

*Understanding Differences  
of  
Boiler Feedwater  
Pretreatment Equipment*

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As a water treatment professional, there are several reasons for understanding the various types of boiler pretreatment equipment:

1. Being able to provide sound advice in selecting pretreatment for a client.
2. Effective problem solving of existing equipment for clients or prospective clients.
3. Improving sales.
4. Knowing the impact on chemical treatment programs.
5. Knowing the impact on chemical consumptions.

It is helpful to grasp all selection criteria for the type of pretreatment. These factors are used for deciding what new equipment to install or why the existing equipment is appropriate or not appropriate.

### **PRETREATMENT SYSTEM SELECTION GUIDELINES**

Consider:

- A. Technical Factors
  - B. Operational Factors
  - C. Economics
  - D. Space Requirements
- A. Technical Considerations
1. What impurities need to be reduced or removed?
    - a. Hardness
    - b. Iron or Manganese
    - c. Alkalinity
    - d. Organics
    - e. Suspended Solids
    - f. Silica - colloidal or soluble
    - g. Total Dissolved Solids
    - h. Others
  2. Does the influent water quality change day-to-day or season to season? What is the temperature range?

3. What are the boiler types and pressures?
4. What are steam purity requirements?
5. What is the amount and quality of the condensate?
6. What are average flows and peak flow demands?
7. Is heat recovery used or going to be used to recapture most of boiler blowdown heat?

B. Operational Factors

1. What are manpower and competency of manpower requirements?  
Is competency available?
2. How easy is the operation?
3. How consistent does the system perform?
4. What is the propensity for failure?
5. What are the consequences of failure?
6. What chemicals are needed and what handling is necessary?
7. What regenerant or sludge disposal is required?
8. What is the internal treatment program?

C. Economic Considerations

1. What is the capital cost? Can it be leased?
2. What are operational costs including electrical, water and sewerage, chemical, maintenance, and replacement components such as resin or membranes?
3. What is the life expectancy of the system?

D. Space Requirements

1. Is there physically room for the system and future expansion to the system?
2. Can it be located outdoor or must it be indoor?

**SOME PRETREATMENT SYSTEMS....**

- A. Sodium Zeolite Softening
- B. Sodium Chloride Dealkalization
- C. Weak Acid/Strong Acid Ion Exchange
- D. Split Stream Softening
- E. Demineralization by Ion Exchange
- F. Countercurrent Ion Exchange
- G. Acid Dealkalization
- H. Cold Lime Softening
- I. Hot Process Softening
- J. Filtration - Sand; Anthracite; Carbon; Greensand
- K. Reverse Osmosis
- L. Electrodialysis (ED), Electrodialysis Reversal (EDR)
- M. Continuous Deionization (CDI)

◆ **Sodium Zeolite Softening**

*Features:* Uses a strong acid cation exchange resin to effectively exchange calcium, magnesium, and perhaps soluble iron for the soluble sodium cation. Typically reduces hardness to less than 1 ppm, but leakage is dependent upon influent characteristics such as hardness, sodium, and TDS.

*Advantages:*

- Simple operation.
- Relatively low capital cost.
- Safe Regenerant (salt).
- Handles varying influent changes.
- Suitable for most any size application.

- Limitations:*
- No effect on other constituents such as alkalinity or silica.
  - Chlorine can degrade the resin.

- Troubleshooting:*
- Maintain proper hydraulic loading (2-4 gpm/ft<sup>3</sup>; 2-14 gpm/ft<sup>2</sup>).
  - Test downstream to catch possible valve leakage.
  - Check influent regularly for changes in hardness and adjust regeneration frequency appropriately.
  - Inspect resin and internals regularly and follow proper preventive maintenance procedures for valves.
  - Ensure saturated brine is being used for regeneration. Assist dissolution with air if necessary.
  - Compare actual soft water produced to theoretical capacity.
  - Run elution studies.

◆ **Sodium Chloride Dealkalization**

*Features:* Uses a strongly basic anion exchange resin and replaces bicarbonate, sulfate, and nitrate for chloride anion after the water has first been softened. Alkalinity reduction is about 90%.

- Advantages:*
- Simple operation.
  - Can easily add on to existing sodium zeolite softener system.
  - Safe regenerant (salt), but some caustic often used also.
  - Relatively low capital cost.

- Limitations:*
- Some alkalinity (10%) still remains.
  - Conductivity of effluent is increased.
  - Adds chlorides to effluent.
  - Susceptible to fouling by hardness and organics.
  - Resin has relatively low capacity.

- Troubleshooting:*
- To prevent fouling and subsequent hardness leakage, influent must be soft and regenerant should be made up with soft water.

- Capacity drops off as influent chlorides ratio to total exchangeable anions increases.
- Resin loss can be cause of low capacity. Check resin depth frequently.
- Capacity better with salt and caustic regeneration.
- Maintain proper hydraulic loading (2-4 gpm/ft<sup>3</sup>, 2-14 gpm/ft<sup>2</sup>).
- Overruns drop subsequent capacity, so double regenerations are recommended if overruns occur.

◆ **Weak Acid/Strong Acid Ion Exchange**

*Features:* Weak acid resin removes hardness associated with alkalinity. The hydrogen exchanged from the resin lowers the pH and results in dealkalization. A decarbonator is used to strip the carbon dioxide from the water and vent it to atmosphere. Hydrochloric or sulfuric acid are typically used.

The strong acid ion exchange resin is regenerated with salt and removes the noncarbonate hardness, or if the influent hardness is less than or equal to the influent alkalinity, the strong acid resin acts as a polisher.

This system can have separate exchange vessels or can use a single vessel. If one vessel is used, the lighter weak acid resin remains on top. It is first regenerated with acid followed by sodium chloride. (The sodium will not exchange onto the weak acid resin, but the sodium as the second step puts the strong acid resin in the sodium form.

After the decarbonator (degasifier), pH neutralization with caustic is accomplished.

*Advantages:*

- Weak acid resin is very efficient, most of the hydrogen exchanging onto the resin. Efficiency is 90% compared to 30-40% for strong acid resins.
- Get softening and dealkalization from the same process.
- Obtain TDS reduction; more for high influent alkalinity waters.

- Limitations:*
- Chemical handling includes acid, caustic, and salt.
  - Neutralization of regenerants should be considered.
  - Higher capital cost for corrosion resistant materials.
  - Higher maintenance.
  - Greater operator attention than sodium chloride ion exchange.

- Troubleshooting:*
- Check carbon dioxide after decarbonator but prior to sodium hydroxide addition. It should be 10 ppm or less. After caustic addition, the carbonic acid will be converted back to bicarbonates and carbonates. Check bicarbonates and carbonates there and figure 1 ppm CO<sub>2</sub> forms 1.26 ppm bicarbonate or 2.86 ppm carbonate.
  - Check specific gravity of influent acid regenerant. Use 4% for HCl. For H<sub>2</sub>SO<sub>4</sub>, use 0.5% to avoid calcium sulfate precipitation.
  - Typical regeneration is when total alkalinity is 10% of influent. Where no steam line treatment is permissible, regenerate at the first leakage of alkalinity or immediately prior to that to minimize carbon dioxide in the steam.

◆ **Split-Stream Softening**

*Features:* Two strong acid cation exchange vessels are used; one is a sodium exchanger and the other is hydrogen. A portion of the raw water goes through the sodium zeolite while the balance passes through the hydrogen zeolite. The two split streams are then mixed and the low pH water of the hydrogen zeolite effluent containing free mineral acidity converts the carbonates and bicarbonates in the sodium zeolite effluent to carbonic acid.

The blended water is passed over a decarbonator to strip the carbon dioxide.

- Advantages:*
- Hardness and alkalinity removal.
  - Reduction in total dissolved solids
  - Can customize final water alkalinity without the addition of caustic.

- Limitations:*
- Must maintain proper mix. If influent alkalinity changes, mix may have to change.
  - Corrosion resistant equipment required.
  - Acid handling.
  - Neutralization of acid waste

- Troubleshooting:*
- If using sulfuric acid, stage acid addition to prevent calcium sulfate fouling.
  - Confirm proper mix with total alkalinity testing.
  - Run elution studies.

### ◆ **Demineralization by Ion Exchange**

*Features:* Uses strong acid cation resin regenerated with hydrogen and strong base anion resin regenerated with hydroxide to remove most of the cations and anions from the raw water, resulting in low conductance water. Weak acid and weak base columns can be used prior to strong acid and strong base units to reduce regenerant cost. A mixed bed unit containing both strong acid and strong base resin produces higher purity water and often is used as a polishing step.

- Advantages:*
- Removal of most all impurities except colloidal silica.
  - Water quality of less than 15  $\mu\text{S}$  and less than 1  $\mu\text{S}$  with mixed bed polishing. (In a mixed bed, more complete removal is possible because the anion resin is located immediately next to the cation resin. As soon as the acid is formed, it is exchanged for hydroxide and less leakage occurs).
  - System can be automated to regenerate based upon conductivity or silica. Can handle variable makeup quality.

- Limitations:*
- Acid and caustic handling.
  - Corrosion resistant equipment required.
  - Neutralization of regenerant waste.

- Troubleshooting:*
- When the anion resin becomes exhausted, silica breakthrough occurs and conductivity temporarily drops as sodium leakage becomes associated with the silica rather

than hydroxide. If silica is a concern, regenerate based upon silica rather than conductivity.

- Follow resin manufacturer's specifications for preheating the 4% sodium hydroxide regenerant solution. 120°F is commonly used, but resins resistant to organic fouling may only tolerate 90°F. (The preheating assists in the removal of silica).
- When checking regenerant strength, make sure to cool the sample or compensate for temperature when using a hydrometer. (Specific gravity changes significantly with temperature. Hydrometers are commonly designed for 60°F).
- Use step-wise acid addition if sulfuric is the regenerant. 2%, then 4% is common. 1% then 4% may be needed, especially in counterflow units. Check calcium sulfate in the regenerant and keep it below 200 mg/L to prevent calcium sulfate fouling.
- Sodium leakage from the cation bed causes high pH and high conductivity in the anion effluent.

#### ◆ **Countercurrent or Reverse Flow Ion Exchange Regeneration**

*Features:* Regeneration is accomplished in the opposite direction of flow as the service cycle flow. This puts highest purity regenerant in contact with the resin nearest the exit point, making it the most highly regenerated. Sodium leakage is less and a higher purity water is obtained without increasing regenerant concentration. Counterflow systems can be downward service flow with upflow regeneration or upflow service with downflow regeneration.

*Advantages:*

- Improves effluent quality and regeneration efficiency. In conventional downflow demineralizer design, the bottom polishing zone of resin bed is underutilized before leakage occurs because it has not been effectively regenerated into the hydrogen form. More of the resin bed capacity is used with countercurrent regeneration.
- Upflow countercurrent regeneration improves upon counterflow design but still uses 100% freeboard expansion area and relatively shallow resin beds.

A packed bed upflow design regenerates in the traditional downflow manner, but the service flow is upward. The area is completely packed with resin allowing for a smaller vessel. Regenerations are more efficient with the elimination of the resin void area.

- Limitations:*
- Resin maintenance tanks may be necessary to periodically transfer resin into for cleaning.
  - Effective resin screens or resin traps are needed to prevent carrythrough of resin.
  - Hideout is possible in some designs. Inert resin may be used in packed bed design at the top to keep active resin out of dead zone pocket areas.

#### ◆ Acid Dealkalization

*Features:* Typically, this process would be used after softening. A flow controller monitors flow and proportionally adds sulfuric acid to depress pH to near free mineral acidity (FMA). The acid is mixed with the water by means of an in-line static mixer. The pH is monitored to assure proper acid addition.

Bicarbonates and carbonates are converted to carbonic acid. The water is passed over a decarbonator to strip off the carbon dioxide, then neutralized with caustic in the receiver/storage tank. Caustic addition is automatically accomplished by using a pH controller and recirculating loop in the storage tank.

- Advantages:*
- Cost effective dealkalization method.
  - Easy add-on to a softening system.
  - No regenerant waste stream or waste stream neutralization.
  - Lowers total dissolved solids.

- Limitations:*
- Only reduces bicarbonate/carbonate alkalinity.
  - Corrosion resistant equipment required.
  - Acid and caustic handling.
  - Requires good control and monitoring to avoid low or high pH upsets.

- Troubleshooting:*
- Test for pH after static mixer and ensure stable desired pH.
  - Make sure acid pump is sized to handle various flows. An equalization tank may be better than a static mixer.
  - Test for carbon dioxide after decarbonater and prior to caustic addition. It should be less than 10 ppm.

◆ **Cold Lime Softening**

*Features:* By adding lime and perhaps soda ash and/or caustic at ambient temperature to a reaction vessel, precipitation occurs which lowers hardness, alkalinity, iron, total dissolved solids, silica, suspended solids, carbon dioxide, and oil. The precipitant and water are separated by allowing settling to occur.

A sludge blanket precipitator is common for boiler makeup applications because it increases reaction time, improves efficiency, and reduces post-precipitation.

- Advantages:*
- Removes or reduces many impurities.
  - Good pretreatment for ion exchange or membrane technologies since suspended solids and oil are reduced. This is of particular benefit for surface or recycled waters.
  - Effluent characteristics can be changed or controlled by adjusting treatment chemical dosages.

- Limitations:*
- Chemical handling of lime and/or soda ash and/or caustic and perhaps others.
  - Magnesium addition may be necessary for improved silica removal.
  - Sludge disposal is required.
  - Rapid flow changes can upset the system.
  - Temperature changes can upset the sludge bed. Influent temperature should not vary by more than 3 or 4°F.
  - Frequent testing and dosage changes required with varying influent quality.

- Troubleshooting:*
- Jar testing can be used to determine dosages. Recycle sludge after the jar tests to improve solids contact and precipitation. 10% solids in the jar is desired, which may take 5-10 jars. Use hydrated lime solutions for testing.
  - Solids contact is very important for silica removal along with reaction time. Addition of magnesium improves silica removal. Magnesium oxide, magnesium hydroxide, and magnesium sulfate may perform differently for silica adsorption.
  - Check for carryover by testing total hardness and total acidified hardness.
  - Ensure proper hydraulic loading and stable temperatures.
  - If quicklime (CaO) is used, check the slaking process regularly to ensure efficient hydration.

#### ◆ **Hot Process Softening**

*Features:* A precipitation softening process differs from cold lime softening in that the temperature is raised to around 220°F with steam to increase reaction rates. Carbon dioxide is driven off with the heat rather than being neutralized by lime. More effective and rapid solids settling occurs because the particulates are heavier and the water is less viscous than in the cold process. The water is then filtered through anthracite filters. Reduction occurs to hardness, alkalinity, iron, total dissolved solids, silica, suspended solids, and oil.

Two basic types are:

1. Downflow
2. Upflow

In the downflow type, there is an internal inverted funnel toward the bottom of the coned bottom vessel; funnel open toward the bottom. Chemicals, water, and recirculated sludge are mixed in the upper portion of the tank then flow downward. A one-hour minimum retention time should be allowed, sludge settles, and clarified water is obtained as it

rises in the uptake funnel. This design is applicable for rapid load swings.

The upflow softener can either be a sludge blanket design or a sludge recirculation design. In the sludge blanket design, the water and sludge flow downward through the funnel (open toward the top) downcomer tube and the water/sludge mixture is released below the sludge blanket, then the water rises on the outside to the top.

The upflow sludge recirculation unit downcomer tube terminates above the sludge level.

Upflow designs are used for fairly constant loads.

*Advantages:*

- Removes or reduces many impurities.
- Good pretreatment for removal of suspended solids in surface or recycled waters.
- More complete silica removal in hot process softening compared to cold lime.

*Limitations:*

- Lime and/or soda ash handling.
- Fairly high maintenance for cleaning chemical feed equipment and sedimentation tank.
- Hardness and alkalinity removal incomplete. Downstream softening may be necessary. Hot zeolite softener design necessary.
- Carryover to filters or downstream softeners is common.
- Dosage changes necessary with variable influent water quality.

*Troubleshooting:*

- Analyze influent water frequently to identify changes and need for dosage changes.
- Run hardness and total acidified hardness tests of effluent before and after filters to determine carryover or post-precipitation.
- Make sure there is at least a one hour retention time. Test by flow measurement and by adding phenolphthalein and timing how long it takes for pink color to show up.
- Test sludge blanket levels regularly.

- Check sludge recirculation for proper operation.
- Slurry tank mixture should be 5% or less.
- Make sure temperature control is consistent.
- Backwash filters regularly. Since backwash is commonly returned to the softener, keep frequency consistent as much as possible to maintain consistent water quality.
- There is lag time between dosage changes and results. Don't over compensate.

◆ **Filtration - Sand; Anthracite; Carbon; Manganese Greensand**

Sand and Anthracite

*Features:*

Sand and anthracite used together or alone and perhaps with different layers of gravel or garnet can be used to remove suspended solids from raw waters or waters which have been clarified or lime softened. The filters may be either gravity or pressure type. Pressure filters require less space because of higher flowrates achieved per square foot of surface area of the media. Repumping is also avoided with pressure filters if they can be installed on pressurized lines in the boiler makeup or feedwater system.

*Advantages:*

- Removes suspended solids that may foul other pretreatment processes such as ion exchange resin or membranes.
- By adjusting flowrates and media type, and perhaps by applying coagulants, suspended solids removal can be very efficient. Particle size reduction to less than one micron is achievable.
- Cleaning can be relatively simple and inexpensive by backwashing when the media becomes loaded, as indicated by excessive pressure drop across the bed.

*Limitations:*

- Media can foul rapidly if suspended solids increase significantly in the influent.
- Does not remove dissolved solids.
- With sand filters, water temperature should be less than 120°F to avoid pickup of silica.

- Troubleshooting:*
- Avoid plugging of the media by backwashing more frequently. Excessive flowrates or inlet pressure can impregnate the bed with solids not easily removed by backwash. Most of the solids should be held to the top 3 or 4 inches of the media bed.
  - Inspect the bed frequently. If the bed becomes compacted and fouled, channeling occurs around the outside of the bed. (A gap between the vessel and media can be seen).
  - Bacteria contamination can occur on low temperature waters. Sterilize appropriately.
  - Inspect the media after backwashing. If the media is not level, suspect plugging or a problem with the underdrain system.
  - If a multibed media becomes mixed with the coarse supporting layers rising toward the top, rebed the filter. Causes include excessive backflow rates, agglomeration of support media, or air bumps.
  - Acid clean media to extend its life.

◆ **Carbon**

*Features:* Activated carbon filters remove chlorine and organics, utilizing the enormous internal surface area of the carbon along with an intricate network of internal pores. The useful service life of the carbon is dependent upon the level of organics and chlorine in the influent and the extent that they are adsorbed onto the carbon. After the area is exhausted, the bed is replaced. (The carbon can be regenerated by various methods including thermal, chemical, hot gas, solvent, or biological). Sediment removal also occurs, but heavy amounts should be filtered prior to the activated carbon.

- Advantages:*
- Chlorine removal and organic removal to protect ion exchange resin or membranes downstream in the system.
  - Chlorine removal can be obtained without chemical addition and control.

- Can accommodate influent fluctuations in concentration of chlorine or organics.

*Limitations:*

- High cost of bed replacement if influent contaminants are high.
- Some organics are not effectively adsorbed.

*Troubleshooting:*

- Bacterial growth can be a real problem. Sterilize with heat or sodium hydroxide.
- Adsorption of organics increases with increasing molecular weight to the point until they become too large to enter the pores.
- Adsorption of organics increases as the solution pH decreases.
- Adsorption increases as temperature increases.
- Adsorption increases with decreasing solubility. Nonpolar organics are adsorbed better than polar organics.
- Pretest a solution to determine removal capability of activated carbon.
- Limit flow to 1 gpm per cubic foot for effective organic removal.

◆ **Manganese Greensand**

*Features:*

A vessel containing a processed natural greensand zeolite is used to remove iron and/or manganese from water by oxidizing ferrous or manganous bicarbonates to insoluble oxides and simultaneously filters them out of the water. Additionally, hydrogen sulfide can be removed by this process.

Two methods of operation can be used: (1) Continuous Regeneration, or (2) Intermittent Regeneration.

Continuous Regeneration: Chlorine and potassium permanganate are fed continuously upstream of the vessel with the chlorine being fed first for at least 10 - 20 seconds contact time prior to permanganate feed. Concentrations are as follows:

$$\begin{aligned} \text{ppm Cl}_2 &= \text{ppm Fe} \\ \text{ppm KMnO}_4 &= (0.2 \times \text{ppm Fe}) + (2 \times \text{ppm Mn}) \\ &\text{or without chlorine} \\ \text{ppm KMnO}_4 &= (1 \times \text{ppm Fe}) + (2 \times \text{ppm Mn}) \end{aligned}$$

Intermittent Regeneration: Regenerate like softener using 1.5 - 2.0 oz. KMnO<sub>4</sub> per cubic foot greensand, 2 - 4 oz. KMnO<sub>4</sub> per gallon regenerant, 7.5 gal. regenerant/cubic foot, 0.25 gpm regenerant rate/cubic foot, 30 minute regeneration time, 1 gpm rinse rate. Backwash sufficiently to clean and provide 40% expansion.

- Advantages:*
- Reduces iron and manganese fouling of ion exchange resins or R.O. membranes.
  - Removes suspended solids as well as iron and manganese.
  - Relatively low capital cost and limited space requirement.

- Limitations:*
- Recommended pH operating range is 6.6 - 8.8.
  - Maximum water temperature is 100°F.
  - Turbidity should be low; less than 10 ppm.
  - Iron should be less than 10 ppm.

- Troubleshooting:*
- Flowrate is designed for 2 - 5 gpm per square foot. Higher concentrations of iron or manganese require lower flowrates.
  - Some iron can be seen after regeneration or restart. A pre-rinse may be advisable to avoid iron/manganese slugs.
  - Continuous regeneration yields longer greensand life and more consistent removal rates. Anthracite layer on top of greensand is recommended for this mode.

#### ◆ Reverse Osmosis

*Features:* Reverse osmosis removes up to 99% of dissolved solids, organic matter, biological matter, and colloidal matter from the raw feedwater by using pressure to force water through a semipermeable membrane.

*Theory:*

1. Pores of membrane < 0.001 micron.
2. Not filtration, strictly. Process of separation. Water passes in preference to the solute. More diffusion - not passage through pores.
3. Percent salt passage of smaller ions, or lesser charge will be greater than larger ions or greater charge.  
  
Ca<sup>++</sup> three times rejection of Na<sup>+</sup>
4. Organics - passage depends upon physical size and shape and chemical characteristics.  
  
MW < 200 more likely to permeate than those > 200.
5. UF - more of a passing through pore. UF fouls 10 times faster than R.O. (mostly from particulate & SS).
6. Rate of salt passage is not a function of pressure, but water flowrate is. A lower concentration of salts results on pure water side at higher pressures on concentrate side because of greater dilution of the salt flow by the increased permeate water flowrate.

### **Design Conditions**

1. First, understand the needs and limitations of the particular application.
  - a. Permeate recovery & quantity and maintenance depend greatly on the quality of water source. Quality of water source determines the pretreatment.
2. Two parameters to be determined:
  - a. R.O. permeate flowrate
  - b. Desired permeate quality

If storage tanks are used and sized correctly, average flowrate can be used. Use peak flow with no storage.
3. Size constraints?
4. Water source:
  - a. Variability of constituents

- b. Water pressure after backflow-preventer
- c. Water temperature (winter vs. summer) - heat exchanger needed?
- d. Bacteria present? If so, biocide treatment will probably be required.
- e. Comprehensive water analysis to determine potential for scale formation as water is concentrated.

**Silt Density Index (SDI) - Fouling Index**

Used as an indicator for the potential for membrane fouling. The test measures the rate of fouling of a 0.45 micron filter membrane by suspended solids.

**Water Chemistry**

Cations and anions of significance include:

<u>Cations</u>	<u>Anions</u>
Calcium	Bicarbonate
Magnesium	Carbonate
Sodium	Hydroxyl
Potassium	Sulfate
Iron	Chloride
Manganese	Fluoride
Aluminum	Nitrate
Barium	Silica
Strontium	Sulfide
Copper	Phosphate
Zinc	

Also, pH should be known. It dramatically affects the solubility of salts.

**General Guidelines:**

Iron or manganese should be held to less than 0.05 ppm.

Barium  $\leq$  0.01

Strontium  $\leq$  0.01

Aluminum should be minimal. Is water treated with alum or any aluminum coagulants?

Copper or zinc and increase oxidation potential of oxidizing agents and damage polyamide membranes.

Silica  $\leq$  20 ppm.

Polyphosphate should be negligible or feedwater should be acidized and/or softened.

### **Membrane Choice**

- A. Cellulose Acetate (CA)
- B. Polyamide (PA)
- C. Polysulfone (PS)

**Cellulose Acetate:** First to be used widely in spiral wound configuration. Today's are cellulose triacetate blend polymers.

- Stable performance.
- Resistant to high free-chlorine concentrations.
- Uncharged membrane (functional groups on the ends of the polymer chains are not extremely polar). Therefore, less likely than PA or PS to attract foulants to surface.
- Hydrolyzes over time so low pH of  $< 6.5$  is desired. Optimum is 4.8.
- Feed pressures 200-400 psig. At 200 psig, permeate flow is about half of what it is at 400 psig. Salt passage into the permeate will be almost double what it would be at 400 psig. 500 psig is upper limit.

### **Polyamide/thin Film**

- High permeate flux (high flow per membrane area).
- First used in hollow-fiber configuration.
- For spiral wound element configurations, the membranes are constructed of a thin layer of an aromatic polyamide extruded onto a polysulfone substrate.  
--- This is a "thin-film" membrane.

- Thin-film flux rate is significantly greater than CA membrane, allowing operation at about half the pressure of CA/RO, with comparable flowrates and better salt rejection.  
Therefore, lower capital cost, smaller pump, less expensive housings. Also lower electrical cost.
- Operating PA membranes at high pressure and high flux results in increased fouling rate.
- Very sensitive to oxidizing agents. Remove oxidizer with a reducing agent such as sodium bisulfite or filter through activated carbon.
- Since biocidal oxidizing agents are removed, biological fouling risk increases.
- PA membranes are normally negatively charged which can attract certain foulants, so chemicals must be compatible with membrane. (only anionic surfactants).

**Charged Polysulfone**

- Better chlorine resistance than CA (5 ppm free chlorine).
- Chemical tolerance equal to or greater than PA.
- Permeate flux comparable to PA.
- Rejection comparable to CA.
- Used for UF.
- Has to be chemically sulfonated for salt rejection capabilities. This sulfonation places sulfonate groups on the surface that repel anions. Cations are indirectly repelled due to their attraction to the anions in solution.
- This sulfonation process is similar to that used for ion exchange resins. Calcium, magnesium, and iron will be held by sulfonate groups, removing the charge characteristic and allowing salts to permeate the membrane.
- Can regenerate membrane with sodium chloride.
- Should have two softeners upstream.

**Performance Comparison of Common R.O. Membrane Types**

	<u>Thin-Film</u>	<u>Std. CA</u>	<u>High-Rej. CA</u>	<u>PS</u>
NaCl Rejection (%) (200 psig)	98	90	95	95
(400 psig)		95	97.5	

Permeate Flow @ 200 psig (gpd) (400 psig)	1800	1000	800	2000
Chlorine Tolerant	No	Yes	Yes	Yes
Relative Cost	Medium	Low	Low	High

**Element Configurations**

Four configurations:

- A. Plate and frame
- B. Tubular
- C. Hollow fiber
- D. Spiral wound

**Plate and Frame:**

- Flat sheets clamped onto plate backing devices. They are stacked such that the concentrated solution from one plate is fed to the next plate.
- Expensive because of high pressure hardware.
- Advantage is membrane is readily accessible so application is for testing and pilot studies, or where heavy fouling is expected and physical cleaning is necessary.

**Tubular:**

- Membrane is cast onto the inside surface of a porous support tube of fiberglass, ceramic, carbon, plastic, or stainless steel. The tube provides support against the R.O. operating pressure present within.
- Tubes are plumbed in series for desired permeate recovery, contained inside a low-pressure collection jacket.
- Can provide high flow velocities through the tubes to reduce fouling and high velocities can be used during cleanings.
- Minimal membrane area compared to flow volume through the tubes, necessitating numerous tubes for decent recovery rates.
- Expensive to purchase and operate, so mainly limited to heavy fouling applications.

**Hollow Fiber:**

- First large-scale R.O. systems.

- Fine hollow fibers are extruded, the ends sealed in an epoxy block connected with the outside of the housing. The epoxy block is cut to allow the flow from the inside of the fine fibers to the other side of the epoxy block where it is collected. The pressurized feedwater passes across the outside of the fibers. Pure water permeates the fibers and is collected at the end of the element.
- Housings can hold a large quantity of fibers, allowing a single element to produce a large permeate flowrate.
- Does not allow for turbulent or uniform flow across the fiber surface, so more prone to fouling and scaling. Difficult to clean because of inability to get the cleaning solution into fouled areas. Improvements in design lately should help hollow fiber elements compete with spiral-wound for brackish water treatment market.

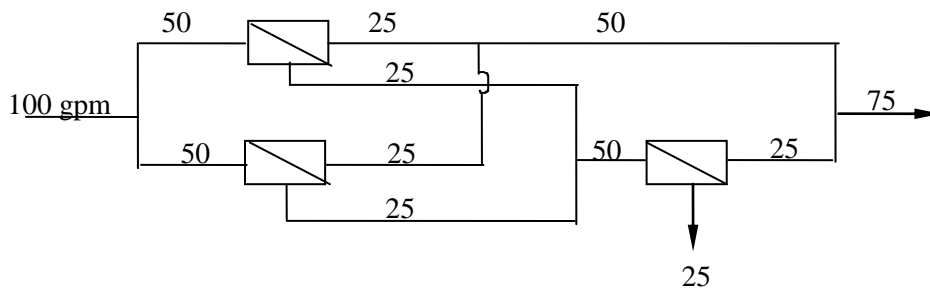
Spiral Wound:

- Most common configuration.
- Relatively inexpensive
- Fairly uniform flow velocities.
- Includes mechanisms to promote turbulence across the membrane surface, reducing fouling potential.
- In construction, flat membrane sheets are folded, two sides are glued shut, and the third open edge is glued to perforations of the center collection pipe. Inside the membrane envelope is a polyester cloth that prevents the envelope from shutting itself off. Depending on the diameter of the desired element, 1-20 envelopes are glued to the collection pipe and wrapped with a plastic spacing material between the envelopes to promote turbulence as it allows the passage of water between the envelopes. Water passes across the envelopes, permeate collects within the envelope and follows the spiral to the center collection tube. Inside pressure is nearly atmospheric.
- On the downstream end of the element is a cylindrical device held against the end of the membrane to prevent its unraveling (telescoping).
- Brine seal gasket is placed around outside element to seal the element to the external housing, preventing water from bypassing the element.
- Permeate collection tubes of adjacent elements are joined by interconnectors and O-rings.

### **R.O. System Permeate Recovery**

Permeate recovery = permeate flowrate ÷ feed flowrate.

- The higher the recovery, the more concentrated the salts will be in the tail end of the system, and subsequently, the higher the salts will be in the permeate.
- Recovery commonly chosen based upon potential for scale formation.
- 75% recovery has become somewhat standard because:
  - A. 75% recovery makes optimum use of the longest housing (most economical) which contains six 40 inch elements or four 60 inch elements. With a 2-1 array where the concentrate of two lead housings are plumbed to feed a third housing, the overall recovery ends up being 75%. A relatively high percentage of feedwater is converted to permeate without using concentrate recycle.



- B. Overall permeate quality is not significantly affected and recovers up to 75%.

### **Optimizing R.O. Permeate Recovery**

- Because adequate turbulence is needed within the R.O. elements, achieving higher recoveries involves more than just reducing R.O. concentrate flowrate.

Concentrate Recycle - return a portion of the concentrate back to the feed of the high pressure pump. (Recycling half of concentrate of 75% recovery design increases recovery to 85.7%).

Additional Staging - install smaller diameter R.O. elements and housings in the concentrate line of the R.O. upstream of the concentrate throttling valve. More R.O. water is available for roughly the same operating costs, but higher salt content from end element permeate.

*Advantages:*

- No regenerant chemical handling and cost.
- Achieve low TDS, good quality water.
- Can be effectively automated and run without much continuous operator attention.
- Less expensive than demineralization by ion exchange for higher TDS waters. (The economic cross-over point where R.O. is favored depends upon many factors, but is in the 75 - 600 ppm range).
- Design can be customized to space requirements.

*Limitations:*

- Capital cost.
- Pretreatment requirements.
- Membrane cleaning and preventive maintenance data logging.
- Electrical cost.
- May require preheating of the water.
- Troubleshooting requires expertise.
- May require antifoulant and/or biocide feed.

*Troubleshooting:*

- Have a convenient CIP (clean in place) setup and follow a strict preventive maintenance cleaning schedule.
- Run exhaustive testing of feedwater to make sure pretreatment is effective.
- Change prefilters frequently. Check with differential pressure
- Check instrument calibrations for conductivity, percent salt rejection, flows, pressure, pH, and temperature.
- Check conductivity of each housing to determine location of fouling or low salt rejection by probing the spiral-wound membrane with a hose.

◆ **Electrodialysis (ED); Electrodialysis Reversal (EDR)**

*Features:*

A DC electric field is applied perpendicularly to water flowing between paired sets of membranes. The membranes are selectively permeable and the electric field drives the positively charged cations toward the cathode (-) and the negatively charged anions to the anode (+). The cations pass through the cation membranes and the anions pass through the anion membranes. Brine and demineralized water are collected in alternating compartments from the paired sets of membranes that may number in the hundreds.

EDR provides a self-cleaning mechanism of the ED process by reversing polarity up to several times per hour. When polarity is reversed, cation and anion flow reverses, making the diluting compartments become concentrating compartments and concentrating compartments then collect the demineralized water. Valves necessary for the collection and distribution of the waters are appropriately switched with each reversal, and a pre-rinse time is incorporated.

*Advantages:*

- Most economical for waters in the range of 1000-3500 ppm.
- Can obtain up to 95% water recovery with minimal chemical feed or pretreatment.
- Operate at low pressure compared to R.O. (30-60 psig versus 200-450). This results in less maintenance requirements.

*Limitations:*

- A single pass-through membrane only yields 30 - 60% ion removal and depends upon water temperature, flowrate, solids content, and applied voltage. Six stages are required for 98% salt removal.
- Does not remove silica, colloids, or uncharged organics.
- High capital cost.
- High electrical demand, proportional to the amount of dissolved solids to be removed. Typically, 2<sup>1</sup>/<sub>2</sub> kilowatt hours of electrical energy are required for each 1000 ppm of TDS removed from each 1000 gallons of product water. Pumping power adds another 2<sup>1</sup>/<sub>2</sub> kilowatt hours.

◆ **Continuous Deionization (CDI)**

*Features:* Continuous deionization or electrodeionization (EDI) uses a combination of electrodialysis with ion exchange. A thin layer of resin beads situated between the ED/EDR membranes temporarily capture and help transport the cations and ions. Excess electric current through the demineralized waters dissociates water molecules into hydrogen and hydroxide ions which continuously regenerate the resin beads by displacing the ions still held at the exchange sites.

*Advantage:*

- Continuous regeneration of ion exchange resin without acid or caustic handling.
- Production of constant purity water.
- Effective polishing system.

*Limitations:*

- High capital cost.
- High electrical demand.

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