

Membrane Post Treatment

Post treatment for low pressure membranes (MF and UF) is typically minimal consisting of disinfection (as a secondary barrier) and sometimes pH adjustment and corrosion control, depending on raw water chemistry. Since these low pressure membranes do not remove dissolved substances and water chemistry remains unchanged, the post treatment approach is similar to conventional sand filtration and therefore not discussed in this fact sheet. Instead, this fact sheet focuses on membrane desalination.

Desalination is intended for the removal of total dissolved salts (TDS) that generally cannot be removed by conventional treatment processes alone. Reverse Osmosis (RO), Nanofiltration (NF) and Electro-Dialysis Reversal (EDR) synthetic membrane processes produce treated water that requires post treatment before delivery to the distribution system as finished water. These membrane processes produce permeate water depleted in minerals which often is found to be aggressive towards distribution system components. Different RO and NF membranes have different mass transfer characteristics; using a membrane with a lower molecular weight cutoff will decrease the permeate concentration. EDR processes are impacted by the amount of electrical current and electrical requirements and less effected by the type of membrane. Regardless of specific membrane formulations, the water produced by RO, NF and EDR membrane processes is incompatible with many components and appurtenances that comprise water distribution system infrastructure. This fact sheet discusses the post-treatment of RO and NF membrane processes

used for desalting drinking water supplies.

MEMBRANE DESALINATION PROCESSES

Many municipal plants have multiple process trains installed in parallel, allowing flexibility in permeate (product water) production and ease of expansion. In some instances it is possible to bypass a portion of the raw or pretreated water around the membrane system and blend that flow with the permeate stream to reduce the size of the membrane system, improve finished water stability, and minimize capital and operating costs. The maximum allowable blend ratio is determined from an analysis of bypass and permeate water qualities.



Post-treatment processes typically include stabilization, disinfection and corrosion control, and can include degasification and/or air stripping processes if carbon dioxide and hydrogen sulfide gases are present in the permeate water. Post-treatment is needed for municipal water treatment before the membrane-treated water is delivered to the distribution system as finished water.

POST-TREATMENT PROCESS OVERVIEW

The choice and sequence of post-treatment operations are typically

determined by regulatory requirements, the design of the system, finished water quality criteria and water chemistry. The need for post-treatment generally depends on a number of factors, which can be grouped into several categories, all of which are related to water quality:

- Chemical stability
- Microbiological Stability
- Palatability and Customer Acceptability
- Secondary Impacts on Wastewater Influent Quality

A recent overview of the current state of 62 full-scale RO/NF plants, 9 greater than one-million gallons per day of capacity, used for either seawater desalination, brackish water desalination (including ground water, surface water and agricultural runoff), or wastewater reclamation provides an insight into post-treatment practices. All of the surveyed facilities reported using at least one post-treatment method for permeate conditioning and corrosion control. These included such methods as caustic addition (31%), blending with raw, semi-treated or finished water (29%), degasification/ decarbonation (25%), and addition of corrosion inhibitor (14%). Most of the brackish water RO plants responding to the survey reported using degasification/ decarbonation and caustic addition, with the majority blending permeate with groundwater. Permeate disinfection was reported to be used by 85% of the surveyed facilities that responded, most of which used chlorine. Other reported disinfection methods included the use of chloramine (24%) and ultraviolet irradiation (4%).

Table 1 presents the typical categorization of permeate post-treatment depending on source water type. There are four primary issues concerning the post-treatment water. These relate to blending, remineralization, disinfection and the materials used for storage and transport of the water to the tap.

Desalinated water is often blended with other sources that contribute minerals to the final blended water. Seawater as a source for blending is limited due to issues related to corrosivity and taste if the blending levels exceed about 1%. Blending of permeate water with seawater results in the addition of sodium, potassium, calcium, and magnesium to the drinking-water but also will contribute bromide and iodide which are DBP precursors, and is limited in quantity due to the significant concentrations of these constituents. Consideration should be given to the natural minerals present and whether these will result in the finished water having unacceptable water qualities in addition to unacceptable taste and odor.

PERMEATE WATER QUALITY CONSIDERATIONS

The chemical composition of permeate water produced by RO or NF when blended with other source water can cause water quality and infrastructure

problems when distributed. Many facilities pump desalinated water directly into the distribution system without being mixed or blended with other finished water supplies that cause concern with regards to distribution system water quality. Consequently, evaluation of water quality parameters for use in determining appropriate post-treatment actions is required for desalination membrane treatment applications. Factors that should be included when referring to the quality of desalinated waters include the chemical and biological stability of water and its interaction with the distribution system. Permeate streams from sea-water and brackish water desalting processes are primarily a dilute solution of sodium chloride. Untreated permeate from sea or brackish water reverse osmosis plants does not conform to the drinking water standards of such organizations as WHO or the EPA. Due to the low TDS values RO permeate water can be unpalatable, corrosive, and suspected as unhealthy.

To stabilize the water, and to prevent corrosion (metal release) of piping systems and domestic plumbing, post-treatment is necessary to return some calcium hardness and bicarbonate alkalinity to the water. In many situations, post-treatment also includes the removal of carbon dioxide to raise the pH, hydrogen sulfide removal when

the pH which will be dependent upon the buffering capacity and bicarbonate alkalinity, calcium, sulfate and chloride, dissolved oxygen, boron, total dissolved solids concentration and corrosion indices. These parameters are interrelated in the final treatment process selected for post-treatment, depending on application and source water (i.e. ocean surface versus brackish ground water supplies).

Alkalinity, Scale and Red Water

Alkalinity in water is a measure of the general buffering capacity or stability of the water. Increasing the alkalinity generally leads to lower and corrosion rate and results in less changes in the pH of distributed water; however, excess alkalinity can cause excessive scale deposition where calcium may be present. Alkalinity is thus directly related to the buffering capacity of water and is considered an important parameter affecting the pH. Alkalinity depends on the concentration of bicarbonate, carbonate, and hydroxide ions in water. For a given pH value, the higher the alkalinity value, the higher the ability of the water to withstand a change in pH due to release of H⁺ and OH⁻ ions to the water. A higher alkalinity at a given pH translates into a higher dissolved inorganic carbon (DIC) concentration of the carbonate species (CO₃²⁻). However, too high of an alkalinity at higher pH levels may accelerate lead and copper metal release. It is also known that red water prevention can be accomplished by maintaining the alkalinity in the system when considering a subsequent pH shift if treatment was to be employed. A non-stabilized finished water can experience fluctuations in pH in the distribution system as scale is deposited (scale) or dissolved (corrosion). It is desirable to maintain the alkalinity concentration in distributed water above one mill-equivalent of alkalinity, or 60 mg/L (as calcium carbonate).

required, and the addition of fluoride which is removed during the desalting process. Corrosion control is a priority when either directly pumping desalted finished waters into the distribution system or when blending different water sources from membrane process. The constituents of concern when establishing a post treatment process include

Table 1: Examples of Post Treatment Processes Based on Supply Type

Supply Type	Process	Examples of Applicable Post-Treatment Processes
Seawater	RO	<ol style="list-style-type: none"> 1. Recarbonation 2. Lime addition 3. Calcite bed filtration 4. pH and/or alkalinity adjustment 5. Addition of corrosion inhibitors 6. Primary and secondary disinfection 7. Blending with fresh water supplies
Brackish Water (Surface)	RO, NF, EDR	<ol style="list-style-type: none"> 1. pH and/or alkalinity adjustment 2. Addition of corrosion inhibitors 3. Primary and secondary disinfection 4. Blending with fresh water supplies
Brackish Water (Ground)	RO, NF, EDR	<ol style="list-style-type: none"> 1. Decarbonation (degasification) 2. Hydrogen sulfide stripping 3. pH and/or alkalinity adjustment 4. Addition of corrosion inhibitors 5. Primary and secondary disinfection 6. Blending with fresh water supplies 7. Bypass blending with raw water supply
Fresh Water (Ground)	NF, EDR	<ol style="list-style-type: none"> 1. Decarbonation 2. Hydrogen sulfide stripping 3. pH and/or alkalinity adjustment 4. Addition of corrosion inhibitors 5. Primary and secondary disinfection 6. Blending with fresh water supplies 7. Bypass blending with raw water supply

Dissolved Oxygen

The oxygen concentration can have varying effects on iron corrosion. The corrosion rate increases with increasing dissolved oxygen. Dissolved oxygen is also responsible for the ability of buffering ions, including phosphates, to inhibit corrosion.

pH

Various studies have been done to correlate the effect of pH on corrosion in pipes. The pH in a system is directly related to the alkalinity, Ca²⁺ and CCPP in the system. The pH determines the buffer capacity of the water sources. When different water sources are blended the chemical stability of the blend is significantly determined by the buffering capacity of the original waters. A higher pH will usually result in a lower buffer capacity, which also can be noted to be associated with low corrosion rates and prevention of red water episodes, however most studies have shown pH to be a isolated single parameter.

Boron

Boron removal is more costly and difficult to process than other ions, especially when dealing with seawater. This is due to the fact that seawater is not drinkable or useable for irrigation. Treatment must be taken into consideration in order to decrease boron, and correct any other corrosive minerals that may be in the water. Boron rejections depend on temperature, pH and salt rejections. Due to low boron levels required for irrigation, several stages of reverse osmosis treatment are used. The first stage will use antiscalants on both passes to avoid risk of salt precipitation. The second stage will use caustic soda to transform boric acid to borate, which is much easier to remove. Residual boron is related to the pH levels in this stage. The degree of boron removal depends on the finished water quality goals, some countries and municipalities having more strict standards than others.

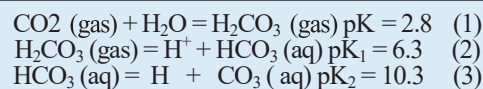
WHO has recently published guidelines for boron value of 2.4 mg/L for human health perspective.

BRACKISH GROUND WATER POST-TREATMENT CONSIDERATIONS

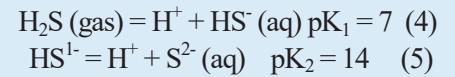
The primary desalination water plant post-treatment unit operations for potable water supplies reliant upon brackish ground waters are the following:

1. Carbon dioxide removal (degasification or decarbonation)
2. Hydrogen sulfide removal (stripping) and odor control treatment (scrubbing)
3. Alkalinity recovery, pH adjustment, stabilization and corrosion control
4. Disinfection

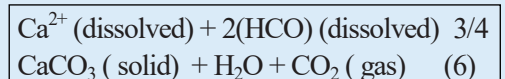
Carbon dioxide is easily removed from brackish permeate water with the use of aeration (degasification or decarbonation). Carbon dioxide exists in equilibrium with other carbonate species as defined by equations (1), (2) and (3). The pH of the permeate water will determine the amount of carbon dioxide available to be removed from the water.



Many of the brackish ground waters used as feed streams to RO or NF plants contain hydrogen sulfide. Conventional pretreatment (acid addition, scale inhibitors, cartridge filtration) will not remove hydrogen sulfide nor will the membrane process, as hydrogen sulfide will permeate the membrane as a gas. Aeration and oxidation are the two primary means for removing hydrogen sulfide. Incomplete chemical reactions in the process are often responsible for formation of polysulfide complexes and elemental sulfur, which manifest themselves as turbidity in the finished water. Hydrogen sulfide dissociates in water according to equations (4) and (5).



As shown in equation (4), since at pH of 7 only 50 percent of hydrogen sulfide exists in the gas form and is available for stripping pH adjustment is typically used to improve removal efficiency. Since the pK for hydrogen sulfide is 7, half of the sulfide speciation is present as a gas and strippable. Hence, hydrogen sulfide gas can be effectively removed at pH levels of 6.0 or less without the formation of turbidity (elemental sulfur). However, all of the carbon dioxide in the permeate water will also be removed. If stripping of sulfide occurs at pH 6.3 (bicarbonate pKa1) some buffering capacity will remain. Unless carbonate is added or a significant amount of alkalinity passes the membrane, there will be no carbonate (alkalinity) buffering in the permeate, a possible problem with respect to stabilization and corrosion control even if pH adjustment with sodium hydroxide is practiced. Better methods are required to resolve this common post-treatment issue; an increase in the pH entering the tower prior to air stripping to recover 1 to 2 meq/L of alkalinity would be beneficial. The use of carbonic acid pH adjustment prior to air stripping of hydrogen sulfide has proven to be beneficial with regards to buffering loss of finished water. The alkalinity of water is a measure of its capacity to neutralize acids. Bicarbonates represent the major form of alkalinity in water, since they are formed in considerable amounts from the action of carbon dioxide upon basic materials in the soil. Temperature, pH and the concentration of bicarbonate are important in the formation of CaCO₃ feed water (equation 6).



TREATMENT METHODS FOR CORROSION CONTROL

The primary options for stabilization and post-treatment of membrane permeate and EDR product water include:

- pH adjustment
- Alkalinity adjustment
- Calcium adjustment
- Corrosion inhibitors
- Blending

pH Adjustment

Adjustment of pH is used to induce the formation of insoluble compounds on the exposed pipe walls. Passivation is the operating mechanisms for this corrosion control strategy. pH adjustment is accomplished with the addition of chemicals, such as lime, soda ash, sodium hydroxide, potassium hydroxide and carbon dioxide. pH adjustment is most suitable for source waters with low to moderate hardness and alkalinity levels (between 80 and 150 mg/L as CaCO₃). Frequently, this treatment technique is used in lieu of calcium carbonate precipitation. Some concerns with pH adjustment include increased formation of disinfection by-products at pH levels above 7.8, decreasing chloramines disinfection efficiency with pH values below 7.8, and a higher potential for calcium carbonate scaling in the distribution system pipe at pHs above 7.9.

Alkalinity Adjustment

Alkalinity adjustment frequently is used to induce the formation of insoluble compounds on the pipe walls of the distribution system. Passivation is the operating mechanism for this corrosion control strategy; carbonate passivation is achieved by incorporation of pipe materials into a metal hydroxide/carbonate protective film. This corrosion control strategy is most suitable for source waters with minimum alkalinity, and is frequently used in lieu of calcium carbonate precipitation. Alkalinity

adjustment alters the concentration of dissolved inorganic carbonate (DIC) in the source water. Alkalinity adjustment can be accomplished with lime, soda ash, sodium bicarbonate, sodium hydroxide, potassium hydroxide and carbon dioxide. Sodium bicarbonate addition is preferable for alkalinity adjustment. Sodium hydroxide contributes little alkalinity to the water, but can cause dramatic increases in pH. The primary disadvantages of alkalinity adjustment include capital, operation and maintenance cost and increased carbonate scaling on pipe walls. The primary benefit of alkalinity adjustment is increasing the buffering capacity for the source water. This helps to prevent wide fluctuations in pH throughout the distribution system.

Calcium Adjustment

The mechanism for this corrosion control strategy is the adjustment of the equilibrium for the calcium carbonate system for the source water. The objective for this treatment technique is the precipitation of a protective film of calcium carbonate onto the pipe walls. Calcium addition or removal is not necessary for the precipitation of calcium carbonate and is accomplished with pH and alkalinity adjustment of the source water. The key to this treatment technique is to provide the conditions necessary for achieving calcium carbonate saturation. Adjustment of the pH/alkalinity is done to create conditions necessary for the calcium and carbonate ions to exceed their solubility limits in water. The concerns with using calcium carbonate adjustment include precipitating a uniform protective film throughout the distribution system, reduction in the hydraulic capacity of the water lines, and scaling in mechanical systems (boilers and hot water heaters). Scaling is of particular concern for those water systems with high levels of non-carbonate hardness and sulfate. Adjustment of the pH is necessary for the precipitation of

calcium carbonate and iron stability. For lower alkalinity waters, sulfate can also precipitate calcium and cause scale.

Odor Control

Some ground waters may have high concentration of H₂S, which being a gas, will not be removed by membrane processes. Post treatment consisting of a single or sometimes two stage odor control system may be required to remove H₂S and other produced gases such as CO₂ (if excessive pretreatment acids are added).



Corrosion Inhibitors

Inhibitors have found wide spread use as a method of corrosion control. The most prominent forms of inhibitors used are polyphosphates, zinc phosphates, and silicates. The inhibitors control corrosion by several mechanisms, including sequestering of the corrosion by-products, specifically lead and copper, scale inhibition, development of a coating film on the pipe walls and buffering the water at the desired pH. Operating data indicate that the choice of inhibitor depends upon pH, alkalinity, calcium and total hardness, chloride, sulfide, iron concentrations, and dissolved oxygen levels of the source water.

Blending

Adding or blending pre treated source water into the (permeate) product water can help in stabilizing the product water thereby reducing the impact of the before mentioned issues. However, blending introduces the need for disinfection of the pre treated water prior to or after blending. Unfortunately, blending will not stabilize the product water completely hence permeate will

still need to have some level of calcium and alkalinity (alkalinity being the more important parameter) present. This can be accomplished by employing either lime or limestone treatment. If the source of the water to be blended with the product water from the reverse osmosis system is from a ground source from a limestone or chalk geological formation, the amount of lime treatment will be substantially reduced. Blending of variable and differing water supplies where desalted water serves as one of the supplies is becoming more frequent. Concern has also been expressed about the impact of extremes of major ion composition or ratios for human health. There is limited evidence to describe the health risk associated with long-term consumption of such water, although mineral content may be augmented by stabilization processes typically used by utilities practicing desalination (WHO, 2003). Desalinated waters are commonly blended with small volumes of more mineral-rich waters to improve their acceptability and particularly to reduce their aggressive attack on materials. Blending water should be fully potable; where seawater is used for this purpose, the major ions added are sodium and chloride. This does not contribute to improving hardness or ion balance, and only a small amount (typically no more than one to two percent) can be added without leading to problems of acceptability.

Bypass Blending of Source Water

Blending can improve the stability of the product water by increasing the alkalinity and calcium in permeate to reduce the corrosiveness of the water. The water to be used for blending may be the source water used for the reverse osmosis process or from another source, but is limited to brackish waters having moderate to low TDS with no significant DBP precursor content. Use of bypass blending or reliance on multiple source waters for blending will reduce the stress on the membrane

system as it reduces the amount of water that needs to be treated and thereby reduce the operating costs of the system. When integrating into an existing system, control over corrosion inhibitors and pH adjustment should be optimized for maximum efficiency.

Blending Multiple Source Waters

Blended waters from coastal and estuarine areas may be more susceptible to contamination with petroleum hydrocarbons or algal toxins, which could give rise to taste and odor problems. Some ground waters or surface waters, after suitable treatment, may be employed for blending and may improve hardness and ion balance. It is necessary to model the affects of different blends to prevent the release of red water in the distribution system. Should multiple sources be used, the utility should consider the need to develop a unidirectional flushing program or distribution system rehabilitation (including replacement) prior to the incorporation of a desalting process into existing infrastructure. In addition, the water purveyor may also need to increase storage reservoir size to be able to control the blending location of multiple source waters. In most cases, the water purveyor (water utility) should expect to see an increase in its operational and maintenance expenses.

SUMMARY

The need to stabilize water in order to prevent metal corrosion and concrete dissociation has been recognized for decades. Permeate typically is adjusted chemically in order to prevent corrosion of pipes in the distribution network and control, pH value and carbon dioxide content for scaling prevention. A buffer intensity greater than 0.5 milli equivalents per pH unit is indicative of a balanced, stabilized source water. The purveyor should focus on producing finished water having an adequate alkalinity and buffer intensity with a target that falls between one and three meq/L of bicarbonate alkalinity.

Alkalinity recovery needs to be considered when selecting scaling control options, and is dependent on how much carbon dioxide and bicarbonate is in the raw water. Regardless, permeate water will require chemical disinfection. Selection of post-treatment processes may not completely consider the impacts on the distribution system, particularly when blending multiple varying supplies. Although pilot studies are often conducted for RO and NF process design considerations related to pretreatment, process optimization and operation considerations, these pilot studies often do not include adequate consideration of post treatment processes focused on specific distribution system related issues that are specific to that system. It has been recommended by researchers that water purveyors mandate studies to evaluate the secondary impact of permeate post treatment (or lack thereof) on water quality and subsequent compliance related topics: disinfection and residual maintenance, the formation of disinfection by-products, maintenance of lead and copper corrosion control, bacteriological re-growth and coliform impacts.

This material has been prepared as an educational tool by the American Membrane Technology Association (AMTA). It is designed for dissemination to the public to further the understanding of the contribution that membrane water treatment technologies can make toward improving the quality of water supplies in the US and throughout the world.

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