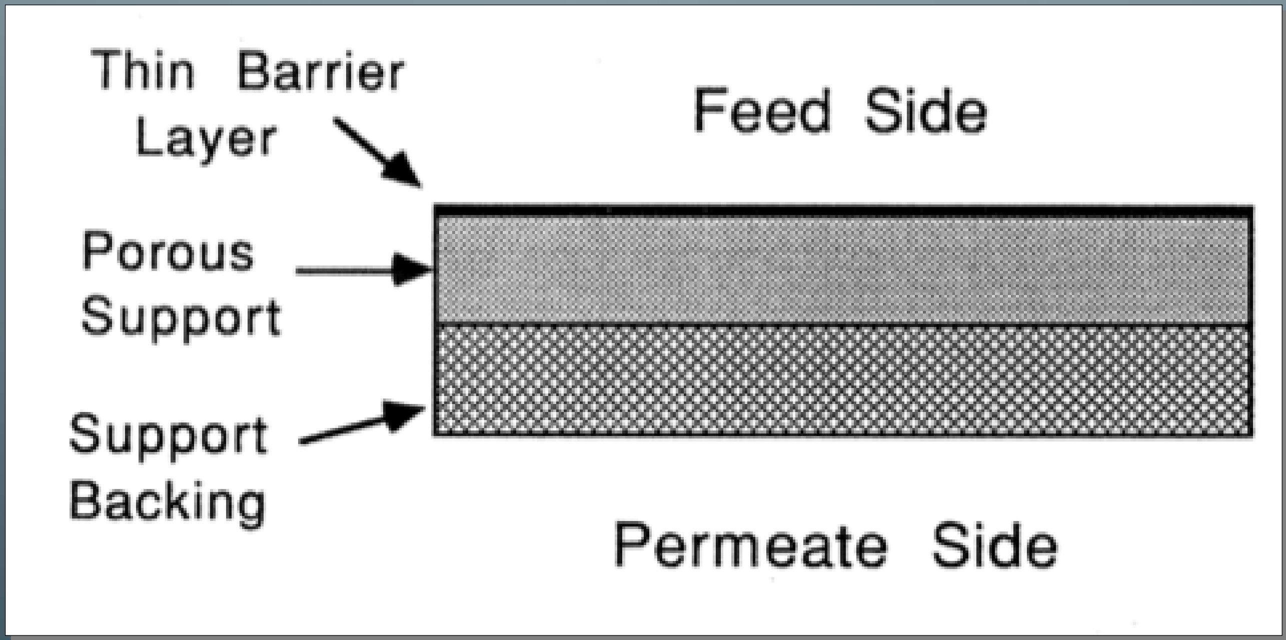
- Semi permeable membranes are used to separate solutes present in the solution
- RO membranes fall into two categories: asymmetric membranes, and thin-film composite (TFC) membranes

(G. Micale (2009), *Seawater Desalination Conventional and Renewable Energy Resources*, Springer Heidelberg Dordrecht London New York

Thin Film Composite Membrane

- Composed of a thin polymer layer on a porous support (polysulfone) and a support backing (polyester cloth)

Figure 12: Illustration of thin film composite membrane

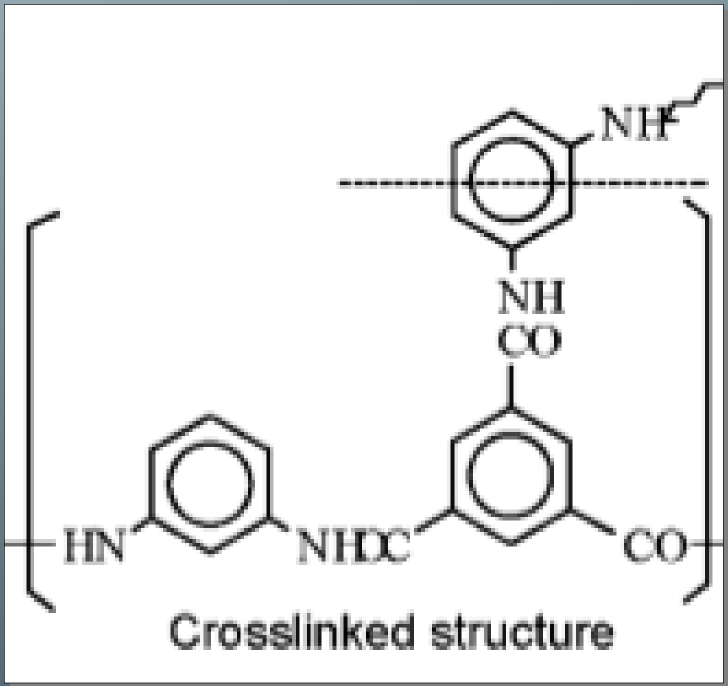


M.E. Williams, 2003, *A Brief Review of Reverse Osmosis Membrane Technology*, pg 1-9

Cross Linked Aromatic Polyamides

- Cross linked aromatic polyamides are the most commonly used polymer
- More beneficial than cellulose acetate
- Displays stronger resistance to bacterial degradation
- Does not hydrolyze
- Stable under a wider pH of 4–11 compared to a pH of 4 – 7

Figure 13: Cross linked aromatic polyamide



J. Roh et at. J. Mater. Chem., 2002, 12, 2334–2338

How is Water Separated?

- The water in polyamide moves by "jumps" between weakly localized sites
- Water oscillates around localized sites until events, such as thermal fluctuations, enable another jump
- Salt diffusion in the polymer depends on both Na^+ and Cl^- to satisfy electroneutrality

Figure 14: Number of molecules participating in solvating of Na^+ and Cl^-

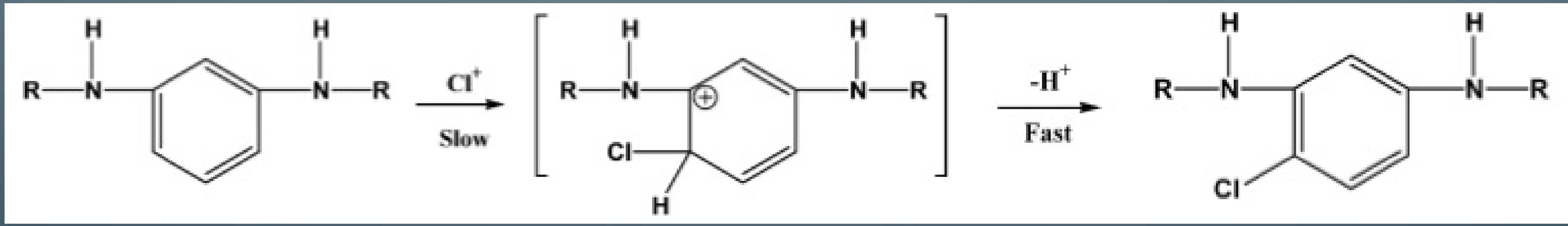
	Carbonyl (–C=O)	Water (H_2O)	Carboxyl Hydrogen (–C–O–H)	Amide Hydrogen (–N–H)	Aromatic Ring
Na^+	1	5	0	0	0
Cl^-	0	4	1	1	1

M.J. Kotelyanskii et al., Journal of Membrane Science 139 (1998) 1-16

Why Dechlorination is important for PA membrane

- $HOCl + H_2O \rightarrow H_3O^+ + OCl^-$
- HOCl acts as a Lewis acid and therefore produces Cl^+
- The Cl^+ attacks the aromatic ring

Figure 14: Reaction of chlorine with the polyamide membrane



C.J. Gabelich et al., Journal of Membrane Science 258 (2005) 64–70

TDS of Permeate After RO

- The TDS is greatly reduced

Figure 15: The concentration of ions after RO

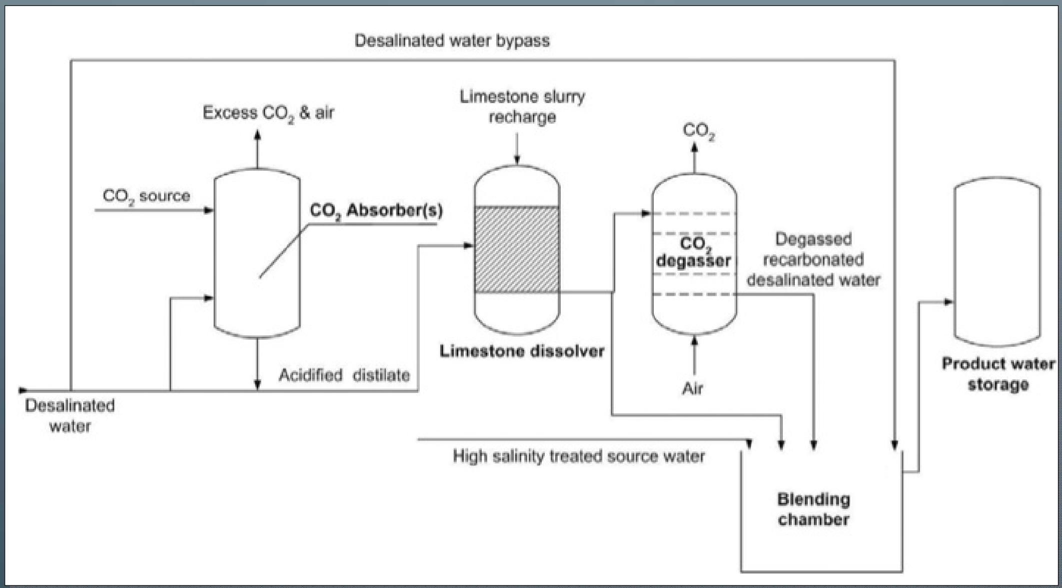
Chemical Ion	Concentration (ppm)
Chloride (Cl^-)	163.57
Sodium (Na^+)	104.28
Sulfate (SO_4^{2-})	2.51
Magnesium (Mg^{2+})	2.78
Calcium (Ca^{2+})	0.95
Potassium (K^+)	4.55
Bicarbonate (HCO_3^-)	1.45
Carbonate (CO_3^{2-})	0

G Migliorini, et al., Desalination 165 (2004)289-298

Post Treatment

- Due to low TDS the drinking was can be unpalatable, corrosive and unhealthy
- Water must be re-hardened
- $CO_2 + CaCO_3 + H_2O \rightarrow Ca(HCO_3)_2$

Figure 16: Illustration of the post treatment process



C. Fritzmann et al. ,, Desalination 216 (2007) 1–76

Disinfection of Water

- Produced water is free of bacteria and viruses
- Disinfection is necessary to protect consumers from pollution introduced during distribution and storage
- Chlorine is a typical chemical used for disinfection

From: http://www.ionizetohealth.com/

Future

- The future of RO is to improve membranes to resist fouling
- Vancouver is fortunate to have readily available drinking water (from snow melts and rain falls)

From: http://www.rent2010.net/i/Listing892/Olympics-2010-Ocean-View-West-Vancouver-