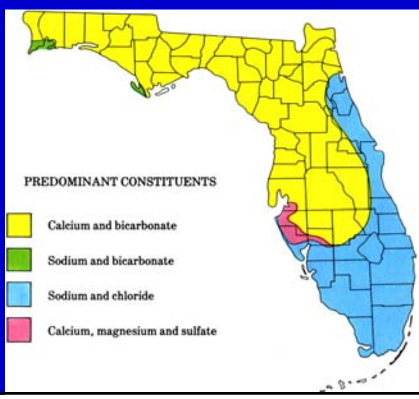
Demineralization (RO, NF, UF, MF, ED, IE)

"The purpose of demineralization is to separate minerals from water"

1

Predominant Constituents of Dissolved Solids



2

Water Supply Classification

- Fresh Water, less than 1,000 mg/l TDS
- Brackish Water, 1,000 – 10,000 mg/l TDS
- Seawater, 35,000 mg/l TDS

3

Types of Demineralization Processes

Phase Change

- Freezing
- Distillation

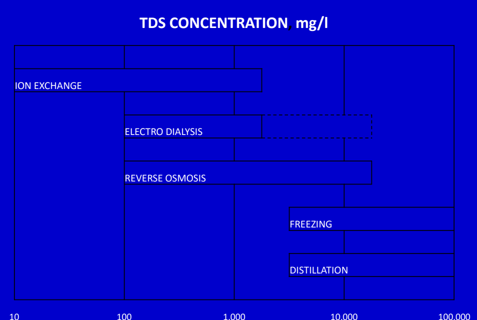
(Seawater)

Non-Phase Change

- Reverse Osmosis (Membrane Filtration)
- Electro Dialysis
- Ion Exchange

(Fresh to Brackish)

4



Note: The dashed lines indicate a feasible range of operation, but not typical range.

5

Selection of Demineralization Process

- Mineral Concentration in Source Water
- Product Water Quality Required
- Brine Disposal Alternatives
- Pretreatment Required
- Other Particle Removal Considerations
- Cost Effectiveness

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Membrane Filtration

"The ability of the membrane to reject minerals is called the mineral rejection."

7

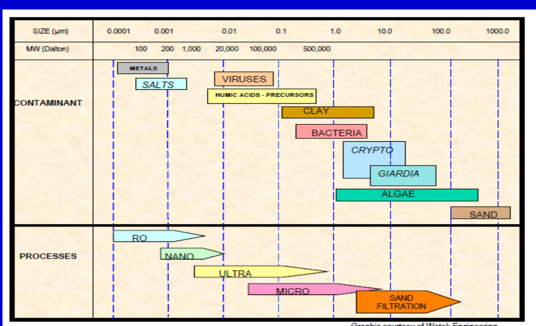

Figure 1.6 Separation Chart

The nanofiltration typically has the highest operating pressures of the other membrane processes shown.

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Pressure Filtration Membrane Treatment Systems

(water flux is dependent on the applied pressure)

Higher Pressures (150 to 1200 PSI)

1200

- Desalination Reverse Osmosis
- Conventional Reverse Osmosis
- Nanofiltration Reverse Osmosis

250

150

Lower Pressure (20 to 70 PSI)

150

- Electrodialysis
- Ultrafiltration
- Microfiltration
- (Conventional)

0

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REVERSE OSMOSIS
(includes RO, NF, UF, MF)

- Osmosis can be defined as the passage of a liquid from a weak solution to a more concentrated solution across a semi-permeable membrane.
- The membrane allows the passage of the water (solvent) but not the dissolved solids (solutes).
- The water flux is the flow of water in grams per second through a membrane area of one square centimeter or in gallons per day per square foot.
- From the previous slide we see that: the water flux is dependent on the applied pressure, while the mineral flux is not dependent on pressure.

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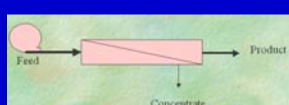
Reverse Osmosis

- Reverse Osmosis (RO) systems are used for inorganic mineral removal and for saline water including desalination of sea water.
- RO excludes atoms and molecules < 0.001 microns; the ionic or mineral size range.



RO Treatment Element

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Reverse Osmosis Treatment

- Two types of selective membranes are used for deminerialization: Cellulose Acetate and Thin Film Composite
- Operated at 200 to 400 psi, @ 5.5 pH
- Salt Rejection above 95%*
- Quality and Quantity of Permeate increase with higher Pressure
- Flow (Flux) Rate depends on Mineral Concentration
- Subject to Fouling from biological contaminants

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Components of a Reverse Osmosis System

Reverse Osmosis System

- Pressure Vessel Housing
- *Concentrate Control Valve
- Sample Valves
- Flush Connection
- Cleaning Connections
- Permeate Rinse Valve
- Permeate Drawback Tank
- Membranes
- Pumps
- Piping

*** Never Left Fully Closed!**

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Reverse Osmosis Treatment Operating Considerations

- Used for mineral removal only
- Turbidity <1 NTU; high turbidity causes deposition of particulate matter on membrane resulting in fouling
- Flux Range 15 – 20 GFD (gallons Flux per day per sq. ft. membrane surface)

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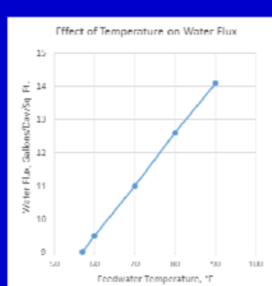
Reverse Osmosis Treatment Operating Considerations

Temperature

- As temperature of feedwater increases the flux increases
- Flux is usually reported at a std temperature



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Types of Semipermeable Membranes

Cellulose Acetate
- First commercially available membrane
- Operating pressure: 400 psi
- Operating pH: 4.0 – 6.0
- Flux rate: 25 GFD (gallons of flux per square foot per day)
- Subject to biological attack and hydrolysis (lessons mineral rejection capability over time)

Thin Film Composites
- Operating pressure: 200 psi
- Operating pH: 3.0 – 10.0
- More expensive than cellulose acetate membrane
- Higher rejection (98%) and flux rates (25 – 30 GFD)
- Not subject to biological attack, hydrolysis, or compaction but is sensitive to oxidants in feedwater

As the membrane hydrolyzes, both the amount of water and the amount of solute which permeate the membrane increase and the quality of the product water deteriorates. T or F

True

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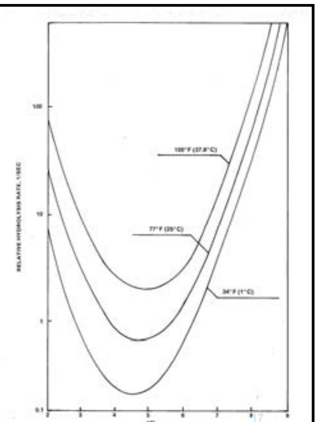
Effect of Temperature and pH on Hydrolysis Rate for Cellulose Acetate Membranes

Time required to achieve a 200% increase in mineral passage at 23ºC

pH	Time
5.0	6 years
6.0	3.8 years
7.0	1 year
8.0	51 days
9.0	3.6 days



Effect of temperature and pH on hydrolysis rate for cellulose acetate membrane

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Membrane Configurations

- Spiral Wound
- Hollow Fine Fiber
- Tubular

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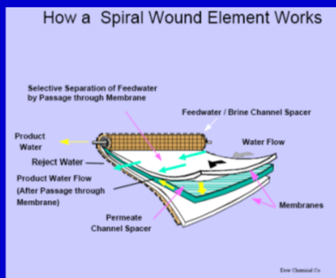
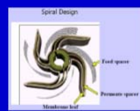
Spiral Wound Membrane Element Configuration





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Spiral Wound Membrane

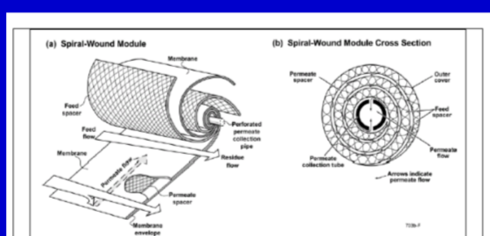

Figure 1: General Design Features of a Spiral-Wound Membrane Module

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Hollow Fine Fiber Membrane Element Configuration

- Fibers are placed in a pressure vessel
- Membranes are about the size of a human hair
- Brackish water is under pressure on outside of fibers
- Product water flows inside of the fiber to the open end

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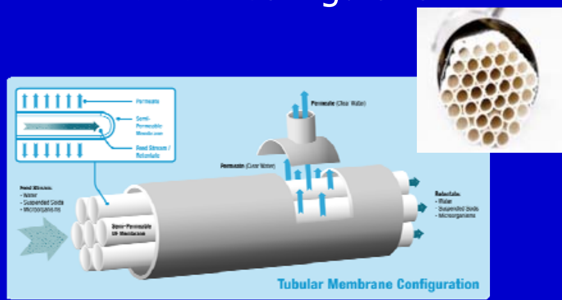
Tubular Membrane Element Configuration



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Constituents Affecting the Reverse Osmosis Process

- pH – slows hydrolysis and extends life of cellulose acetate membranes
- Temperature – as the temperature of the feedwater increases, flux increases
- Suspended Solids & Turbidity
- Mineral Content (salts)
- Microbes

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pH Adjustment with Reverse Osmosis

- pH is lowered with acid prior to treatment to prevent minerals from coming out of solution and clogging membranes
- A pH of 5.5 is standard for most feedwater
- If pH and temp. are allowed to increase, Hydrolysis (breakdown of the acetate membranes) will occur and mineral rejection will decrease

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Pretreatment Requirements for Reverse Osmosis Systems

What is the most frequently used scale inhibitor?

Hexametaphosphate

Constituent	Problem	Treatment
Gross suspended particulates	Blockage	Media Filtration
Colloidal materials	Fouling	Coagulation/Filtration
Microbiological Matter	Fouling	Add oxidizing agent
Oxidizing agents (Cl)	Failure	GAC or Dechlorination
Carbonates (CO_3, HCO_3)	Scaling	pH adjust or softening
Sulfate (SO_4)	Scaling	Inhibitor or Cation Rem.
Silica	Scaling	Lime Softening
Iron (Ferric, +3)	Scale/Foul	Greensand (no aeration)
Hydrogen Sulfide (H_2S)	Scale/Foul	Degasification

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Removal of Microbial Contaminants with Reverse Osmosis

- The bacterial film covering the entire filtration area of a membrane is known as confluent growth.
- Organisms removed to keep them from fouling or plugging membranes.
- Organisms can be removed by pre-chlorination and maintaining 1 to 2 mg/l chlorine residual through the RO process. Too much chlorine can impair membrane efficiency.
- If oxidant-intolerant (composite polyamide-type) membranes are used then chlorination must be followed by de-chlorination

Why is chlorine added to the feedwater of an RO unit?

Prevent Biological Fouling

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Polarization in Reverse Osmosis Systems

- Polarization is the buildup of mineral deposits along the edges of the membrane.
- Polarization reduces both flux and reject
- Polarization is reduced by increasing flow velocity causing deposits to breakaway from the membrane walls.
- Brine flow rates can be kept high as product water is removed by staging.
- The most common and serious problem resulting from concentration polarization is the increasing tendency for precipitation of sparingly soluble salts and the deposition of particulate matter on the membrane surface.

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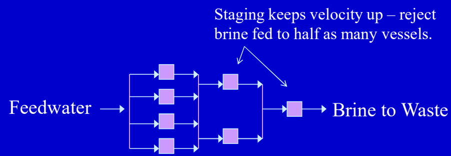
Staging

Vessels in a 4-2-1 configuration yields an 85% recovery of feedwater as product water.



Product Water not Shown

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NF and RO Comparison

Softening (Nanofiltration)
- Applied pressure: 150 psi
- Min Salt Rejection: 75-80%
- Hardness Rejection >95%
- Flux Range: 25 – 30 GFD
- Used for softening or special applications

- Reverse Osmosis
- Applied Pressure: 225 psi
- Min Salt Rejection: 97-98%
- Hardness Rejection >99%
- Flux Range: 25-30 GFD
- Used for mineral removal

GFD – gallons of flux per sq. ft. per day

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When Should RO Elements be Cleaned?

- Element cleaning should be performed at regular intervals to keep pressure as low as possible.
  - When pressure to maintain rated capacity increases by 15%.
  - When product water flow decreases by 15% at constant pressure.
  - When a rise of 15% in the system differential pressure has been observed.
- Symptoms of membrane fouling
  - Lower product water flow rate
  - Lower salt rejection
  - High ΔP

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How to Clean RO Membranes

- To remove inorganic precipitates, use an acid flush of citric acid.
- For biological or organic fouling, use various solutions of detergents, sequestrants, chelating agents, bactericides, or enzymes.
- Clean at low pressure not to exceed 60 psi.
- Membranes are typically cleaned for approximately 45 minutes.

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Ultrafiltration Membrane Systems

- Generally used for Pretreatment
- Can replace several treatment processes
- Extremely flexible for changed feed water conditions
- Operates at 50 psi

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Ultrafiltration Operation

- Units are operated in parallel with some product recirculated to maintain high flow velocity
- Increase recirculation rates for higher TDS removal
- Units are backwashed to remove fouling with product water

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Microfiltration Membrane Filtration Treatment Process

- Microfiltration is used for removal of particles, suspended solids, bacteria and cysts in source water.
- Organics are not removed.
- Operates at 20 to 35 PSI.
- Typically used for Pretreatment in front of RO Systems

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Advantages of Microfiltration

- Highly automated with little operator attention
- Water quality achieved regardless of source water changes
- Chlorine Demand Reduced
- Replaces conventional treatment processes
- Wide flow ranges (.6 to 22 MGD)

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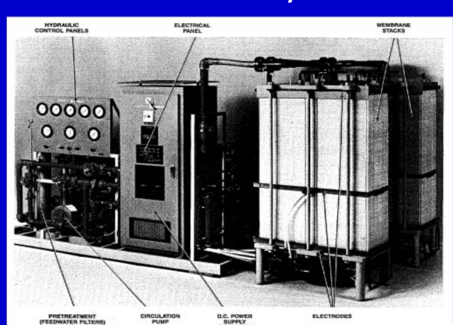
Electrodialysis



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Electrodialysis Applications

- Selective membrane process for removing Minerals Only!
- Uses membrane filtration in combination with electricity.
- Electrodialysis can be less expensive to operate for low TDS waters or when a 50% mineral removal is adequate.
- Positive ions are attracted to a negatively charged cathode and negatively charged ions are attracted to a positively charged anode.

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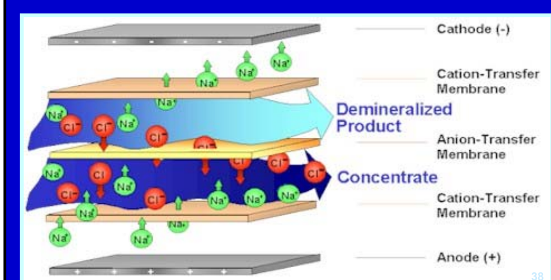
Electrodialysis

- Uses electrical power to draw ions from product water to the concentrate stream.

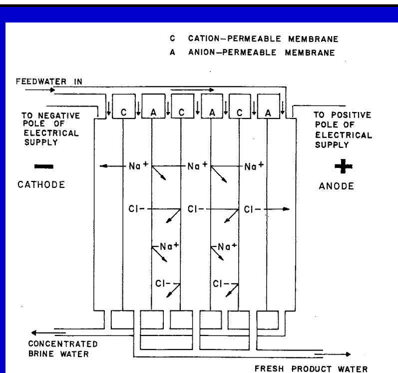


<u>Cations</u>

Sodium	Na^{+}
Calcium	Ca^{2+}
Magnesium	Mg^{2+}

<u>Anions</u>

Chloride	Cl^{-}
Bicarbonate	HCO_3^{-}
Sulfate	SO_4^{2-}



Electrodialysis demineralization process

Operating and Maintenance Considerations for ED Systems

- Fouling and Plugging of Membranes
- Water Temperature
- Alkaline Precipitation
- Pretreatment for Solids Removal
- Undesirable Minerals (Fe, Mn, H_2S & Cl)
- Hexametaphosphate

40

Do Not Operate if Feedwater has any of the following:

- Chlorine residual of any concentration
- Hydrogen sulfide of any concentration
- Calgon or other hexametaphosphates in excess of 10 mg/l
- Manganese in excess of 0.1 mg/l
- Iron in excess of 0.3 mg/l

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Which of the following items is/are acceptable in the feedwater to an electrodialysis unit?

1. Chlorine residual
2. Hydrogen sulfide
3. Iron
4. Manganese
5. Sodium

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Ion Exchange

Ion exchange can be defined as exchanging hardness causing ions (calcium and magnesium) for the sodium ions that are attached to the ion exchange resins to create a soft water. The term "ion exchange" is the same as the term "Zeolite".

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ION EXCHANGE

- The removing of non-desirable ions by replacing them with more desirable ions.
- Generally, the process is used for softening but can be used with any positively charged ion including Tannins.
- Can also be used with negative charged particles.

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Ion Exchange Unit Types

- Upflow
- Gravity Sand Filter Type Unit
- Pressure Downflow

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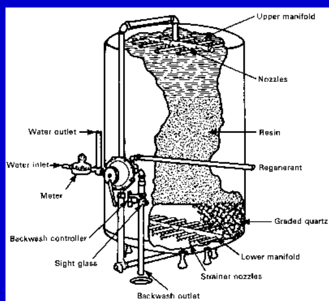
Parts of an Ion Exchanger



- Vessel
- Distributor
- Backwash Space
- Resin
- Resin Support
- Underdrain
- Piping & Valves

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Ion Exchange Resins

- Natural zeolites (crystalline aluminosilcates) no longer used
- These have been replaced by synthetic resins.
- Resins made of cross-linked polymer matrixes that attached to functional groups with covalent bonds
- Resins are manufactured as beads and typically screened to 0.3 to 1.3 mm dia.
- A typical resin used for softening is poystyrene attached to 6 to 8% divinylbenzene (DVB).
- Service life can be as much as 10 years with 3 to 5 typical. Generally resin replaced when capacity is reduced by 25%.

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Flow Considerations for Ion Exchange Softening

- Limited by pressure loss and physical characteristics of the Cation resin
- Flows above 20 gpm/sf will break beads
- Pressure losses above 50 psi across bed will also break beads
- Pressure losses across beds < 20 psi
- Generally a flow rate of 10 gpm/sf and a bed depth of 3 feet is typical.
- Ion Exchange Design is based on empty bed contact time (EBCT), 1.5 - 7.5 min or its reciprocal service flow rate (SFR) 1 - 5 gpm/cf

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Operating Considerations Ion Exchange Softening

- Iron: Ferrous captured deep inside resin bead or Ferric (precipitation) causes beads to become clogged and can not be removed.
- Corrosiveness of Brine Solution on metallic parts
- Oxidation of polymer from high chlorine level
- Strainer blockage
- Fouling of Resin from oil, grease or organic matter (Resin cleaning takes about 8 hours)
- Normal chlorine dosages will not present a problem, but high residuals could damage the resin and reduce its life span.

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Optimal Water Characteristics for Ion Exchange

pH	6.5 – 9.0
NO_3	< 5 mg/l
SO_4	< 50 mg/l
TDS	< 500 mg/l
Turbidity	< 0.3 NTU
Total Hardness	<350 mg/l

Selectivity Considerations

$S04^{-2} > NO3^{-2} > CO3^{-2} > NO2^{-2} > CL^{-1}$

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Stages of Ion Exchange

Stage 1. Service Stage

Stage 2. Backwash Stage

Stage 3. Brine or Regeneration Stage

Stage 4. Rinse Stage

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Ion Exchange Service Stage 1

- Normal operating stage where actual softening takes place.
- Length of service is mainly dependent on source water hardness.
- High source water sodium and or TDS can hinder process.
- TDS, unit size, and removal capacity affect length of time between regeneration.
- Beware of iron and manganese. Insoluble particles will plug the filter media. Monitor source water on a routine basis.

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Ion Exchange Backwash Stage 2

- A reverse flow through the softening unit is used to expand and clean resin particles.
- Ideal bed expansion during backwash is 75 - 100 %
- Some resin could be lost during backwash. Should be monitored to minimize loss.
- Too much loss of resin may be caused by an improper freeboard on the tank or wash troughs.
- Backwash durations widely vary based on the manufacture, type and size of resin used and the water temperature.

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Ion Exchange Regeneration Stage 3

- Sodium ion content is recharged by pumping concentrated brine solution onto the resin.
- Optimum brine solution is between 10 -14% sodium chloride solution.
- A 26% brine solution (fully concentrated or saturated) can cause resin to break up.
- The salt dosage used to prepare brine solution is one of the most important factors affecting ion exchange capacity. Ranges from 5 to 15 lbs/ft^3.
- The lower the concentration, the longer will be the regeneration time.

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Ion Exchange Rinse Stage 4

- Clean water is washed through the system to rinse the resin and to washout the excess brine solution.
- If rinse is not sufficient for removal of concentrate a salty taste will be noticed in the effluent. If a salty taste is noticed then rinse rate and time should be increased.

55

Question: An ion exchange softener contains 50 cubic feet of resin with a hardness removal capacity of 20,000 grains per cubic foot of resin. The water being treated has a hardness of 300 mg/l as $CaCO_3$. How many gallons of water can be softened before the softener will require regeneration?

- First, calculate the exchange capacity:

Exchange capacity, grains = (removal capacity, gr/ft^3) x (media vol, ft^3)

$$\text{Exchange capacity, grains} = \frac{(20{,}000\ \text{gr})}{\cancel{ft^3}} \times (50\ \cancel{ft^3}) = 1{,}000{,}000 \text{ grains of removal cap}$$

- Water treated before regeneration

Water treated, gal = (exchange capacity, grains) / (hardness removed, grains/gal)

$$\text{Water treated, gal} = \frac{1{,}000{,}000\ \cancel{gr}}{1} \times \frac{1}{300\ \cancel{mg/L}} \times \frac{17.1\ \cancel{mg/L}}{1\ \cancel{gr}/gal} = 57{,}000 \text{ gal}$$

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Corrosion Concerns in Ion Softening

- Ion Exchange produces a water with zero hardness.
- Water with zero hardness is very corrosive creating red water problems.
- "Ideal" water hardness for drinking water ranges between approximately 50 to 100 mg/L.
  - Above this level, hardness can contribute to scaling of water heaters and boilers.
  - Water with hardness below this level tends to be more aggressive and can cause deterioration of the inner surface of pipes, eventually leading to pinholes or leaks.
- Water is adjusted by blending to achieve 86 mg/l or 5 gpg Hardness

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Blending or Bypass Flow

- If a softener plant treats 120,000 gal/day determine the Blending Volume or Bypass Flow if the raw water hardness is 17.5 gr/gal and the desired finished water hardness is 5 gr/gal.

$$\text{Bypass flow, gal/day} = \frac{\text{(total flow, gal/day) x (finished water hardness, gr/gal)}}{\text{Raw water hardness, gr/gal}}$$

$$\text{Bypass flow, gal/day} = \frac{\text{(120,000 gal/day) x (5 } \cancel{\text{gr/gal}}\text{)}}{\text{17.5 } \cancel{\text{gr/gal}}} = \text{34,286 gal/day}$$

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Concentrate Disposal

- Combine with reclaimed water and release to surface water. (CWA & NPDES)
- POTW (TBLL; Effluent & Biosolids)
- Deep Well injection – (UIC)
- Evaporation/Crystallization - Capacity limited (RCRA)
- Landfill (PELT (paint test), TCLP (leaching)

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