

## Reverse Osmosis (RO) Water Chemistry

### Alkalinity

Alkalinity is comprised primarily of bicarbonate, carbonate and hydroxide ions. Naturally occurring alkalinity functions as the earth's natural buffering system. An example of this buffering capability occurs when small doses of strong acids (e.g. acid rain) react with the alkalinity in water. The acid converts carbonates to bicarbonates and converts bicarbonates to carbon dioxide, with both reactions resulting in very little change in the pH of the water. It should be noted that dissolved carbon dioxide gas will react with water to form a very weak carbonic acid, but this is not considered to be part of total alkalinity since it has no acid buffering capacity.

Carbon dioxide and bicarbonate are in a balance between the pH range of 4.2 to 4.5 at the low end and 8.2-8.4 at the high end. At a pH of 4.2 to 4.5 or lower, all alkalinity is in the form of carbon dioxide. At a pH of 8.2 to 8.4, there is no carbon dioxide and all alkalinity is bicarbonate. Bicarbonate and carbonate are in a balance between the pH range of 8.2 to 8.4 at the low end and 9.6 at the high end. At a pH of 9.6, there is no carbon dioxide or bicarbonate, and all alkalinity is carbonate. As the pH increases above 9.6, hydroxyl alkalinity (due to the presence of the hydroxide ion) starts to occur. Most naturally occurring water sources have a pH between 6 and 8.4, so the presence of hydroxides is the result of man-made activity. Alkalinity, especially by boiler water chemists, can be reported as M-Alkalinity and P-Alkalinity. M-Alkalinity (also known as Total Alkalinity) measures the amount of carbonate, bicarbonate and hydroxide present in terms of "ppm as calcium carbonate".

The M-Alkalinity measurement is based on a sulfuric acid titration using a Methyl orange indicator that goes from yellow at a pH of 4.5 to orange at pH of 4.4 at the endpoint. P-Alkalinity measures the amount of carbonate and hydroxyl alkalinity present in terms of "ppm as calcium carbonate". The P-Alkalinity measurement is based on a sulfuric acid titration using a Phenolphthalein indicator that goes from pink at a pH of 8.3 to colorless at pH of 8.2 at the endpoint.

Author's note: A range of pH values have been reported in a number of published sources for the M-Alkalinity (4.2 to 4.5) and P-alkalinity (8.2 to 8.5) titration endpoints. The above values are the best estimate.

### Aluminum (Al)

Aluminum, based on its low solubility, is typically not found in any significant concentrations in well or surface waters. Aluminum, when present in an RO feed water, is typically colloidal in nature (not ionic) and is the result of alum carryover by an on-site or municipal clarifier or limesoftener. Alum (aluminum sulfate) is a popular coagulant that is effective in the absorption and precipitation of naturally occurring, negatively charged colloidal material (e.g. clay and silt) from surface waters. Alum, when introduced into water, dissociates into trivalent aluminum and sulfate.

The hydrated aluminum ion reacts with the water to form a number of complex hydrated aluminum hydroxides, which then polymerize and starts absorbing the negatively charged colloids in water. Fouling by aluminum-based colloid carryover can occur, with alert levels for the RO designer ranging from 0.1 to 1.0 ppm aluminum in the feed water. Aluminum chemistry is complicated by the fact that it is amphoteric. Aluminum at low pH's can exist as a positively charged trivalent cation or as an aluminum hydroxide compound. Aluminum at high pH's can exist as a negatively charged anionic compound. Typically, the range of least solubility for aluminum compounds is in the pH range of 5.5 to 7.5.

### Ammonium ( $\text{NH}_4^+$ )

A monovalent cation. Ammonium salts are very soluble and do not cause a RO scaling problem. The ammonium ion is the result of very soluble gaseous ammonia ( $\text{NH}_3$ ) being dissolved in water. Non-ionized ammonia ionizes in water to form the ammonium ion and hydroxide ion. The degree of ionization of ammonia to ammonium is dependent on pH, temperature, and the ionic strength of the solution.

At higher pH the ammonia gas is prevalent, and being a gas, will not be rejected by a RO (similar to carbon dioxide gas). At lower pH the ammonium ion is prevalent and is rejected by a RO. Ammonia and ammonium exists in an equilibrium at varying relative concentrations in the general pH range of 7.2 to 11.5. Ammonium is typically not found in well water sources, having been converted by bacterial action in soils to the transitory nitrite ( $\text{NO}_2^-$ ) ion and then oxidized into the more prevalent nitrate ion.

Ammonium is found in surface water sources at low levels (up to 1 ppm as the ion), the result of biological

activity and the breakdown of organic nitrogen compounds. Surface sources can be contaminated with ammonium from septic systems, animal feed lot runoff, or agricultural runoff from fields fertilized with ammonia or urea. Ammonium is prevalent in municipal waste facilities with levels up to 20 ppm as the ion in the effluent, the result of high levels of organic nitrogen compound compounds and biological activity. Another source of ammonium is the result of adding ammonia to chlorine to form biocidal chloramines.

### **Barium (Ba)**

A divalent cation. The solubility of barium sulfate ( $\text{BaSO}_4$ ) is low and can cause a RO scaling problem in the back-end of a RO. Barium sulfate solubility is lower with increasing sulfate levels and decreasing temperatures. Typically, barium can be found in some well waters, with typical concentrations less than 0.05 ppm to 0.2 ppm. It is important that barium be measured with instruments capable of 0.01 ppm (10 ppb) minimum detection levels. With saturation at 100%, super-saturation up to 6000% is typical with an antiscalant.

### **Bicarbonate ( $\text{HCO}_3^-$ )**

A monovalent anion. The solubility of calcium bicarbonate is low and can cause a RO scaling problem in the back-end of a RO. Calcium bicarbonate solubility is measured using LSI (Langlier Saturation Index) for brackish waters or the Stiff-Davis Index for seawaters and is lower with increasing temperature and increasing pH. Bicarbonate is one component of alkalinity and its concentration is in a balance with carbon dioxide between the pH range of 4.4 and 8.2 and in a balance with carbonate between the pH range of 8.2 and 9.6.

### **BOD (Biological Oxygen Demand)**

BOD is a non-specific test that measures the quantity of “biologically-degradable” organic matter and is reported as “ppm as oxygen”. The test measures the quantity of oxygen depletion resulting from the ability of common bacteria to digest organic matter during a 5-day incubation period at 20°C.

### **Boron (B)**

Boron can be found in seawater at levels up to 5 ppm and at lower levels in brackish waters where inland seas once existed. Boron is not a foulant. The removal of boron to ppb levels is an important issue in the electronics industry as it adversely affects the process in some applications. The removal of boron is important in the production of potable/irrigation water in seawater desalination, with suggested limits of 0.5 ppm boron.

The element boron exists in equilibrium as the borate monovalent anion  $\text{B}(\text{OH})_4^-$  at higher pH and as non-ionized boric acid  $\text{B}(\text{OH})_3$  at lower pH. The relative concentrations of borate and boric acid are dependent

on pH, temperature and salinity. The borate ion becomes more prevalent at higher pH, higher salinity and higher temperature. The rejection of boron by RO is better for the borate ion due to its charge. The rejection of non-ionized boric acid is low due to its smaller size and lack of electric charge.

### **Brackish Water**

Brackish water, in one sense, is defined as a fresh low TDS water source that experiences a large increase in normal TDS due to seawater intrusion. In the RO field, brackish water can be defined as feed water with low to medium TDS levels (up to 10,000 to 15,000 ppm) that can be treated with a “brackish RO element” designed for 600 psi maximum applied feed pressure.

### **Calcium (Ca)**

A divalent cation. Calcium, along with magnesium, is a major component of hardness in brackish water. The solubility of calcium sulfate ( $\text{CaSO}_4$ ) (gypsum) is typically limited to 230% with the use of an antiscalant. The solubility of calcium carbonate is typically limited to a LSI (Langlier Saturation Index) value of positive 1.8 to 2.5.

### **Carbon Dioxide ( $\text{CO}_2$ )**

Carbon dioxide is a gas that when dissolved in water reacts with the water to form weak carbonic acid ( $\text{H}_2\text{CO}_3$ ). If a pure water was completely saturated with carbon dioxide, its concentration would be about 1600 ppm and the pH would be about 4.0. A typical source for carbon dioxide in natural waters is the result of a balance with bicarbonate alkalinity based on the pH of the water.

The concentration of carbon dioxide in water is typically indirectly determined by graphical comparison to the bicarbonate concentration and pH. Carbon dioxide and the bicarbonate ion are in a balance between the pH range of 4.4 and 8.2. The alkalinity is all carbon dioxide at pH 4.4 and is all bicarbonate at pH 8.4. The RO design program calculates the carbon dioxide level based on the bicarbonate level and pH of the water. Carbon dioxide, being a gas, is not rejected or concentrated by a RO membrane, therefore its concentration will be the same in the feed, permeate and concentrate. Acidifying the RO feed water will lower pH by converting bicarbonate to carbon dioxide.

## Carbonate ( $\text{CO}_3$ )

A divalent anion. The solubility of calcium carbonate is low and can cause a RO scaling problem in the back-end of a RO. Calcium carbonate solubility is measured using LSI (Langlier Saturation Index) for brackish waters or SDSI (Stiff-Davis Index) for seawaters and is lower with increasing temperature and increasing pH. Carbonate is one component of alkalinity and its concentration is in a balance with bicarbonate between the pH range of 8.2 and 9.6. At a pH of 9.6 and higher, there is no carbon dioxide or bicarbonate, with all alkalinity being in the carbonate form.

## Cations and Anions

Cations are ions with a positive valence state (they are willing to accept electrons) and have the ability to react with anions which are ions with a negative valence state (they have extra electrons to share). The sharing of electrons creates electroneutrality.

For example, the calcium ion is a divalent cation and will combine with two monovalent chloride ions to form the electrically neutral salt known as calcium chloride. A balanced water analysis will have the same concentration of cations as anions when reported as "ppm as calcium carbonate" or as meq/l. Silica, a very weak anion, is not used to calculate the ionic balance of cations and anions (though it is used in the calculation of TDS).

## Chloride (Cl)

A monovalent anion. The solubility of chloride salts is high and does not create a RO scaling problem. Chloride, in seawater, is the prevalent anion. Chloride is the anion used to automatically balance a RO feed water analysis. The recommended upper limit for chloride in potable water by the US EPA and WHO is 250 ppm based on taste issues.

## COD (Chemical Oxygen Demand)

COD is a non-specific test that measures the quantity of both biodegradable and non-biodegradable organic matter and is reported as "ppm as oxygen". The test measures the ability of a hot chromic acid solution to oxidize organic matter.

## Color

Color is a non-specific test that measures the relative level of organic compounds in water based on their contribution to adding color and is reported in APHA units relative to the platinum standard.

## Conductivity

Conductivity is a measurement of the ability of water to transmit electricity due to the presence of dissolved ions. Absolute pure water with no ions will not conduct an electrical current. Conductivity is measured by a conductivity meter and is reported as micromhos/cm

or microSiemens/cm. Conductivity is a convenient method of determining the level of ions in a water but is non-specific in what the ions are.

The electrical conductance of ions will vary by ion and will decrease as the concentration of ions increase. TDS (Total Dissolved Salts) meters utilize conductivity measurements with a conversion factor applied. Conductivity can also be estimated using individual conversion factors from the reported ion concentrations of a water analysis or by using a single conversion factor based on the sum of the ions (TDS).

Carbon dioxide conductivity can be estimated by taking the square root of the ppm concentration and then multiplying by 0.6. The silica ion does not contribute to conductivity. The most accurate conductivity readings for high quality RO permeate are obtained on-site since carbon dioxide levels, being a gas, can vary when exposed to the atmosphere.

## Fluoride (F)

A monovalent anion. Fluoride is found naturally at low levels in some well waters, but normally its presence is due to injection into municipal water to provide a residual up to 2.5 ppm for the control of dental caries. Fluoride levels in potable waters above 5 ppm can cause mottled and brittle teeth.

The rejection of fluoride by a RO membrane is pH dependent. Rejections with polyamide membranes in the basic pH range can be greater than 99% due to fluoride being in the salt form. Rejections in the acidic pH range can drop below 50% due to fluoride being in the acid form.

## Grains (per gallon)

Ion exchange and boiler water chemists frequently report the concentration of hardness as "Grains per Gallon (as calcium carbonate equivalents)". One Grain per U.S. Gallon (as calcium carbonate) is equal to 17.1 ppm (as calcium carbonate).

## Hydrogen Sulfide ( $\text{H}_2\text{S}$ )

Hydrogen sulfide is a gas that causes the noticeable "rotten egg" smell in feed waters, with a threshold odor level of 0.1 ppm and a noticeable offensive odor at 3-5 ppm. Hydrogen sulfide is readily oxidized to elemental sulfur by oxidants (e.g. air, chlorine or potassium permanganate). Sulfur acts as a colloidal foulant and has a history of not being removed well by conventional multimedia filtration. The preferred RO system design suggests leaving the hydrogen sulfide in its gaseous form, let it pass through the RO into the permeate, and then treat the permeate for its removal.

## Ionic Strength

The solubility of sparingly soluble salts increases with increasing feed TDS. To account for this effect in calculating the solubility of a salt (e.g. calcium sulfate, barium sulfate, strontium sulfate or SDSI), the Ionic Strength of a water is calculated. The Ionic Strength of each ion is derived by taking the ppm concentration of each ion (as calcium carbonate) and multiplying each monovalent ion by  $1 \times 10^{-5}$  and each divalent ion by  $2 \times 10^{-5}$ . Summing the Ionic Strength of each ion then derives the total Ionic Strength of the water.

## Iron (Fe)

Iron is a water contaminant that takes two major forms. The water-soluble form is known as the ferrous state and has a + 2 valence state. In non-aerated well waters ferrous iron behaves much like calcium or magnesium hardness in that it can be removed by softeners or its precipitation in the back end of the RO system can be controlled by the use of a dispersant chemical in an RO feed water. The waterinsoluble form is known as the ferric state and has a + 3 valence state. Typically, RO manufacturers will recommend that combined iron levels be less than 0.05 ppm in the RO feed. If all iron is in the soluble ferrous form, iron levels up to 0.5 ppm in the feed can be tolerated if the pH is less than 7.0 (though an iron dispersant is recommended). The introduction of air into water with soluble ferrous iron will result in the oxidation to insoluble ferric iron.

Soluble iron can be found in deep wells, but can be converted into the more troublesome insoluble iron by the introduction of air by being placed in tanks or by leaky pump seals. Soluble iron can be treated with dispersants or can be removed by iron filters, softeners or lime softening. Insoluble ferric iron oxides or ferric hydroxides, being colloidal in nature, will foul the front end of the RO system. Sources of insoluble iron are aerated well waters, surface sources, and iron scale from unlined pipe and tanks.

Insoluble iron can be removed by iron filters, lime softening, softeners (with limits), ultrafiltration (with limits) and multimedia filtration with polyelectrolyte feed (with limits). Precautions are required with the use of potassium permanganate in manganese greensand iron filters in that potassium permanganate is an oxidant that could damage any polyamide membrane.

Precautions are also required with a cationic polyelectrolyte in that they can irreversibly foul a negatively charged polyamide membrane. Corrosion proof vessels and piping (e.g. FRP, PVC or stainless steels) are recommended for all RO systems, RO pretreatment, and distribution piping coming to the RO system. Iron as foulant will quickly increase RO feed pressure requirements and increase permeate TDS. In some cases, the presence of iron can create a bio-fouling problem by being the energy source for

ironreducing bacteria. Iron-reducing bacteria can cause the formation of a slimy biofilm that can plug the RO feed path.

## LSI (Langlier Saturation Index)

LSI is a method of reporting the scaling or corrosive potential of low TDS brackish water based on the level of saturation of calcium carbonate. LSI is important to boiler water and municipal plant chemists in determining whether a water is corrosive (has a negative LSI) or will tend to scale calcium carbonate (has a positive LSI). LSI is important to RO chemists as a measurement of the scaling potential for calcium carbonate.

The LSI value is calculated by subtracting the calculated pH of saturation of calcium carbonate from the actual feed pH. Calcium carbonate solubility decreases with increasing temperature (as evidenced by the liming of a teakettle), higher pH, higher calcium concentration, and higher alkalinity levels. The LSI value can be lowered by reducing pH by the injection of an acid (typically sulfuric or hydrochloric) into the RO feed water.

A recommended target LSI in the RO concentrate is negative 0.2 (which indicates that the concentrate is 0.2 pH units below the point of calcium carbonate saturation). A negative 0.2 LSI allows for pH excursions in actual plant operation. A polymer-based antiscalant can also be used to inhibit the precipitation of calcium carbonate. Some antiscalant suppliers have claimed the efficacy of their product up to a positive LSI value of 2.5 in the RO concentrate (though a more conservative design LSI level is +1.8). Sodium hexametaphosphate, an inorganic antiscalant, was used in the early days of RO but the maximum concentrate LSI was + 0.5 and it had to be made in short-lived batches as the air easily oxidized it.

## Magnesium (Mg)

A divalent cation. Magnesium can account for about a third of the hardness in a brackish water, but can have a concentration five times higher than calcium in sea water. The solubility of magnesium salts is high and typically does not cause a scaling problem in RO systems.

## Manganese (Mn)

Manganese is a water contaminant present in both well and surface waters, with levels up to 3 ppm. Manganese, like iron, can be found in organic complexes in surface waters. In oxygen-free water, it is soluble. In the oxidized state, it is insoluble and usually in the form of black manganese dioxide ( $MnO_2$ ) precipitate. An alert level for potential manganese fouling in a RO aerated RO feed waters is 0.05 ppm. Drinking water regulations limit manganese to 0.05 ppm due to its ability to cause black stains. Dispersants used to control iron fouling can be used to help control manganese fouling.

## Meq/l

A method of reporting the concentration or “equivalent” weight of an ion or substance in a given volume of water as milli-equivalents per liter. Meq/l is calculated by dividing the mg/l by the equivalent weight of the ion or substance. Reporting the concentration of ions as meq/l is popular by RO chemists for determining whether a water analysis is “balanced” where the sum of the cations equals the sum of the anions.

## Mg/l

A method of reporting the “actual” weight (milligrams) of an ion or substance in a given volume of water (liter). For dilute solutions, mg/l and ppm are equivalent. For example, a 1,000 mg/l (ppm) sodium chloride solution would result in a residue of 1,000 mg of NaCl after evaporation of one liter of water. RO chemists use mg/l frequently in the calculation of TDS.

## Nitrate ( $\text{NO}_3^-$ )

A monovalent anion. Nitrate salts are highly soluble and do not cause a RO scaling problem. Nitrate, along with ammonia gas and ammonium, is a nitrogen-based ion whose presence is tied with nature’s nitrogen cycle. The primary sources of nitrogen introduction in a feed water come from decomposing animal and plant waste, septic systems, animal feed lot runoff, or agricultural field runoff from fields fertilized with ammonia.

In well water sources, ammonia and ammonium are not found, having been converted to the transitory nitrite ion by certain types of bacteria in soils and then oxidized into the more prevalent nitrate ion. Frequently, nitrate concentrations are reported as “ppm as nitrogen” in water analysis and not as “ppm as nitrate” as required for RO projections. To convert “ppm as nitrogen” to “ppm as nitrate”, multiply “ppm as nitrogen” by 4.43. The US EPA has set a maximum recommended limit of nitrate at 10 ppm as nitrogen (44.3 ppm as nitrate) for potable drinking water. Nitrates are harmful in that they compete with oxygen for carrying sites in blood hemoglobin. The reduced oxygen content can result in the “blue-baby syndrome” which is why babies and pregnant women are at higher risk to the effects of nitrates.

## Osmotic Pressure

The pressure phenomena resulting from the difference of salt concentrations across a RO membrane. Increasing TDS levels result in increased osmotic pressure. The RO feed pump has to generate sufficient pressure to overcome this osmotic pressure before permeate is produced. A rough rule of thumb is that 1,000 ppm TDS equals 11 psi osmotic pressure. A brackish water at 550 ppm TDS produces 5 psi osmotic pressure. A seawater at 35,000 ppm TDS produces 385 psi osmotic pressure.

## pH

The pH of the feed water measures the acidity or basicity. A pH of 7.0 is considered neutral. A pH between 0.0 and 7.0 is acidic. A pH between 7.0 and 14.0 is basic. To the analytical chemist, pH is a method of expressing hydrogen ion concentration in terms of the power of 10 with the pH value being the negative logarithm of the hydrogen ion concentration.

To the water chemist, pH is important in defining the alkalinity equilibrium levels of carbon dioxide, bicarbonate, carbonate and hydroxide ions. The concentrate pH is typically higher than the feed due to the higher concentration of bicarbonate/carbonate ions relative to the concentration of carbon dioxide.

The IMSDesign projection software allows the user to adjust the pH of the feed water using hydrochloric and sulfuric acid. Lowering the feed pH with acid results in a lower LSI (Langlier Saturation Index) value, which reduces the scaling potential for calcium carbonate. Feed and concentrate (reject) pH can also effect the solubility and fouling potential of silica, aluminum, organics and oil. Variations in feed pH can also affect the rejection of ions. For example, fluoride, boron and silica rejection are lower when the pH becomes more acidic.

## Potassium (K)

A monovalent cation. It is typically found at much lower concentrations than sodium. The salts of potassium are highly soluble and do not cause a RO scaling problem.

## ppb (parts per billion)

A method to report the concentration of an ion or substance in a water. The following conversions apply for dilute waters with a specific gravity of 1.0: One ppb is equal to one microgram per liter (ug/L). One ppm is equal to 1,000 ppb.

## ppm (parts per million)

A method for reporting the concentration of an ion or substance in a water. The following conversions apply for dilute waters with a specific gravity of 1.0: One ppm is equal to one mg/L. One Grain per U.S. Gallon is equal to 17.1 ppm. One Pound per 1,000 U.S. Gallons is equal to 120 ppm. A one per cent solution is equal to 10,000 ppm. One ppm is equal to 1,000 ppb.

## ppm as $\text{CaCO}_3$

A method of reporting the concentration or “equivalent” weight of an ion or substance in a given volume of water as “ppm as calcium carbonate”. Reporting the concentration of ions as “ppm as calcium carbonate” is popular by ion exchange chemists for the calculation of ionic loading of cation or anion resins. It is also popular in determining whether a water analysis is “balanced”

where the sum of the cations equals the sum of the anions when the concentration of the ions are reported as calcium carbonate equivalents.

Water chemists use the concept of “equivalecy” when balancing cation and anion electroneutrality levels since ions combine in nature based on their valence state and available electrons, not on their “actual” weight. Calcium carbonate was arbitrarily picked because its molecular weight is 100 and its equivalent weight is 50 since its divalent. The formula to convert an ion reported as “mg/l as the ion” to “ppm as calcium carbonate” is to multiply “mg/l as the ion” times the ratio of the “equivalent weight of the ion” by the “equivalent weight of calcium carbonate”.

As an example, a water with sodium at 100 ppm as calcium carbonate and chloride at 100 ppm as calcium carbonate are in ionic balance since every sodium ion has a corresponding chloride ion. However, sodium concentration at 100 ppm as calcium carbonate is only 47 mg/l of actual substance (since its equivalent weight is 23.0) and 100 ppm of chloride as calcium carbonate is only 71 mg/l of actual substance (since its equivalent weight is 35.5). The calculated TDS of this solution is 118 mg/l.

### SDI (Silt Density Index)

An empirical test developed for membrane systems to measure the rate of fouling of a 0.45 micron filter pad by the suspended and colloidal particles in a feed water. This test involves the time required to filter a specified volume of feed at a constant 30 psi at time zero and then after 5 minutes, 10 minutes and 15 minutes of continuous filtration. Typical RO element warranties list a maximum SDI of 4.0 at 15 minutes for the feed water.

If the SDI test is limited to only 5 or 10 minute readings due to plugging of the filter pad, the user can expect a high level of fouling for the RO. Deep wells typically have SDI's of 3 or less and turbidities less than one with little or no pretreatment. Surface sources typically require pretreatment for removal of colloidal and suspended solids to achieve acceptable SDI and turbidity values.

### SDSI (Stiff Davis Saturation Index)

SDSI, in similar fashion as LSI, is a method of reporting the scaling or corrosion potential of high TDS seawater based on the level of saturation of calcium carbonate. The primary difference between SDSI for high TDS seawater and LSI for low TDS brackish water is the effect that increasing ionic strength has on increasing solubility. The solubility of sparingly soluble salts increase with higher TDS and ionic strength, based on the theory that a denser ion population interferes in the formation and/or precipitation of the sparingly soluble salt.

### Silica ( $\text{SiO}_2$ )

Silica (silicon dioxide), in some cases, is an anion. The chemistry of silica is a complex and somewhat unpredictable subject. In similar fashion as TOC reports the total concentration of organics (as carbon) without detailing what the organic compounds are, silica reports the total concentration of silicon (as silica) without detailing what the silicon compounds are.

The “Total Silica” content of a water is composed of “Reactive Silica” and “Unreactive Silica”. Reactive silica (e.g. silicates  $\text{SiO}_4$ ) is dissolved silica that is slightly ionized and has not been polymerized into a long chain. Reactive silica is the form that RO and ion exchange chemists hope for. Reactive silica is the form of silica to be used in RO projection programs. Reactive silica, though it has anionic characteristics, is not counted as an anion in terms of balancing a water analysis but it is counted as a part of total TDS. Unreactive silica is polymerized or colloidal silica, acting more like a solid than a dissolved ion.

Silica, in the colloidal form, can be removed by a RO but it can cause colloidal fouling of the front-end of a RO. Colloidal silica, with sizes as small as 0.008 micron can be measured empirically by the SDI (Silt Density Index) test, but only that portion that is larger than 0.45 micron or larger. Particulate silica compounds (e.g. clays, silts and sand) are usually 1 micron or larger and can be measured using the SDI test. Polymerized silica, which uses silicon dioxide as the building block, exists in nature (e.g. quartzes and agates).

Silica, in the polymerized form, also results from exceeding the reactive silica saturation level. The solubility of reactive silica is typically limited to 200-300% with the use of a silica dispersant. Reactive silica solubility increases with increasing temperature, increases at a pH less than 7.0 or more than 7.8, and decreases in the presence of iron which acts as a catalyst in the polymerization of silica. Silica rejection is pH sensitive, with increasing rejection at a more basic pH as the reactive silica exists more in the salt form than in the acidic form.

### Sodium (Na)

A monovalent cation. The solubility of sodium salts is high and does not cause a RO scaling problem. Sodium, in seawater, is the prevalent cation. Sodium is the cation used to automatically balance a RO feed water analysis. Dietary sodium levels can range from 2000 mg/l for low-sodium diets to 3500 mg/l for average consumption levels. The US EPA has set a DWEL (Drinking Water Equivalent Limit) of 20 mg/l for potable water but is reevaluating the limit as to low. Daily consumption of 2 liters (0.53 gallons) of water with 100 mg/l of sodium would be only 200 mg. A relatively “hard water” with 10 grains per gallon (171.2 mg/L) of hardness (as calcium carbonate) results in only an additional 79 mg/L of sodium when softened.

## Strontium (Sr)

A divalent cation. The solubility of strontium sulfate is low and can cause a RO scaling problem in the back-end of a RO. Strontium sulfate solubility is lower with increasing sulfate levels and decreasing temperatures. Typically, strontium can be found in some well waters where lead ores are also present, with typical concentrations less than 15 ppm. With saturation at 100%, super-saturation up to 800% is typical with an antiscalant.

## Sulfate (SO<sub>4</sub>)

A divalent anion. The solubility of calcium, barium and strontium sulfate is low and can cause a RO scaling problem in the back-end of a RO. The solubility of these sparingly soluble salts is lower with decreasing temperature. The recommended upper limit for sulfate in potable water is 250 ppm based on taste issues.

## TDS (Total Dissolved Solids)

TDS, in water treatment, is the inorganic residue left after the filtration of colloidal and suspended solids and then the evaporation of a known volume of water. TDS is reported as ppm or mg/l. TDS, in RO design projections, is determined by calculation using the sum of the cations, anions and silica ions (with the ion reported "as such", not "as calcium carbonate"). Feed or permeate TDS, in RO design projections, can also be estimated by applying a conversion factor to the conductivity of the solution. TDS can also be determined in the field by use of a TDS meter.

TDS meters measure the conductivity of the water and then apply a conversion factor that reports TDS to a known reference solution (e.g. ppm sodium chloride or ppm potassium chloride). The user is cautioned that TDS levels for waters with a mixture of ions and determined from conductivity measurements may not agree with TDS calculated as a sum of the ions. As a rough rule of thumb, one ppm of TDS (when referenced to a NaCl solution) correlates to a conductivity of two micromhos/cm (microSiemens/cm).

## Temperature

Temperature is a critical design parameter. It has significant effects on feed pump pressure requirements, hydraulic flux balance between stages, permeate quality, and solubility of sparingly soluble salts. As a rough rule of thumb, every 10-degree Fahrenheit decrease in feed temperature increases the feed pump pressure requirement 15%.

The hydraulic flux balance between stages (or in other words the amount of permeate produced by each stage) is impacted by temperature. When water temperature

increases, the elements located in the front end of the system produce more permeate which results in reduced permeate flow by the elements located at the rear of the system. A better hydraulic flux balance between stages occurs at colder temperatures.

At warmer temperatures, salt passage increases due to the increased mobility of the ions through the membrane. Warmer temperatures decrease the solubility of calcium carbonate. Colder temperatures decrease the solubility of calcium sulfate, barium sulfate, strontium sulfate, and silica.

## TOC (Total Organic Carbon)

TOC, an acronym for Total Organic Carbon or Total Oxidizable Carbon, is a non-specific test that measures the amount of carbon bound in organic material and is reported in units of "ppm as carbon". Since the TOC only measures the amount of carbon in organic matter, the actual weight of the organic mass can be up to 3 times higher in natural surface waters.

Organics are compounds that contain carbon (with the exception of carbon dioxide, bicarbonate and carbonate). In water treatment, organics can be classified as naturally occurring or man-made.

Naturally occurring organic matter are typically negatively-charged colloids or suspended solids, comprised of tannins, lignin's, water soluble humic acid compounds resulting from the decay of certain vegetative matter, or fulvic acid compounds resulting from the decay of certain vegetative matter. Naturally occurring organic material can be a foulant to RO membranes, particularly the negatively charged composite polyamides. Neutrally charged RO membranes (e.g. neutrally charged composite polyamides and cellulose acetate) are more resistant to organic fouling. A RO will reject organic compounds.

Generally, organic compounds with a molecular weight greater than 200 are rejected at levels greater than 99%. The rejection of compounds with molecular weights less than 200 will vary based on molecular weight, shape and ionic charge. As a rough rule of thumb, alert levels for potential organic fouling in natural water sources are TOC at 3 ppm, BOD at 5 ppm, and COD at 8 ppm.

## Turbidity

Turbidity is a suspension of fine colloidal particles that do not readily settle out of solution and can result in a "cloudiness". Turbidity is determined by a Nephelometer that measures the relative amount of light able to pass through a solution. Turbidity is reported as NTU (Nephelometric Turbidity Units). Typical RO element warranties list a maximum of 1.0 NTU for the feed water.