Feed Water Parameters Assessing RO & NF Feed Water Quality

When designing a system, it is important to assess the feed water quality in order to understand the potential for fouling or scale formation in a RO or NF system. This also allows for the determination of whether pretreatment or special cleanings are necessary for the system. For questions or additional information, please contact MANN+HUMMEL Water & Fluid Solutions Technical Service.

FEED WATER QUALITY

The quality of the feed water is typically defined in terms of concentration of dissolved and suspended particles, and saturation levels of the sparingly soluble salts. Below is a list of the most common parameters that are seen in many water quality analyses.

Alkalinity

Alkalinity consists of anions (specifically carbonate, bicarbonate and hydroxide ions) that remove hydrogen ions from solution causing the water to have a higher pH. Alkalinity 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. 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 end point. P-Alkalinity measures the amount of carbonate and hydroxide alkalinity present. 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.

Aluminum (Al^{3+})

Due to its valence charge of +3 and relatively small size (which results in aluminum metal ions having a particularly high charge density), aluminum is very reactive. Aluminum will combine with oxygen to form an insoluble oxide. It also tends to complex with negatively charged organic colloids and will readily precipitate when silica is present. Because of this, it is recommended to limit the amount of aluminum in contact with the membranes to 0.05 mg/L (maximum).

Ammonia (NH_3)

Ammonia is a dissolved gas and will not be rejected by an RO or NF membrane. However, ammonia is in equilibrium with the ammonium cation (NH_4^+). As long as the temperature and pH are less than 40°C (104°F) and 7 respectively, more than 95% will be present as NH_4^+ and the rejection should be better than 98%. However, if both the temperature and pH are allowed to increase, the amount of ammonia will increase and rejection will decrease.

Ammonium (NH_4^+)

Ammonium is a monovalent cation (i.e. it has a valence charge of +1). Ammonium salts are very soluble and generally do not cause scaling problems.

Barium (Ba^{2+})

Barium is a divalent cation (i.e. it has a valence charge of +2). When in the presence of sulfates, barium sulfate ($BaSO_4$) easily falls out of solution due to its low solubility and may lead to a scaling problem. Barium sulfate solubility is lower with increasing sulfate levels and decreasing temperatures. Barium sulfate scale is extremely difficult to redissolve; barium is generally controlled with antiscalants.

Bicarbonate (HCO_3^-)

Bicarbonate is a monovalent anion (i.e. it has a valence charge of -1). The solubility of calcium bicarbonate is low and can cause a scaling problem. Calcium bicarbonate solubility is measured using LSI (Langelier Saturation Index) for brackish waters or the Stiff-

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Davis Index for seawaters and is lower with increasing temperature and pH. Bicarbonate is one component of alkalinity. 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 in the water source. The test measures the quantity of oxygen depletion resulting from the ability of common bacteria to digest organic matter during a five day incubation period at 20°C (68°F). As a rough rule of thumb, it is recommended to keep BOD levels below 5 ppm using pretreatment (typically some sort of filtration) to prevent organic fouling in natural water sources.

Boron (B)
Unlike most of the other elements in water, boron is not ionized (has no charge). Boron takes two forms in water: boric acid, $B(OH)_3$, or borate ion, $B(OH)_4^-$. The relative concentrations of boric acid and borate ion are dependent on pH, temperature and salinity. Boric acid becomes more prevalent at pH < 8, whereas the borate ion will become dominant at pH > 10. Because RO and NF membranes are much better at removing charged ions, the removal of borate ion is easier than the removal of boric acid.

Brackish Water
Brackish water can be defined as feed water with low to medium TDS (Total Dissolved Solids) levels (up to 15,000 ppm) that can be treated with a brackish water RO element designed for 41.4 bar (600 psi) maximum feed pressure (high pressure elements also available).

Calcium (Ca^{2+})
Calcium is a divalent cation. Calcium, along with magnesium, is a major component of hardness in brackish water. Hardness can fall out of solution, leaving behind scale formation. The solubility of calcium sulfate, $CaSO_4$, is typically limited to a LSI (Langelier Saturation Index) value of positive 1.8 to 2.5 when using an antiscalant; and LSI of < 0 is recommended when no antiscalant is employed. Additionally, the positive charge characteristics of calcium may cause it to bind up with phosphate ions, which are strongly anionic.

Carbon Dioxide (CO_2)
Carbon dioxide is a gas that when dissolved in water reacts with the water to form weak carbonic acid, H_2CO_3. 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 equilibrium between the pH range of 4.4 and 8.2. At pH 4.4, the equilibrium reaction favors carbon dioxide, whereas at pH 8.2, the reaction favors bicarbonate. Carbon dioxide levels are calculated based on the bicarbonate levels 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.

Carbonate (CO_3^{2-})
Carbonate is a divalent anion. The solubility of calcium carbonate is low and may cause a scaling problem. Calcium carbonate solubility is measured using LSI (Langelier Saturation Index) for brackish waters or SDSI (Stiff-Davis index) for seawaters. Calcium carbonate is unusual in that its solubility lowers with increasing temperature and increasing pH. Carbonate is one component of alkalinity and its concentration is in equilibrium with bicarbonate between the pH range of 8.2 and 9.6. At a pH of 9.6 and higher, all alkalinity is in carbonate form.

Chloride (Cl^-)
Chloride is a monovalent anion. Nearly all chloride salts are soluble in water and pose little threat to a membrane system. However, if the system concentrate is heavily concentrated with chloride, a higher grade stainless steel may be required for the high-pressure piping (or housings if stainless steel) to prevent corrosion. Chloride is also the anion used to automatically balance a feed water analysis.

COD (Chemical Oxygen Demand)
COD is a non-specific test that measures the quantity of both biodegradable and non-biodegradable organic matter. The test measures the ability of a hot chromic acid solution to oxidize organic matter. As a rough rule of thumb, it is recommended to keep COD levels below 8 ppm to prevent organic fouling in natural water sources.

Color & True 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. True color is the color that remains after the sample is filtered through a 0.45 micron filter. True color can irreversibly adsorb to the membrane, resulting in permanent flux loss. For that reason, true color should be less than 3 APHA units in RO feed water.

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Conductivity

Conductivity is a measurement of the ability of water to transmit electricity due to the presence of dissolved ions. 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. Absolute pure water with no ions will not conduct an electrical current.

Copper (Cu^{2+})

Copper is usually not present in natural water sources, but it is possible to pick up trace concentrations from piping materials. Copper tends to fall out of solution with increasing pH. As a transition metal, copper may increase the oxidation potential of oxidizing agents.

Fluoride (F$^-$)

Fluoride is a monovalent anion. Fluoride concentrations are usually low in most water sources. Calcium fluoride is fairly insoluble. Antiscalants do not generally do a good job at inhibiting formation of calcium fluoride, so acid feed is typically recommended to minimize formation of this scale on RO membranes.

Free Chlorine

Under certain conditions, the presence of chlorine and other oxidizing agents will cause premature membrane failure. It is highly recommended to removal residual free chlorine by pretreatment prior to membrane exposure.

Note: Cellulose acetate membranes are able to tolerate a small amount of free chlorine in the feed water whereas thin-film composite membranes cannot.

Hardness

Calcium and magnesium make up the vast majority of what is called water hardness. Hardness can fall out of solution, leaving behind scale formation. The positive charge characteristics of hardness can also cause it to bind up with phosphate ions (which are strongly anionic). Calcium phosphate scale is also not inhibited well by antiscalants, so removal of calcium hardness or acid feed is recommended to control formation of this scale.

Hydroxide (OH$^-$)

Alkalinity consists of anions that remove hydrogen ions from solution and causing the water to have a higher pH. These anions include carbonate, bicarbonate and hydroxide.

Iron (Fe^{2+} or Fe^{3+})

Iron is a water contaminant that takes two major forms. The water-soluble form, known as its divalent ferrous state (Fe^{2+}) is a divalent cation. Ferrous iron (when it isn't exposed to air) behaves much like calcium or magnesium in that it can be removed by softeners or its precipitation can be controlled by the use of a dispersant chemical in the feed water (note that ferrous iron concentrations of over 1 ppm can foul softener resin). The water-insoluble form, known as its ferric state (Fe^{3+}) has a +3 valence charge. Typically, membrane manufacturers will recommend that combined iron levels be less than 0.05 ppm in the feed. If all iron is in the soluble ferrous state, 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 will result in the oxidation to insoluble ferric iron. 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 a system. It can also catalyze the oxidative effects of residual oxidizing agents which may lead to membrane degradation. Insoluble iron can be removed by various pretreatment methods, but precautions must be taken to prevent membrane damage.

LSI (Langelier 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 in determining whether a water is corrosive (has a negative LSI) or will tend to scale calcium carbonate (has a positive LSI). 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, 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 -0.2 without use of antiscalant (which indicates that the concentrate is a pH of 0.2 below the point of calcium carbonate saturation) which allows for pH excursions in actual plant operation. The use of an antiscalant allows for a concentrate LSI of up to 2.5.

Magnesium (Mg^{2+})

Magnesium is a divalent cation and accounts for about a third of the hardness in brackish water, but can have a concentration five times higher than calcium in sea water. Hardness can fall out of solution, leaving behind scale formation. The positive charge characteristics of hardness can also cause it to bind up with phosphate ions which are strongly anionic.

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Manganese (Mn^{2+})

Manganese is a divalent cation and 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. If the manganese concentration is greater than 0.05 mg/L, means for removal should be heavily considered to prevent fouling and possible membrane degradation. Dispersants used to control iron fouling can be used to help control manganese fouling.

NOM (Natural Organic Matter)

NOM is the organic material in surface or ground water and typically consists of negatively charged colloids or suspended solids comprised of tannins or lignins (water soluble humic acid compounds resulting from the decay of certain vegetative matter). Naturally occurring organic material can be a foulant to RO and NF membranes, particularly to negatively charged polyamide thin-film composite membranes. Neutrally charged RO and NF membranes (i.e. neutrally charged thin-film and cellulose acetate) are more resistant to organic fouling. A RO and NF membrane will reject organic compounds and 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.

Nitrate (NO$_3^-$)

Nitrate is a monovalent anion. Nitrate salts are highly soluble and generally do not cause a scaling problem. It is desirable to maintain a nitrate concentration below 40 mg/L in drinking water. Because nitrates are weakly charged, they typically exhibit higher passage rates compared to other monovalent ions such as chloride.

Oil & Grease

Oil & Grease can easily foul an RO or NF membrane. It is therefore highly recommended to completely remove oil and grease prior to the membrane via pretreatment. Effective pretreatment will target complete removal of oil & grease to prevent membrane fouling.

pH

The pH of the feed water measures the concentration of hydrogen ions which determines whether the water is acidic or basic. A pH of 7.0 is considered neutral. A pH between 0.0 and 7.0 is acidic, while a pH between 7.0 and 14.0 is basic. 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. Feed and concentrate (reject) pH can also effect the solubility and fouling potential of calcium carbonate, 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.

Phosphate & Orthophosphate (PO$_4^{3-}$)

Phosphates, with a valence charge of -3, have a strongly negative charge and a tendency to react with multivalent cations. Calcium phosphate has a very limited solubility at neutral pH, and an even lower solubility at higher pH. If phosphates are present in a feed water to any appreciable extent, unless the water is acidified, the phosphate will likely fall out of solution. Orthophosphate readily forms a very insoluble scale with calcium.

Potassium (K$^+$)

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

SDI (Silt Density Index)

SDI is 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, 10 and 15 minutes of continuous filtration. Typical RO element warranties list a maximum SDI of 5.0 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. Surface sources typically require pretreatment for removal of colloidal and suspended solids to achieve acceptable SDI.

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 increases 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.

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Silica (SiO₂)

Silica (or silicon dioxide), is a complex and somewhat unpredictable subject. 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 molybdate "reactive silica" and "unreactive silica". Reactive silica is dissolved silica that is slightly ionized and has not been polymerized into a long chain. 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 at 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 the portion that is 0.45 micron or larger. Particulate silica compounds (i.e. clay, 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 (i.e. quartzes and agates) and can also result from exceeding the reactive silica saturation level. 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. If silica is present in the feed water at a concentration greater than 20 ppm, the potential for silica precipitation should be evaluated. Silica concentrations in the reject stream should be limited to less than 200 ppm at 25°C (77°F) and near neutral pH values.

Sodium (Na⁺)

Sodium is a monovalent cation. The solubility of sodium salts is high and typically does not cause a RO scaling problem.

Strontium (Sr²⁺)

Strontium is a divalent cation. If strontium is present in relatively small concentrations (0.01 mg/L or more) along with sulfates, they can easily fall out of solution as scale on the membrane surface. Strontium sulfate scale is extremely difficult to redissolve, therefore it is generally controlled with antiscalants.

Sulfate (SO₄²⁻)

Sulfate is a divalent anion. Sulfates have limited solubility in water, depending on the concentrations of divalent cations also present. The prevention of sulfate scale formation in an RO system is usually performed by reducing or controlling the divalent cations in the raw water. Note that when using sulfuric acid for pH control, the potential for forming sulfate-based scales may increase.

Sulfide (S²⁻)

Sulfides present as a dissolved gas (hydrogen sulfide, H₂S), will fall out of solution as elemental sulfur if oxidized by oxygen from the atmosphere or by chlorine injected into the water for biological control. Hydrogen sulfide gas can be removed by running the water through a degasifier or intentionally oxidizing it using chlorine injection and removing the precipitated sulfur with media filtration prior to the membranes.

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 is determined by calculation using the sum of the cations, anions and silica ions. Feed or permeate TDS 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 (i.e. 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 for brackish waters, one ppm of total ions in solution correlates to a conductivity of 1.6 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 rule of thumb, every 5°C (41°F) decrease in feed temperature increases the feed pump pressure requirement 10 – 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. In practice, RO system design projections should be run at both the highest and lowest expected temperatures.

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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), however in water treatment, organics can be classified as naturally occurring (NOM) or man-made. A RO and NF membrane will reject organic compounds and 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, it is recommended to keep TOC levels below 3 ppm to prevent organic fouling in natural water sources.

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 Nepholometer that measures the relative amount of light able to pass through a solution and is reported as NTU (Nepholometer Turbidity Units). The maximum turbidity levels for RO and NF elements is 1.0 NTU for the feed water.

Zinc (Zn^{2+})

Zinc is usually not present in natural water sources, but it is possible to pick up trace concentrations from piping materials. Zinc tends to fall out of solution with increasing pH. As a transition metal, zinc can increase the oxidation potential of oxidizing agents.

Contact

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