WATER FUNDAMENTALS HANDBOOK

Second Edition

driSteem

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FORWARD

The focus of this handbook is water. What is it about water that gives it such unique properties? How do those properties relate to DriSteem products? All DriSteem products involve water processing in some way, whether creating steam for humidification, passing water over media, injecting small droplets of water into spaces for cooling and humidification, or removing dissolved substances from water to purify or soften it. Since water is such an integral part of all customer systems, including DriSteem systems, it seems appropriate to dig a little deeper into the impacts of water as it relates to the products DriSteem offers.

Since 1965, DriSteem's focus has been on developing competitive products that meet the needs of its customer base. In order for DriSteem to continue enhancing customer satisfaction by offering maximum performance and functionality in its products, a deeper understanding of water and how it affects products is essential to the company.

The reason for this handbook is to help the reader better appreciate the uniqueness of water and how such tiny molecules can affect the products we design and build every day to satisfy the needs of the many customers we serve.

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Section I: Water basics

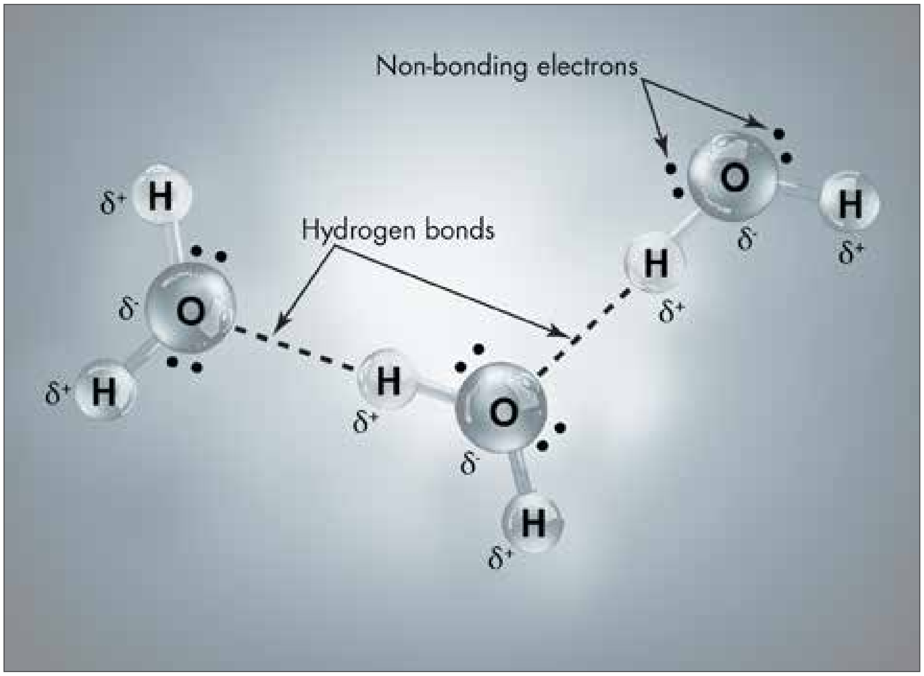
UNIQUE CHARACTERISTICS OF WATER

Water, H_2O, is one of the most interesting substances on earth, a substance that we all use in one way or another every day of our lives. We drink it to sustain life, we sweat it, we swim in it, and plants require it for growth. Up to 75% of our body weight is water, and almost the same percentage covers the earth's surface. Water freezes from top to bottom, not from bottom to top like other liquids. It is the only substance that exists in all three phases (solid/ice, liquid/water, and vapor/humidity) within the relatively small temperature range that we all live in. Why is this? What makes water so unique that it is the only substance than can exist in all three phases in such a small temperature range? And, how can we relate this to effects on our products?

HYDROGEN BONDS

Let's start with what every first-year chemistry student learns; that is the phenomenon of "hydrogen bonds," which are not true intramolecular (or covalent) bonds as in a molecular compound. Hydrogen bonds are given special prominence because they are the strongest intermolecular forces in nature. Hydrogen bonds allow certain molecules to act like miniature magnets that attract molecules to each other. Only hydrogen bonded with oxygen, nitrogen, or fluorine can exhibit hydrogen bonding due to the strong electronegative characteristic of these atoms. The positive end of one molecule is attracted to the negative end of another molecule (see Figure 2-1).

FIGURE 2-1: HYDROGEN BONDS BETWEEN WATER MOLECULES



Hydrogen bond strength is an estimated 1/20 of covalent bond strength. Therefore, although strong, hydrogen bonds often make and break, combining with and releasing from other molecules.

BENT STRUCTURE

Water is a “bent” molecule. This allows a water molecule to possess a positive end (the end with the hydrogen atoms) and a negative end (the end with the oxygen atom). Since electrons carry a negative charge, the oxygen end of the molecule is more negative, and the hydrogen end is more positive, as shown by the shading in Figure 3-1. The result is a bipolar molecule with unique and very important properties. For example, water exists in both liquid and vapor states within the temperature range that supports human life.

Water is a liquid at room temperature, while most other substances with nearly the same or even higher molecular weight are vapors at room temperature. For example, water is lighter than both oxygen and nitrogen, but at room temperature oxygen and nitrogen are vapors that make up the major components of the air we breathe. These molecules are vapors because they do not possess hydrogen bonds.

Hydrogen bonds are also the reason a relatively high amount of energy is required to boil water into vapor, yet water can freeze into ice with relative ease. Hydrogen bonds also account for the high surface tension properties of water, as illustrated in Figure 3-2.

FIGURE 3-1: BENT STRUCTURE OF A WATER MOLECULE

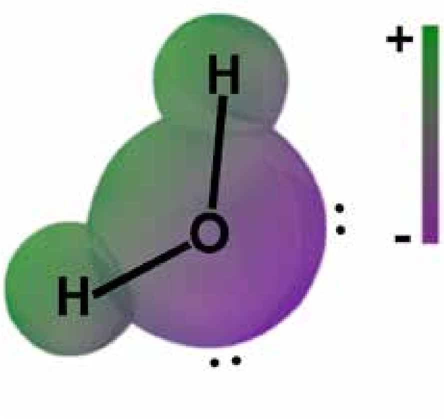


FIGURE 3-2: HIGH SURFACE TENSION

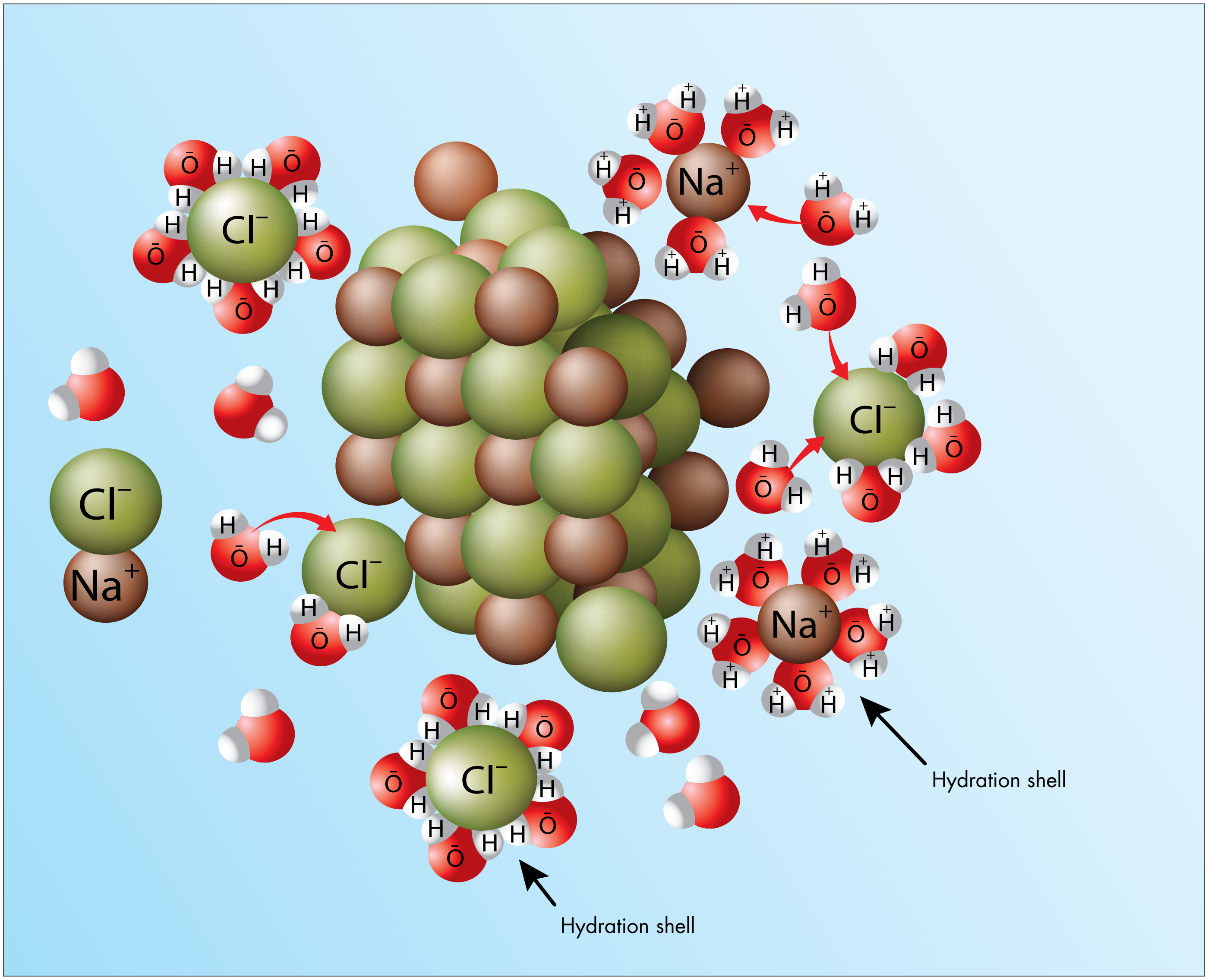
ATTRACTION TO OTHER SUBSTANCES

Hydrogen bonds not only allow intermolecular attraction between multiple molecules of water, they also allow attraction to other substances. Many of these substances have positive or negative charges, which makes them soluble in water. In fact, water dissolves more substances than any other liquid. That is why we call water the universal solvent.

Substances that are ionic (meaning they carry positive or negative charges), like salt, dissolve in water. See the salt crystal in Figure 4-1. Note that the negative ends of a water molecule surround positive ions (cations), and the positive ends of water molecule surround negative ions (anions). This creates hydration shells around the ions, causing particles to become evenly dispersed in the water.

Understanding water chemistry will help us to create more robust designs and effectively address water-related issues.

FIGURE 4-1: SALT CRYSTAL IN WATER



Water does not form hydration shells around nonpolar molecules. Because nonpolar molecules do not have partially positive and partially negative charges, they are not attracted to water molecules. Instead, they stay separate. Oil is nonpolar and does not dissolve in water.

IMPLICATIONS OF DISSOLVED SOLIDS

The amount of dissolved substances in a volume of water is referred to as total dissolved solids (TDS). The specific makeup of dissolved solids can significantly impact equipment maintenance requirements, performance, and even the potential for corrosion. For that reason, it is important to understand whether supply water has high TDS of a type that can cause scale formation over time, or whether it can cause equipment degradation due to corrosion. Understanding water chemistry will help us to create more robust designs and effectively address water-related issues. The remaining sections of this handbook will expand on these topics.

Section II: Scale

HARD WATER

What is hard water (sometimes called potable or tap water)? Technically, it is water that contains dissolved positive ions with multiple plus charges (polyvalent cations). Generally, these are calcium ions (Ca^{+2}) and/or magnesium ions (Mg^{+2}). There are other positive ions that can form scale or cause accelerated corrosion.

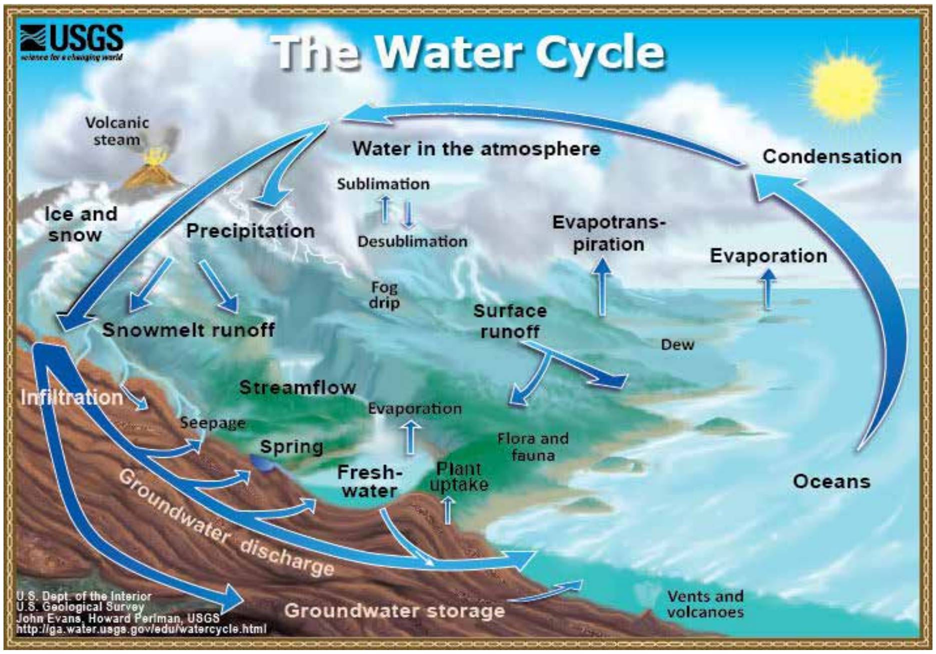
Typically, calcium ions are predominant, accounting for as much as 75% or more of the hardness. The precipitated form of the calcium ion contribution to hardness is calcium carbonate, which is known as lime scale or hard water scale. This scale adheres to surfaces and is difficult to remove, as discussed in the next subsection.

Where does water hardness come from? Following is a summary.[1]

1. Water from rain enters the topsoil
2. Bacteria respiration (organic matter decomposition) produces CO_2
3. CO_2 and water react to form carbonic acid (H_2CO_3):
   $CO_2 + H_2O \leftrightarrow H_2CO_3$
4. Limestone, which is calcium carbonate ($CaCO_3$) reacts with carbonic acid (H_2CO_3) to form calcium bicarbonate ($Ca(HCO_3)_2$) in water solution:
   $CaCO_3 + H_2CO_3 \leftrightarrow Ca(HCO_3)_2$

   Note: In water, $Ca(HCO_3)_2$ is ionic as Ca^{+2} and 2 HCO_3^-

Boiling water with these constituents creates a major potential for scale formation and maintenance issues in steam humidifiers because as hard water heats to the boiling point, precipitation of scale occurs.



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[1] Mackenzie Davis and David Cornwell, *Introduction to Environmental Engineering* 5th Edition (New York: McGraw-Hill, 2012)

HARD WATER SCALE

Typically, substances become more soluble when heated unlike the process of scale formation. Although calcium carbonate is a solid, when dissolved in water at neutral or nearly neutral pH, it exists mainly as calcium bicarbonate.

Calcium bicarbonate: calcium ions (Ca^{+2}) and bicarbonate ions (HCO_3^{-})

While calcium bicarbonate is soluble in water at low temperatures, when heated to a boil, calcium carbonate forms. Calcium carbonate has very low solubility in boiling water and precipitates as scale. This is referred to as the inverse solubility of calcium carbonate. The process is shown below:

- Heat provides the energy to break down bicarbonate ions (HCO_3^{-}) in an endothermic process that initiates the reactions to produce the following:
  - carbonate ion (CO_3^{-2})
  - carbon dioxide (CO_2)
  - water (H_2O)
- CO_2 is less soluble at higher temperatures (or lower pressures) and evolves as a vapor, and the water stays behind as another water molecule.
- Calcium ions (Ca^{+2}) in the water combine with carbonate ions (CO_3^{-2}) once they are formed, and calcium carbonate ($CaCO_3$) precipitates due to low solubility:
  $Ca^{+2} + 2\ HCO_3^{-} \leftrightarrow CaCO_3$ (solid) + H_2O (liquid) + CO_2 (gas)

Hardness is split into two groups:

- Group 1: Temporary hardness or carbonate hardness. This is what is shown in Figure 9-1. It is the group that we are concerned about because this is scale-forming hardness.
- Group 2: Permanent hardness or non-carbonate hardness. This group, by definition, contains hard water ions (such as calcium and/or magnesium) as in group 1, but it does not contain the bicarbonate ion. Therefore, this hardness does not form scale upon heating. It does not exhibit inverse solubility; rather, it follows standard rules of solubility and precipitates only when it becomes saturated.
  Note: Total hardness is the sum of temporary and permanent hardness.

FIGURE 9-1: HARD WATER SCALE ON HEATING ELEMENTS

Scale must be removed from humidifier tanks, heaters, and heat exchangers to restore like-new performance. Removing scale by chipping and scraping with tools is time consuming and labor intensive.

FIGURE 9-2: POURING DE-SCALING SOLUTION INTO A HUMIDIFIER TANK

The easier and more thorough method for removing scale is by dissolving it with de-scaling solution.

ALKALINITY

Alkalinity is technically the capacity of an aqueous (water) solution to neutralize an acid. This means substances like bicarbonates, carbonates, and hydroxyl ions (OH^-) that make up the alkalinity in water can accept or give off hydrogen ions. These ion exchanges help to stabilize the pH of the water because pH is a function of hydrogen ions.

The temporary (scale-forming) hardness of water at or near neutral pH can be estimated from the bicarbonate alkalinity.

BICARBONATE ALKALINITY AND SCALE

The contribution of hydroxyl ions to alkalinity in water at or near neutral pH is negligible; however, alkalinity from carbonate species in water at or near neutral pH is mainly in the form of bicarbonate.

Because of that, the temporary (scale-forming) hardness of water at or near neutral pH can be estimated from its bicarbonate alkalinity. High concentrations of hard water ions and bicarbonate ions reacting with each other will produce scale.

Therefore, knowing the bicarbonate alkalinity of water can help us to estimate the scale-forming potential of water.

APPROACHES TO SOLVING THE HARD WATER PROBLEM

Maintenance is always a concern with equipment when hard water containing temporary hardness is present due to its scale forming potential, especially when water is heated to produce steam. That is why some building owners opt to soften their water. Others choose even more sophisticated water treatment systems to drastically reduce or even eliminate maintenance by using reverse osmosis (RO) or deionized (DI) water in their steam humidifiers.

SOFTENED WATER

Water softening is an ion exchange process that exchanges hard water ions like Ca^{+2} or Mg^{+2} for single-charged ions like sodium (Na^+) or potassium (K^+). Water softeners do not remove negative ions like bicarbonate and chlorides. So, what's the benefit? When in solution with bicarbonate, sodium ions do not exhibit inverse solubility. Even when the bicarbonate ion breaks down upon heating to form carbonate, it is still over 30,000 times more soluble than calcium carbonate. So, as shown below, instead of forming calcium carbonate scale, the sodium and carbonate ions stay in solution to much higher concentrations.

$$2\,Na^+ + 2\,HCO_3^- \leftrightarrow 2\,Na^+ + CO_3^{-2} + H_2O\text{ (liquid)} + CO_2\text{ (gas)}$$

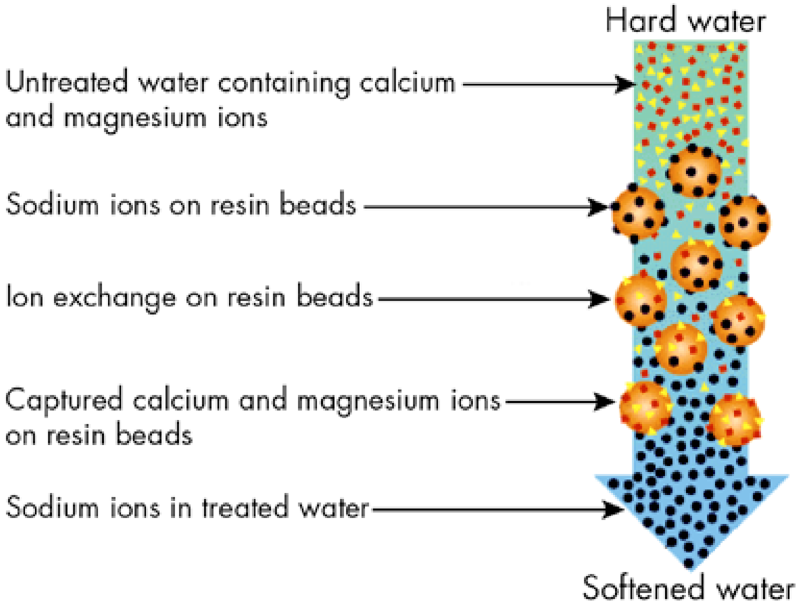
Softened water is one approach to preventing scale build up in steam humidifiers. Water softeners remove hard water cations and exchange them for softened water cations like sodium ions. Also, softening water does not appreciably change the conductivity of the water, because for every calcium ion (containing two positive charges) that is removed, it is replaced with two sodium ions, each of which have one positive charge.

Water softeners use resin beads with sodium (sometimes potassium) attached to them. An ion exchange occurs when hard water containing calcium and/or magnesium ions flows through the resin beads. The resin beads release sodium ions to the water while capturing the calcium and/or magnesium ions. See Figure 11-1.

Once the resin is depleted, it must be regenerated to flush out the captured hard water ions and replace them with a new source of sodium ions. This is done by using a salt solution (sodium chloride, potssium chlrodie, iron, or manganese) from a brine tank or fouling can occur. Once the regeneration process is complete, the system is rinsed to remove residual hard water ions and chloride ions from the salt, and the rinse water is sent to drain.

After being put back online, the newly softened water contains all the original substances that were in the incoming supply water minus the hard water ions that have been replaced with sodium ions. The process continues until the resin is again depleted of sodium, and another regeneration process occurs.

FIGURE 11-1: WATER SOFTENING PROCESS[2]



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[2] Image courtesy of Andrea Kubisch, Courtney Korff (UCD), *Case Study: Hard Water* (LibreTexts, 2015), Creative Commons

SILICA AND SILICATES

Silica and silicates are especially challenging for water treatment and other equipment. Magnesium silicate is described as glass like; it will be near impossible to remove without damaging the equipment. Pretreatment or lower cycles of concentration is the best way to handle silicate.

SULFATE

Sulfate is another ion that forms scale. It is different than carbonate scales but still has an insulating effect. It tends to be more soluble that calcium carbonate but still might be present.

DEPOSITS

Deposits such as iron, manganese, and suspended solids present a significant challenge in HVAC water systems, particularly in maintaining efficient heat exchange. When these contaminants precipitate or accumulate within piping, heat exchangers, or coils, they form insulating layers that reduce thermal conductivity, impair flow, and increase energy consumption due to the added resistance to heat transfer.

Iron and manganese, in particular, can oxidize and create dense, "tacky" deposits that are difficult to remove once established.

Suspended solids can settle in low-velocity areas and lead to under-deposit corrosion or biological fouling. Effective mitigation strategies include implementing robust filtration systems, regular drain procedures, and the use of dispersants or sequestrants in the water treatment program (typically not done in a humidifier as we are trying to produce "clean steam").

Additionally, proactive system monitoring—such as turbidity, iron, and manganese testing—combined with scheduled maintenance can help prevent the accumulation of these deposits and ensure the long-term performance and reliability of the HVAC system.

DriSteem has small inline filters on the inlet of most generators to be the last line of defense. These can be overwhelmed if the loading is too great and the water should be treated more vigorously upstream. These inline filters should be changed or cleaned on a preventative maintenance basis.

REVERSE OSMOSIS (RO) WATER

To understand reverse osmosis, it is important to understand normal osmosis. Think back to high school biology and cells and electrolytes (which are biological dissolved solids). Cell walls are semipermeable membranes that allow the flow of water molecules through, but not many of the electrolytes because they are too large. If the concentration of electrolytes is higher on one side of the cell wall than the other, water flows through the cell wall to the side with more electrolytes. This flow of water dilutes the concentration of electrolytes on one side of the cell wall in an effort to equalize the concentration on both sides of the cell wall. This creates a pressure differential across the membrane called osmotic pressure. Normal osmosis is the process of water flowing from the less concentrated side of the cell wall to the more concentrated side of the cell wall.

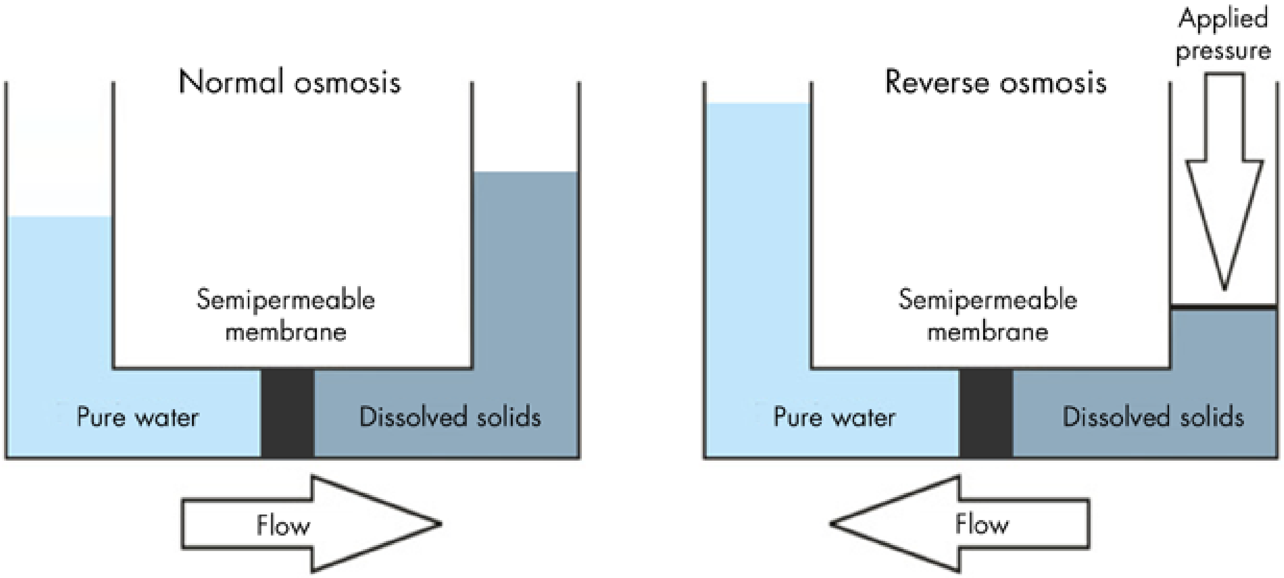
RO water treatment does the opposite. It is a process that purifies water by flowing it through a semipermeable membrane from the more concentrated side to the less concentrated side, creating water that is nearly free of dissolved solids. Since this is not a natural process, mechanical pressure must be used. A pump is used to push the water through the membrane. In Figure 13-1, the left side shows natural osmotic flow, while the right side shows reverse osmotic flow.

RO water treatment creates two flows, the concentrate (the source water side of the membrane) and permeate (the downstream side of the membrane with clean water). The concentrate flow carries the concentrated solids to the drain, and the permeate flow consists of purified water that can be stored and used by downstream equipment.

Normal osmosis is the process of water flowing from the less concentrated side of the cell wall to the more concentrated side of the cell wall.

Reverse osmosis is the opposite in that it pushes water through a semipermeable membrane from the more concentrated side to the less concentrated side.

FIGURE 13-1: NORMAL OSMOSIS AND REVERSE OSMOSIS



DEIONIZED (DI) WATER

The main method used in the industry to create DI water from water containing TDS is by using ion exchange. This is somewhat similar to a softener, but much more thorough. Positive ions are called cations and negative ions are called anions. DI water treatment systems use two types of resin and removes all cations and anions.

Page 10 and 11 explains that in water softening, sodium (Na^+) ions are released during the capture of calcium and magnesium ions. In the deionization process, the cation resin bed is used for positive ion removal and a hydrogen (H^+) ion is released (typical from hydrochloric acid). In the anion resin bed, used for negative ion removal, a hydroxyl (OH^-) ion is released (typical from sodium hydroxide). The two released ions, H^+ and OH^-, form water (H_2O). The result is DI water—all TDS removed—for downstream equipment requiring very clean water.

Care must be taken to replace spent DI water treatment system resin beds with regenerated resin beds, or pass-through will occur, resulting in impure water downstream. Spent cation and anion resin beds are regenerated with a strong acid (containing H^+ ions) and a strong base (containing OH^- ions) similar to using salt to regenerate a softener.

OTHER WATER TREATMENT TECHNOLOGIES

There are many water treatment technologies, new and old, being used in various industries. While it is not the purpose of this handbook to go into detail on all technologies, following are comments on a few.

NOTE: Physical water treatment has been tested by many sources. It has mixed results and it is not recommended to use around heat exchange processes.

Chemical treatment

Municipal water treatment systems use a large chemical treatment process called lime softening to at least partially soften the water sent out to the community. They also provide chlorination to prevent bacterial growth in the water supply.

Physical water treatment

The goal of physical water treatment (PWT) is to change the crystal structure of the calcium carbonate from calcite to aragonite. Calcite is a lower-energy structure that forms a hard, scaly deposit requiring mechanical or chemical cleaning to remove. Aragonite, on the other hand, forms more of a powdering deposit that, if managed properly, may help to avoid or lessen the maintenance burden on equipment. There are various approaches to PWT, including template assisted crystallization (TAC) and various magnetic techniques.

Capacitive deionization

Capacitive deionization (CDI) uses capacitance to capture the ionic solids when water flows through the system. Positive ions flow toward a negative electrode, and negative ions flow toward to a positive electrode. Reversing the polarity of the electrodes releases the ions, which can then be flushed to the drain.

Sequestering agents

Sequestering agents are used to form a “shield” around the ions to help prevent them from reacting with other ions and forming scale. Over time, sequestering agents form a type of flocculent in the water that can be drained or filtered out.

Section V: Corrosion

Everyone has seen degradation of metals, including rust formation, throughout their lives. Just what is corrosion? It's a natural process that causes metal degradation/disintegration due to chemical reactions from its surroundings. Corrosion will occur when the right set of ingredients are available to convert a metal to a more chemically stable form, such as an oxide. Iron corrodes to form iron oxide (rust). Corrosion can be caused by either of the following:

- Direct chemical attack followed by oxidation
- Electrochemical oxidation, where a potential difference is set up within or between metals by creating a miniature electrochemical cell. Metals react and form an oxide or some other compound. The following three essential ingredients are required:
    - Anode
    - Cathode
    - Electrolyte (for example, conductive water)

Metal corrodes at the anode. The anode is the "active" site where the corrosion (oxidation) takes place. It enters the electrolyte as a positive ion, and electrons travel toward the cathode.

The cathode completes the electrical circuit and is not consumed. The cathode is the "protected" site where the metal does not corrode.

The electrolyte provides the corrosive medium, such as chlorides in water, and the electrical path through the water via ion flow.

WHY CORROSION MATTERS TO DRISTEEM

DriSteem must understand corrosion for the following reasons:

- Prepares us to understand how water chemistry can negatively impact the reliability of our products
- Enables us to create water quality guidelines, which are needed to protect our equipment and mitigate corrosive effects on our products
- Equips us to discover innovations for improving product reliability in corrosive environments

Several factors can influence the potential for corrosion in our products. Some of these corrosion influences are listed below:

- Temperature: High temperatures increase the rate of corrosion.
- Flow rate: Low flow rates can allow oxygen to concentrate in "cells" and enhance corrosion potential.
- pH: Low pH (less than 7) is acidic and creates the potential for corrosion. CO_2 dissolved in water forms carbonic acid, which can lower pH.
- TDS: High TDS contribute to conductivity, enhancing the electrolytic effect and increasing the rate of corrosion.
- Alkalinity
- Hardness
- Oxidizing agents, such as oxygen
- Corrosive agents: Chlorides, for example, are aggressive ions that can accumulate and concentrate in cavities, contributing to corrosion of stainless steel.
- Bacteria: Among potential mechanisms, bacteria can release CO_2 to form carbonic acid and enhance corrosion potential (micro-biologically influenced corrosion).
- Electromotive potential: Dissimilar metals can create galvanic corrosion potential.

Among these, the primary factors include:

- Alkalinity
- Hardness
- pH
- Corrosive agents

CHLORIDES IN HUMIDIFICATION APPLICATIONS

Managing chlorides is among the most difficult aspects of humidification systems. Each humidifier is designed with an inlet guideline. Questions often arise regarding cycles of concentration and tank thresholds. Although we have noted variations, these general guidelines provide a baseline reference.

- Chlorides can start stress corrosion cracking at levels as low as 10 ppm (parts per million), when at atmospheric boil. See pages 25 and26.
- It is possible, although not guaranteed, to get full equipment life out of 200 ppm (with 304L stainless steel) or 400 ppm (with 316L stainless steel).
- Complexity stems from the combined factors of temperature, alkalinity, chlorides, pH, and hardness.
- Although scale is not desirable for heat transfer in humidifiers, it does offer a degree of protection against chloride-driven corrosion. As a result, DI source water that contains chlorides can be more corrosive than hard city water in terms of chloride impact. When DI systems are operated improperly, chloride-related problems can intensify due to the way cycles of concentration behave. Compounding this is the misconception that spent DI resin performs to the same standard as fully regenerated, fresh resin, which can create a misleading sense of security.

CORROSIVE WATER VS. SCALE-FORMING WATER

Water can be categorized in many ways. For the purpose of this handbook, water is in two groups: corrosive water and scale-forming water. Scale-forming water is less corrosive because the process of forming scale removes/evolves acid-forming CO_2. As a side benefit, scale also provides a certain amount of protective barrier against corrosive agents.

Corrosive water characteristics include:

- Low pH
- Non-carbonate hardness (permanent hardness)
- Low alkalinity
- Concentrated corrosive agents to high levels

Scale-forming water characteristics include:

- High pH
- Carbonate hardness (temporary hardness)
- High alkalinity
- Low levels of corrosive agents

A general summary or take-away from the two lists above is as follows:

- Low-pH water has excess H^+ ions (acid) to enhance corrosion.
- High-pH water lowers the solubility of calcium carbonate ($CaCO_3$), making it more likely to form scale.
- Low-alkalinity water lacks buffering capacity, creating less ability to stabilize pH. Following are two consequences:
  - Makes it harder to deal with acidic/corrosive conditions
  - Limits scale potential that can act as a barrier to corrosion
- Corrosive agents, like chlorides, are aggressive, prevalent, and can concentrate.

CORROSION-RESISTANT PROPERTIES OF STAINLESS STEEL

Moving away from water characteristics and their corrosive effects for a moment, there are a few points to be made about stainless steel, since that is what DriSteem uses in most humidifier products, particularly the tanks and some heat exchangers.

- Corrosion resistance in stainless steel is due to its ability to form a protective layer.
  - The surface of the metal forms an invisible, “passive” film of chromium oxide.
  - Passivation is instantaneous in the presence of oxygen.
  - Stainless steels perform well under oxidizing conditions where other materials do not.
- Halogen salts (chlorides) can be a problem.
  - They are soluble, “active” ions and good electrolytes, which makes them good corrosion agents.
  - They are common in nature and are likely to be in natural waters.
  - Penetration of the protective passive film on stainless steel by chlorides is affected by concentration, temperature, and stress.

- 300 series (austenitic) stainless steel is resistant to but not impervious to chlorides.
    - Above 50 °F (10 °C) it is susceptible to chlorides at concentrations of only a few parts per million.
    - Stress corrosion can occur at higher temperatures with chloride levels as low as 10 ppm.
    - Chlorides can concentrate in crevices (up to 100x).
    - Processing parameters, such as chromium depletion (sensitization), can affect corrosion resistance.

- Stainless steel composition (various grades) can help to minimize corrosion in given environments.
    - Austenitic stainless steel (300 series) contains chromium-nickel for corrosion resistance.
    - Lower carbon content reduces the potential for chromium carbide formation and precipitation in the grain boundaries during the welding process.
        - Removal or depletion of chromium reduces corrosion resistance/passivation of steel near the weld joint. The weld joint is the heat-affected zone and more susceptible to corrosive attack. See Figure 22-1.
        - Solution annealing at very high temperature (1600˚F or higher) can re-distribute the carbon and the chromium into the steel. To allow for repassivation of the chromium, the temperature must be dropped quickly (quenched) to prevent forming chromium carbide again.
        - 316 stainless steel contains molybdenum for improved resistance to chloride crevice and/or pitting corrosion.

The following subsections provide an overview of some types of corrosion that can occur, including: galvanic corrosion, intergranular or intercrystalline corrosion (page 24), stress corrosion (page 25), and crevice and pitting corrosion (page 26).

FIGURE 22-1: STAINLESS STEEL CORROSION EXAMPLES

GALVANIC CORROSION

Galvanic corrosion (Figure 23-1)can occur when two different metals are in contact with each other via an electrolyte, with the following paths present:

- Ionic
- Electrically conductive

More active metals corrode and dissolve. Stainless steels are generally cathodic to other metals, but the degree of passivation can have an impact on corrosion resistance.

To help mitigate for galvanic corrosion, electrical isolation of the two metals is sometimes used. The isolation barrier must, of course, be non-conductive. Another approach is sacrificial anodes made of zinc or magnesium. These metals are more active than most others, so they can be intentionally corroded to protect other metals.

Table 23-1 lists metals in order from active (anodes) to noble/less active (cathode). This list is called the galvanic series of metals. The greater the separation in the galvanic series, the greater the potential difference, which means the greater the opportunity for corrosion.

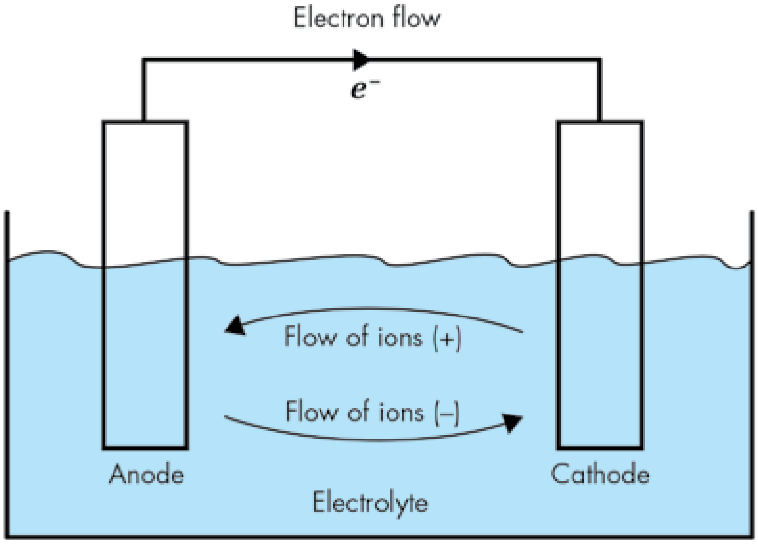
Figure 23-1 shows the flow of electrons to complete a circuit using an electrolyte and an anode and cathode that are connected by a conductive path.

FIGURE 23-1: GALVANIC CORROSION

Table 23-1:
Galvanic series of metals

Anode (more active/corroded end)
Magnesium
Zinc
Aluminum
304 Stainless (active)
316 Stainless (active)
Lead
Tin
Brass
Copper
Bronze
304 Stainless (passive)
316 Stainless (passive)
Silver
Gold
Platinum
Cathode (more noble/protected end)

FIGURE 23-1: ION AND ELECTRON FLOW BETWEEN ANODE AND CATHODE



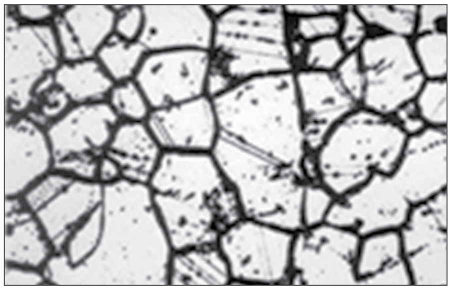
INTERGRANULAR (INTERCRYSTALLINE) CORROSION

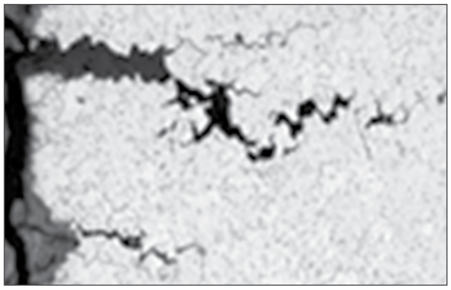
Intergranular corrosion, as the name implies, occurs at or near the grain boundaries of the metal. When chromium carbide precipitates in the grain boundaries (the space between the grains), it renders the adjacent areas susceptible to corrosion. This known in the industry as "sensitization." Sensitization occurs at temperatures between 800°F (427°C) and 1650°F (899°C) and is a common result of welding. Once sensitized, corrosion can occur in these areas near the weld joints if the water chemistry is suitable. Acidic water and chlorides are the main contributors.

How can this mechanism be minimized in real applications? There are several ways to address this issue but some are less desirable than others. The following are some examples:

- Do not allow the water quality to create a corrosive environment. Water treatment can be applied and, depending on the supply water constituents, draining to mitigate for concentration build up should also be considered.
- When welding tanks and heat exchanges, institute an annealing process to re-dissolve the carbon and chromium, and quench the metal to reduce the heat quickly so as not to reform chromium carbide. This will allow the chromium to be available for repassivation.
- Use low carbon stainless steel ("L" grade). Less carbon will offer less opportunity for chromium carbide precipitation, resulting in less opportunity for sensitization.
- Use another type of stainless steel that will have more corrosion resistance. As mentioned earlier, 316 stainless steel is an alloy that has molybdenum that can combat corrosion caused by chlorides. Other stainless steel alloys that contain elements like niobium or titanium can act as a stronger carbon "getter" than chromium to assist with corrosion prevention.

FIGURE 24-1: INTERGRANULAR CORROSION EXAMPLES





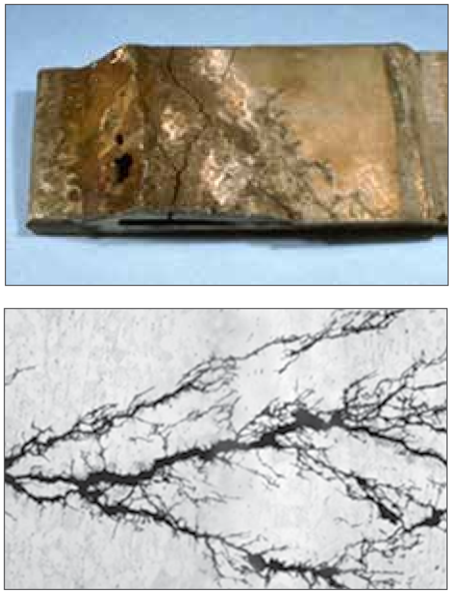
STRESS CORROSION

Stress corrosion, often referred to as stress corrosion cracking (SCC), occurs when the metal is under stress from bends or other stress agents while in the presence of a corrosive agent. The stress can be applied from an external source such as a bolt or from residual processing stress from welding. If intergranular corrosion (transgranular corrosion can also occur) is occurring, the stress will accelerate the corrosion process. The main culprit is chloride solution coupled with stress and temperature. The chloride can enter the process through a variety of compounds such as sodium chloride (NaCl), zinc chloride ($ZnCl_2$), and others. Under magnification SCC looks like a dendritic structure with the crack forming from a stress riser location (see Figure 25-1).

Factors that can affect stress include the hardness level of the metal (the cold rolled hardness) as well as assembly requirements like bolts, bends, and welding.

Stress corrosion cracking can be reduced or eliminated by either reducing or eliminating stress on the metal or removing corrosive agents from the water. Adding elements to the metal provides little value.

FIGURE 25-1: STRESS CORROSION EXAMPLES



CREVICE AND PITTING CORROSION

Corrosion occurs where passivation is removed/destroyed (resulting in pits) or where cavities/crevices are built into a product, especially where the crevices are on the water side and welded. These locations become anodic (corrosion susceptible) with respect to the passivated areas. This leaves small, active areas prone to attack. The larger the difference between the anodic area and the cathodic area, the greater the rate of corrosion.

Contributors to crevice and pitting corrosion include the following:

- Stagnant solutions preventing oxygen from getting to susceptible areas to provide passivation
- Chlorides and acids filling pits and crevices

It is widely believed in the industry that the crevice and pitting corrosion mechanism follows the sequence below:

1. Chlorides penetrate the passivation layer and start the corrosion process, which is accelerated if pH is low.
2. Lack of fluid flow (flushing) in the area of the pit or crevice prevents oxygenation of the exposed metal, so the corrosion progresses uninhibited.

   Note: Welded joints are particularly susceptible when chromium is depleted at or near the weld joint (the heat affected zone) and cannot be re-oxygenated or re-passivated.

Some ways to combat this mechanism are listed below:

- Reduce the severity of corrosion by adding molybdenum, and reduce the carbon content of the stainless steel (for example, 316L).
- Remove the corrosive agents via water treatment.
- Remove the crevices in the design process, or completely seal the crevices with non-porous material.

FIGURE 26-1: CREVICE AND PITTING CORROSION

PREVENTING CORROSION

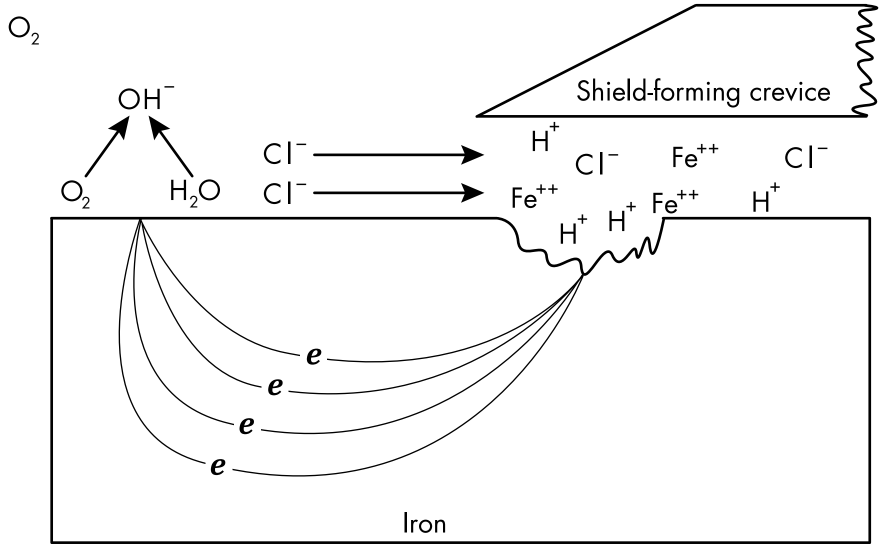
A theory of crevice corrosion has been presented in a study developed by a partnership between steel manufacturing companies and automobile manufacturing companies.[1]

While there are varying opinions on the mechanism of crevice corrosion, one potential mechanism has been presented by this group. And while mechanism is complex, a short summary follows:

1. Oxygen is depleted in a crevice while being more abundant at the surface.
2. The oxygen concentration gradient induces an oxidation/reduction reaction that results in metal oxidation forming positive metal ions.
3. The positive charge of the metal ions is balanced by attracting negatively charged ions, like chlorides, into the crevice.
4. Hydrolysis of metal chloride forms acid and lowers the pH, which results in an auto-catalytic process.
5. The auto-catalytic process then promotes more metal ion formation,
   followed by more chloride migration to the crevice,
   followed by more acid production,
   followed by more corrosion, and so on.

The process continues to repeat itself as long as all the ingredients are present. Figure 27-1 shows this mechanism.

FIGURE 27-1: REDUCING CORROSION



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[1] *A Guide to Corrosion Protection: For Passenger Car and Light Truck Underbody Structural Components,* 1st Edition (Southfield, MI: Auto/Steel Partnership, 1999)

What would we, at DriSteem, really like to have to prevent corrosion in our products? In an ideal world we would like the following:

- No sensitization
- No metal stress
- The ability to maintain the integrity of the passivation layer

But, it is impossible to guarantee all this things. So, what do can we do? We can look at one of the main factors in most of the corrosion we see, and that is the level of chloride ions.

Chloride ions are present in many supply water sources, generally in low amounts (around 10 to 20 ppm), but they can be present up to 100 ppm or even higher. We can try to eliminate chlorides from our supply water using water treatment; however, care must be taken so as not to allow the buildup of chloride concentration over time. DI water, if well maintained, would be an option. RO water is also a good choice because it eliminates up to 98% of dissolved solids, including chlorides from the supply water. **But,** 2% can still pass through. Over time, concentrations can build up to levels that cause corrosive effects.

We need to prevent concentration build up, even with RO water, by using drain events on a frequency based on some level of tolerance that we are willing to accept. This is what we did, after reviewing several sources, when we came up with our supply water guidelines in Table 28-1 to help us determine an appropriate level based on water type. We looked at work from resources such as the Nickel Development Institute, Atlas Steel, Allegany Ludlum Corporation, the National Physical Laboratory, the *Water Purification Handbook*, and others, including competitive positions.

The end result is that we now have chloride concentration level supply water guidelines depending on water type for DI/RO water, softened water, and hard water (also known as tap or potable water) as shown in the table.

We do not want the average overall concentration in a humidifier tank to be more than 10 times these levels. It is now possible to determine cycles of concentration in the tank in order to determine the drain frequency needed to mitigate corrosion potential based on chloride concentrations in the supply water.

Table 28-1:
DriSteem supply water guidelines

Chlorides*	
RO or DI water	< 5 ppm
Softened water	< 25 ppm
Tap water	< 50 ppm
* Damage caused by chloride corrosion is not covered by your DriSteem warranty.	
Total hardness	
Tap water	< 500 ppm
pH	
RO, DI, or softened water	7 to 8
Tap water	6.5 to 8.5
Silica	< 15 ppm
You may wish to take action to mitigate potential negative effects to your humidifier. Supply water outside of these guidelines may void your DriSteem warranty. Please contact your DriSteem Representative or DriSteem Technical Support if you need advice.	

Notes

Section IV: Electrical conductivity of water

CONDUCTIVE IONS IN WATER

Electrical conductivity in water is proportional to the concentration of conductive ions in the water. The higher the concentration of conductive ions, the higher the conductivity of the water.

Resistivity is the inverse of conductivity. Ultra-pure water has so few conductive ions that it is, for all practical purposes, infinitely resistive.

Conductivity is determined by the following:

- Charge on the ions
- Size of the ions
- Temperature of the water

Without doing extensive chemical testing, TDS can be estimated from conductivity. Since different ions can have different charges, translating conductivity to TDS actually depends on the items listed above. Most estimates, including what is used in TDS sensors, use a factor of 50% when converting from microsiemens per centimeter to TDS in parts per million. For example, if the conductivity of a water sample is 100 μS/cm, the estimated TDS is 50 ppm. In most situations this estimate is sufficient.

CONDUCTIVITY AND ELECTRODE HUMIDIFIERS

Conductivity and resistivity are critical to the operation of an electrode humidifier. In electrode humidifiers, steam output is directly related to the resistance of the water in the steam cylinder and, therefore, to the conductivity of the water between the electrodes. Higher water levels cover more electrode surface and result in more steam; lower water levels cover less electrode surface and result in less steam.

Water conductivity and water level both correlate to steam output. Some manufacturers of electrode humidifiers employ a proprietary algorithm to monitor conductivity and manage drain and fill cycles to optimize humidifier performance and provide proper steam output.

Water containing temporary hardness precipitates scale, removing conductive ions from solution. This results in fewer required drain-and-fill cycles to manage conductivity than would be required with softened water. As a result, water containing temporary hardness generally provides more consistent steam output and less energy usage in electrode humidifiers than softened water can provide.

Hard water is generally the preferred water type for electrode humidifiers; it provides the most consistent steam output and results in less energy and water usage.

However, it should be understood that if the hardness is all or nearly all permanent hardness with little to no temporary hardness, the hard water will not form calcium carbonate scale to slow the growth in conductivity. This will result in a humidifier performing more closely to a softened water situation than a more typical hard water scenario when the hardness is temporary.

On the other hand, if the water contains temporary hardness but few dissolved solids to contribute to conductivity in the supply water, then when the temporary hardness precipitates out of solution the conductivity may actually drop after initially increasing. Since the calcium carbonate precipitate does not have significant solubility in water, and there are not many other dissolved solids present to contribute to conductivity, there is no alternative to having the conductivity drop until the few dissolved solids concentrate enough to overcome the precipitation of the temporary hardness. This is somewhat rare, but it can happen. Understanding this is critical to knowing what is going on. **Water quality lab analyses are invaluable in helping to understand whether this phenomenon is occurring.**

As the water in an electrode humidifier cylinder heats up, the conductivity increases (Figure 33-1). When it boils into steam, the concentration of the conductive ions increases until it reaches a threshold that triggers a drain-and-fill cycle (Figure 33-2). This rids the cylinder of highly conductive water and replaces it with less conductive supply water.

The more conductive the supply water and the higher the demand, the more quickly the threshold is reached, and the more frequently the cylinder automatically drains and fills to stay within the parameters for the proper steam output. The frequency and duration of the drain-and-fill cycles is proportional to the conductivity of the supply water. Generally, less conductive supply water takes somewhat longer to reach full output at startup but requires less frequent drain-and-fill cycles. This results in more consistent steam output over time and more efficient use of energy and water.

FIGURE 33-1: ELECTRODE HUMIDIFIER BOILING WATER

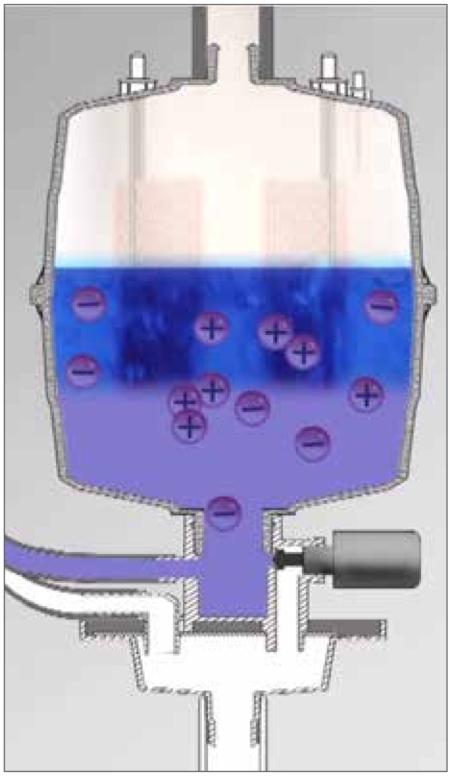
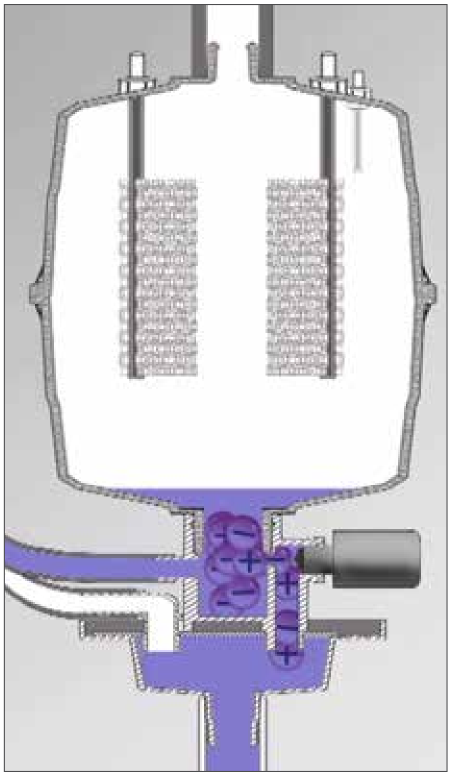


FIGURE 33-2: ELECTRODE HUMIDIFIER FLUSHING CONDUCTIVE WATER



Section III: Water treatment and downstream equipment

Humidification and evaporative cooling require transforming water into vapor, so it is not surprising that water can have a great impact on system performance and maintenance. In order to maintain relative humidity (RH) and other space requirements while keeping systems running the way they were intended, it is important to understand how water types can affect those systems.

APPROACHES TO EQUIPMENT MAINTENANCE

Maintenance is a major concern for many building owners and facility managers. It is a constant struggle for customers who process water, especially if that water is very hard. So, how do customers manage hard water scale formation? The three primary approaches to maintenance that DriSteem customers take are in-process management, post treatment, and pretreatment.

In-process management

In-process management is managing the system during use by periodically draining the tank. Draining frequency and duration are based on water type, tank size, and the volume of water boiled or evaporated. Systems using hard water are designed to perform well with a moderate amount of scale; however, the in-process management approach to equipment maintenance has limited effect in steam humidifiers due to inverse solubility when hard water is boiled to produce steam.

Post treatment

The post-treatment approach is to remove scale on a scheduled or as-needed basis. This approach requires shutting the system down and manually removing scale with tools or dissolving scale with de-scaling solution (acid).

Post-treatment maintenance can be costly and can contribute to future corrosion issues. Scraping and chipping can compromise the stainless steel chromium passivation layer, and de-scaling solution must be properly neutralized and rinsed from the tank.

Pretreatment

Pretreatment keeps the system up and running as much as possible while minimizing downtime for maintenance. This approach requires additional equipment but, for some customers and for some product lines, it is essential.

Typical pretreatment technologies include RO, DI, and softening systems. Other technologies, such as sequestering agents and physical water technologies, are sometimes used in certain industries.

Factors that affect the amount of scale produced and the maintenance frequency include:

- Concentration of temporary hardness in the water
- Temperature and/or pressure conditions
- Volume of water boiled (throughput)

APPLICATION CONSIDERATIONS

Customers need to evaluate what type of system they need to meet their specific needs. Some applications are critical and must have humidity production available whenever called for. Some components, such as atomizing nozzles and piezo electric transducers, cannot tolerate any scale buildup and require DI or RO water.

On the other hand, space conditions for comfort applications are broad and do not require tight control. Customers with non-critical applications may opt for hard water, or if they want to lessen the effort and frequency of maintenance, they may opt for softened water. Customers with treated water on-site and enough capacity to supply their humidification systems may want to consider using their on-site water.

Customers with tap water only and applications requiring water treatment can obtain water softening and RO systems from DriSteem.

HYGIENE

Hygiene in HVAC water systems is critical for ensuring both system efficiency and occupant safety, as poorly maintained systems can become breeding grounds for microorganisms such as bacteria, algae, and fungi.

Biofouling, the accumulation of microbial growth on surfaces, can lead to serious issues including reduced heat transfer efficiency, increased corrosion under biological films, and the potential spread of harmful pathogens such as Legionella.

Routine water hygiene practices are essential to mitigate these risks, beginning with a comprehensive testing program that monitors microbial activity, including dip slide testing, ATP analysis, or periodic lab sampling. The importance of hygiene extends beyond mechanical performance; it also addresses regulatory and health concerns, making proactive management essential.

Treatment methods typically include the controlled use of biocides (oxidizing and non-oxidizing), bio-dispersants, and physical cleaning procedures such as system flushing (such as inactivity flush) or high-velocity water treatment. UV treatment and filtration is another method we use at DriSteem to minimize the growth of biology.

Maintaining proper chemical balance, controlling nutrient levels, and ensuring good system design to minimize stagnant zones further reduce biofouling potential.

A robust hygiene program, reinforced by regular inspection and documentation, is key to sustaining safe, reliable, and energy-efficient HVAC water systems.

ISOTHERMAL HUMIDIFIERS

Figures 38-1 through 38-3 are meant to show the varying effects of using hard, softened, and RO water in humidification systems. Note the solubility difference of calcium carbonate scale from hard water versus sodium carbonate from softened water.

Hard water forms scale requiring cleaning with chemicals or mechanical means.

- Upon heating to create steam, calcium carbonate is formed via inverse solubility.
- Calcium carbonate is a hard scale.
- Calcium carbonate solubility is very low: 0.0014 g/100 cc at 77 °F (25 °C).

FIGURE 38-1: HARD WATER SCALE ON HEATERS AND TANK

Softened water does not form hard scale and may extend maintenance intervals by a factor of three.

- Sodium has replaced calcium in the softener via ion exchange.
- Sodium carbonate is a soft, powdery substance.
- Sodium carbonate is over more than 30,000 times more soluble than calcium carbonate: 45.5 g/100 cc at 77 °F (25 °C).

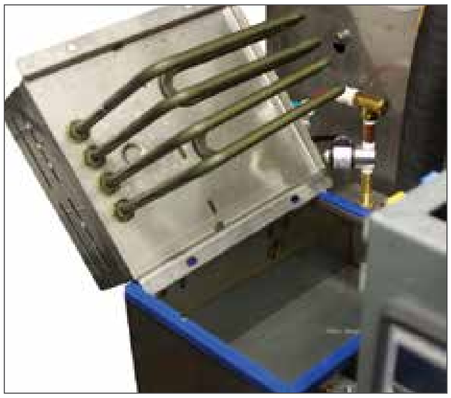
FIGURE 38-2: SOFTENED WATER RESIDUE IN HUMIDIFIER TANK

RO water provides nearly pure water which significantly reduces maintenance.

- RO systems provide water with approximately 98% TDS removed.
- RO systems use replaceable membranes and filters and may eliminate significant humidifier maintenance.
- DriSteem uses low-energy membranes in all RO systems to maintain higher permeate water flow at lower temperatures.

  DriSteem rates permeate flow at 50˚ F (10 °C).

FIGURE 39-1: RO WATER LEAVES NO RESIDUE ON HEATERS AND TANK



All of DriSteem's isothermal humidifiers can use hard, softened, DI, or RO water except for XT Series electrode humidifiers. Electrode humidifiers require conductive water and, therefore, cannot use water with little or no TDS (such as DI/RO), or softened water.

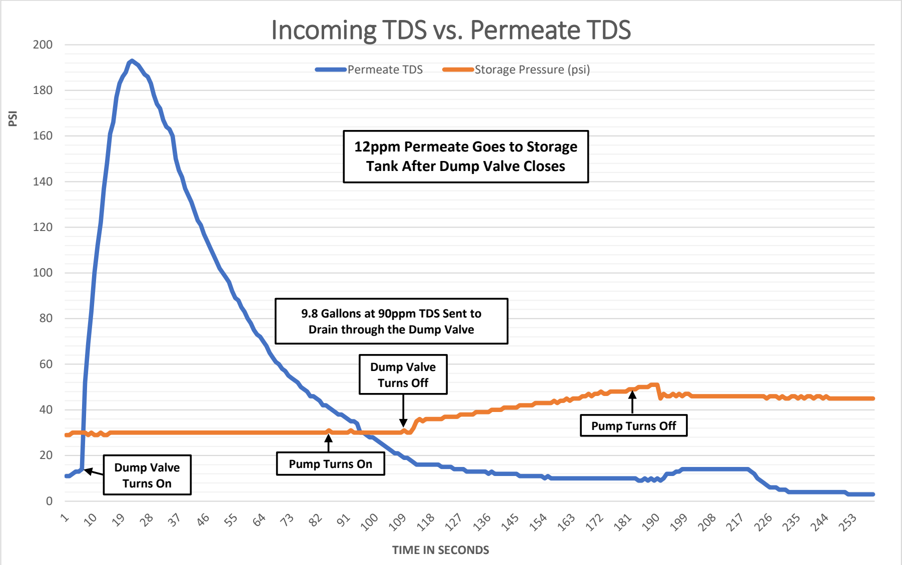
As discussed in Section 2, scale formation requires maintenance and results in equipment downtime, and it is a common problem with hard water. In critical applications when humidity must be available on demand, DI or RO water is generally used so as to avoid the maintenance downtime due to scale build up.

Softened water too, helps avoid maintenance downtime. It does not form scale, and humidifiers typically run three times longer between maintenance shutdowns than systems using hard water. However, if corrosive agents such as chlorides are present, corrosion effects could show up faster with softened water than with hard water. How can this be? Ironically, the scale from hard water can provide a "pseudo barrier" that prevents corrosive agents from reaching vulnerable areas (such as weld joints) in a tank. This barrier can actually help to extend the life of the tank.

Properly maintained DI water systems do not have dissolved solids. In theory, they provide the cleanest water for use in humidifiers; however, carbon dioxide, which is present in the atmosphere, can dissolve in water and create carbonic acid. This can lower the pH into the acidic range making some systems vulnerable over time to acidic attack in susceptible areas.

RO systems remove as much as 98% of the dissolved solids, but a small amount does pass through. If any corrosive agents such as chlorides are in the pass-through, they can concentrate in the tank water because they do not vaporize during the boiling process. In such cases, drain intervals should be established based on DriSteem guidelines for supply water, even if the humidifier is configured for DI or RO water.

FIGURE 39-1: INCOMING TOTAL DISSOLVED SOLIDS



DEHUMIDIFICATION CONDENSATE AND WATER QUALITY CONSIDERATIONS

Dehumidification condensate is the water that collects when moisture is removed from air as it passes over cold evaporator coils, typically in air handling units (AHUs) or dedicated dehumidifiers. This condensate is often perceived as a clean water source due to its low mineral content; however, it is not inherently suitable for reuse—especially in sensitive applications like humidification—without appropriate treatment. The quality of condensate can be compromised by the presence of airborne contaminants, biofilm development in drain pans or coils, and metallic ions leached from coil materials or system piping.

Despite these concerns, condensate offers a promising opportunity for **water reuse and reclamation**, particularly in buildings with high dehumidification loads, such as data centers, museums, or indoor agriculture facilities. Reclaiming this water can reduce overall water consumption and support sustainability initiatives, but it must be treated before reuse. Potential contaminants include microorganisms (due to the moist, stagnant environments condensate collects in), low pH levels (from CO_2 absorption), and trace metals (from corrosion or coil materials).

To safely reuse condensate for humidifier make-up water, a multi-step treatment process is often recommended. This may include filtration to remove particulates, UV sterilization or chemical disinfection to address microbial content, pH adjustment to neutralize acidity, and potentially reverse osmosis or deionization to further reduce dissolved ions and ensure compatibility with steam generation equipment. Proper treatment not only protects the humidifier from scale and corrosion but also ensures the indoor air quality remains uncompromised. Monitoring and regular maintenance of both the condensate collection and treatment systems are crucial to ensure the reclaimed water consistently meets the required specifications for reuse.

Incorporating condensate reuse into building water strategies presents a cost-effective and environmentally responsible approach, but it must be executed with rigorous attention to water quality, treatment design, and operational best practices.

CONDENSATE MANAGEMENT IN STEAM HUMIDIFIER SYSTEMS

Condensate management is a critical design consideration in steam humidification systems, especially for maintaining system efficiency, water quality, and sustainability.

As steam is transported from the humidifier to the dispersion grid, some of it naturally condenses within the piping due to heat loss. This condensate must be properly handled to prevent issues such as capacity insufficiencies, microbial growth, or equipment inefficiency.

There are three common strategies for managing this condensate: pitching the dispersion piping back to the humidifier, utilizing a condensate receiver for recirculation, or draining the condensate to waste. Each option carries distinct implications for energy efficiency, water conservation, and operational quality.

1. Pitching Dispersion Piping Back to the Humidifier (Short Run Applications)
   In systems with short steam pipe runs and sufficient vertical clearance, piping can be pitched back toward the humidifier to allow condensate to naturally drain back to the humidifier.

   This approach is highly efficient, both thermally and in terms of water usage, as the returned condensate is hot and clean, minimizing energy loss and maximizing reuse. It simplifies system design and reduces the need for additional components. However, this method is only viable when elevation and distance allow for proper slope and when the condensate return volume is minimal.
2. Condensate Receiver with Reuse to Humidifier Inlet
   For longer or more complex systems where gravity return is not feasible, a condensate receiver tank and pump can be used to collect and route condensate back to the humidifier's inlet or feedwater tank.

   This approach supports energy and water sustainability by reclaiming relatively clean, pre-heated water, reducing both the volume of makeup water required and the energy needed to generate steam.

   However, water quality must be closely monitored, as stagnation or biofilm in the return line or receiver can introduce microbial or particulate contamination. Additional water treatment might be required if the contamination is too great.

3. Draining Condensate to Waste
   The most straightforward method—particularly in systems with poor layout for return or where contamination risks are high—is to route condensate directly to drain.

   While this approach is operationally simple and avoids any risk of contaminating the humidifier, it represents a loss in both water and thermal energy. Over time, this can significantly impact utility costs and environmental performance, especially in high-capacity or continuously running systems.

Each condensate management option must be evaluated in context with the system layout, building sustainability goals, and maintenance capabilities. Where feasible, reclaiming condensate offers compelling benefits for water and energy efficiency, provided that water quality is assured. Selecting the appropriate strategy requires balancing these trade-offs with long-term performance, reliability, and operational cost considerations.

RECLAIMING UNEVAPORATED WATER IN ADIABATIC HUMIDIFICATION SYSTEMS

In adiabatic humidification systems, such as high-pressure mist, or ultrasonic, not all water introduced into the air stream fully evaporates. A portion of this unevaporated water—often referred to as residual or drain water—can be collected and reclaimed, offering a significant opportunity for improving water efficiency and system sustainability. Without a reclaim strategy, this residual water is typically discharged to drain, leading to unnecessary water waste and increased operational costs.

To address this, DriSteem and other advanced system providers implement a reclaim loop that captures unevaporated water from the humidifier's drain basin or sump and routes it back into the water treatment system for reuse. Central to this design is a collection tank and pump system that manages water level and provides consistent flow and pressure for return. Rather than allowing this drain water to be discarded, the tank collects and stores the water, which is then reintroduced into the reverse osmosis (RO) system for reprocessing.

Before re-entry into the RO system, DriSteem employs pre-filtration techniques to remove particulates or biological contaminants that may have accumulated during circulation or exposure to air. This step is crucial, as particulates and organic matter can quickly degrade membrane performance or introduce fouling in downstream components. Once adequately filtered, the reclaimed water is blended into the RO feed line, reducing the demand for fresh inlet water and enhancing overall system sustainability.

The successful execution of this strategy depends on careful design of the return system, regular monitoring of water quality, and periodic maintenance to ensure sanitary conditions are preserved. When properly managed, reclaiming unevaporated water transforms a waste stream into a valuable resource, aligning high-performance humidification systems with modern sustainability goals.

ADIABATIC HUMIDIFIERS AND EVAPORATIVE COOLING

HIGH-PRESSURE ATOMIZATION SYSTEMS

DriSteem's High-pressure atomization system requires RO water to prevent the nozzles from scaling and to prevent white deposits from TDS being distributed in the conditioned space.

Supply water to the RO system must be softened to prevent scale buildup on the RO membranes. Scale would shorten membrane life.

Thin film composite (TFC) extra-low-energy membranes are used in DriSteem RO systems. To prevent oxidation from chlorination of the water supply and shortened membrane life, a carbon filter/dechlorinator is required upstream from the RO system. Tank-style carbon filters/dechlorinators are offered in multiple sizes to match softener capacities. They contain large quantities of carbon and employ backwash cycles to rinse the filter media and send the rinse water to the drain. Tank-style carbon filters/dechlorinators can be used for larger capacities up to 5500 pph.

Smaller RO systems (up to 500 pph) can get by with a cartridge-style carbon filter/dechlorinator. Because cartridge-style filters do not have a backwash cycle, they need to be changed regularly.

A sediment filter is also used with all DriSteem RO systems to capture suspended solids in the supply water.

ULTRASONIC HUMIDIFIERS

Water quality is integral to the operation and longevity of DriSteem's Ultrasonic humidifier. Required maintenance, system performance, and water/energy usage are all affected by water quality. Operating with treated water reduces or eliminates hard water scale on equipment surfaces, thereby reducing maintenance requirements. Performance improves in systems using treated water with benefits such as reduced downtime and higher energy transfer.

Humidifier performance, humidification vapor quality, indoor air quality, and maintenance requirements are significantly affected by humidifier supply water type. Most humidifier technologies can operate using either treated or untreated water; however, most contaminants in supply water pass through a humidifier system. Especially when misted or sprayed, supply water with minerals produces white dust, which along with other water contaminants can be an inhalation hazard. Settling white dust can also contaminate processes and accumulate in ducts and on furnishings.

- Ultra-pure water can eliminate white dust fallout and bacteria/virus proliferation, that can occur when using potable water.
- Using water technologies such as hygienic drain, silver ionization and UV technology helps prevent bacterial and viral proliferation.
- Scale buildup on PETS can decrease PET lifespan.
- Having a level unit helps keep PET lifespan. The key to output and longevity is consistent water level.
- Use only stainless steel or non-metallic piping for RO/DI water.

WETTED MEDIA SYSTEMS

RO water is generally not considered for wetted media systems because nearly pure water can become aggressive if the pH falls into the acid range from absorbing CO_2, thereby forming carbonic acid. RO water that becomes acidic over time could degrade the structural supports in the media and cause it to degrade/collapse.

CYCLES OF CONCENTRATION

To use hard water most effectively, it is necessary to determine the cycles of concentration (COC) to maintain in the water tank for optimal performance of the Wetted media system. The COC determination depends on the following supply water quality parameters:

- Calcium hardness (as $CaCO_3$)
- Total alkalinity (as $CaCO_3$)
- Conductivity
- Wet bulb temperature

Note: Other parameters such as chlorides and silica content may also be of interest; preventing corrosion or silica deposits from forming if these constituents are present in significant enough quantities.

DriSteem's media works well with hard water that has some amount of scale potential. The trick is to determine the correct COC range for not too much and not too little scale.

DriSteem can help determine the COC range that should be targeted given the supply water quality parameters listed above. The Wetted media system's Vapor-logic controller manages the drain water volume and frequency to keep the system within the selected COC range.

CYCLES OF CONCENTRATION INDEXES

There are multiple methods for determining the scaling potential of water. Examples of such methods are the Langlier Index, Ryznar Index, and Puckorius Scaling Index. DriSteem uses the Puckorius Scaling Index as a factor in determining the COC range for the wetted media system and other humidification applications.

The COC target range is determined by using equations from Munters with variable inputs for hardness, alkalinity, conductivity, and wet bulb temperature. Table 47-1 shows the values for the Langlier Index, Ryznar Index, and Puckorius Scaling Index. Note that target values should fall in the low-scale-forming, low-scale-dissolving area in the table.

The target range using the Puckorius Scaling Index is from 6 to 7, with 6 representing low scale-producing potential and 7 representing low scale-dissolving potential. This is the "sweet" spot for the media. The pH range should be from 7 to 9. Note that this is not acidic water which is important for the reason given earlier—media degradation.

Table 47-1:
COC range

Langlier Index	Ryznar Index	Puckorius Scaling Index	Water Activity
3	3	3	High
2	4	4	
1	5	5	**Scale forming**
0.5	5.5	5.5	
0.2	5.8	5.8	Low
0	6	6	
-0.2	6.5	6.5	Low
-0.5	7	7	
-1	8	8	**Scale dissolving**
-2	9	9	
-3	10	10	High

Langelier Saturation Index

The Langelier Saturation Index (LSI), is a water chemistry calculation that predicts the scaling or corrosive tendency of water by comparing its actual pH to its theoretical saturation pH, making it a useful indicator for understanding if calcium carbonate will precipitate or dissolve. LSI is most accurate in relatively stable, low-temperature waters and becomes less reliable in high-temperature or high-TDS environments.

Ryznar Stability Index

The Ryznar Stability Index (RSI), interprets similar underlying chemistry but focuses on empirical correlations rather than theoretical saturation, which makes RSI more useful in predicting long-term scaling potential in cooling tower systems and industrial waters. However, it can sometimes over-predict corrosivity in well-buffered system.

Puckorius Scaling Index

The Puckorius Scaling Index (PSI), attempts to refine these models by emphasizing the buffering capacity of water and the expected operating pH of the system. It is particularly useful for recirculating cooling systems where cycles of concentration, alkalinity shifts, and real-world pH behavior diverge from equilibrium assumptions. However, PSI requires accurate field data and loses value if actual system pH deviates significantly from design conditions. DriSteem tends to use this as it best describes the process we work within.

NOTE: LSI offers a theoretical snapshot, RSI delivers a more empirical stability measure, and PSI provides a field-aligned operational perspective. All three indices are approximations and should be used in combination with actual system monitoring, heat-transfer observations, and expert interpretation to ensure reliable control of scale and corrosion.

DRISTEEM WATER SOFTENER SYSTEMS

Water softener systems can be used directly with isothermal humidifiers as well as for producing softened water for input to RO systems.

The softener system needs to be sized for the equipment directly downstream:

- If the equipment is an isothermal humidifier, the capacity of the softener must meet the humidifier requirements.
- If the equipment is an RO system from an isothermal humidifier or high pressure atomization system, the softener needs to meet the needs of the RO system, which is more than the needs of the humidifier. That's because the RO system does not send all the water it processes to the humidifier. It sends only the purified permeate water to the humidifier and sends the concentrate water to the drain. Given this understanding, it is possible for an isothermal humidifier to require a different sized softener based on whether the softener is used directly with the humidifier or via an RO system.

Resin and regeneration

Softener resin can hold a maximum of 30,000 grains of hardness per cubic foot of resin. Generally, it is a good practice to give some sort of safety margin on this number to prevent hardness pass-through under certain conditions. For example, using less salt to regenerate the resin will result in less-than-complete regeneration and, thus, less capacity.

Set DriSteem softeners for a recommended 10 pounds of salt usage per cubic foot of resin. Table 48-1 lists typical resin derate factors based on the softener's salt usage setting.

Table 48-1:
Typical resin derate factors

Salt usage (pounds per cubic foot)	Resin capacity (grains per cubic foot)
15	30,000
10	29,000
7.5	25,700
5	20,000

To initiate a regeneration based on the volume of water, it is necessary to know the hardness. Given the capacity of the resin shown in the table above, one can calculate the gallons of water needed to reach the capacity of the softener. This is the volume that can be programmed into the softener to initiate a regeneration cycle. A timed regeneration is generally used as a backup for volume regeneration. Typically, a timed regeneration should not exceed 14 days, so if the volume is not reached within the timed regeneration period a regeneration will automatically occur at the end of the time period.

Flow rate

Flow rate through a softener is also important. Though rare, a phenomenon called “channeling” can occur under very low flow rates for down flow softeners. This results in lowering the resin capacity of the softener due to water trickling through the resin and not using the full capacity of the total volume of resin.

Humidifiers drawing fill water from an RO storage tank should not cause channeling in upstream water softeners, because the RO storage tank fills at an adequate flow rate. Channeling in the water softener resin does not occur when humidifiers draw water (even at a trickle) from the storage tank. However, if a softener is dedicated for humidifier use, and the humidifier flow requirements are low, channeling can occur.

If channeling occurs, regeneration cycles may need to be more frequent. Another problem with very low flow rates (typically under 0.5 ft/sec) is that the impeller in the water meter might not rotate, so flow is not measured. The solution to unmetered water flow is to set up regeneration intervals based on time instead of volume. Clearly, low-flow conditions are not ideal. If any of the situations described above occur, then it is best to look for alternative water treatment options.

As a rule, the higher the hydraulic or volumetric flow rate is, the larger the pressure drop. An example is the same flow generalities as velocity through a given pipe size. Also, the higher the flow, the more hardness leakage into the effluent.

Alternatives include small, point-of-use softening systems that are designed for low-flow conditions.

Some of DriSteem’s smaller humidifiers have restrictive orifices to reduce flow so as not to quench the boil. Others employ a pulsed-fill approach. These slow-filling humidifiers will need special consideration in order to assure proper water softener performance, especially when using a dedicated softener from DriSteem. If a softener supplies multiple humidifiers, low-flow conditions might be eliminated but could still occur. Even with multiple humidifiers, there could be times when only one humidifier is running at a time.

For best softener performance some companies suggest that the flow rate range through the softener is from 5 to 15 gpm/ft^2 of resin surface. The Dow Chemical Company manufacturers water softener resin and specifies a minimum flow of 2 gpm/ft^2 of resin surface.

SOFTENERS USED WITH RO SYSTEMS

Although RO systems remove about 98% of dissolved solids, some solids still pass through. If a softener is not used to treat the water prior to sending it to the RO system, the pass-through water may contain enough hard water ions to form scale over time. Care must be taken to assure that softened water is supplied to the RO system to prevent equipment from being affected by scale buildup, as scale may affect operation of the RO system, requiring unwanted maintenance. Softeners can also prevent these other scales that are less common in humidifier application.

As explained on page 48, sizing a softener to match an RO system may result in a larger softener than one sized for a downstream device using only softened water.

DRISTEEM RO SYSTEMS

DriSteem manufactures and sells two series of RO systems, the 400 series and the 200 series. Both series use thin film composite (TFC) low-energy membranes, which allow for greater permeate production at colder temperatures where DriSteem products might be used. All membranes from DriSteem are rated for use in DriSteem RO systems at 50 °F (10 °C), where the industry standard for rating RO membranes is at 77 °F (25 °C). The drop in permeate production is quite significant at lower temperatures, so this is why DriSteem has chosen to only offer low-energy membranes in all RO systems.

Table 51-1 shows the impact of temperature on TFC membranes. Note that the table does not represent low-energy membranes, but only typical TFC low-energy membranes. At 50 °F (10 °C). low-energy membranes produce about 50% more permeate than low-energy membranes, dramatically reducing the negative impact due to cold water use. This allows for larger capacities with fewer membranes, which can reduce overall cost and the size of product.

At 50 °F (10 °C) extra-low-energy membranes produce about 50% more permeate than do low-energy membranes, dramatically reducing the negative impact due to cold water use.

Table 51-1:
Permeate flow and temperature

Feed water temperature		Temperature correction factor for thin film	Feed water temperature		Temperature correction factor for thin film	Feed water temperature		Temperature correction factor for thin film
°C	°F		°C	°F		°C	°F	
1	33.8	3.64	18	64.4	1.29	35	95.0	0.73
2	35.6	3.23	19	66.2	1.24	36	96.8	0.71
3	[illegible]	[illegible]	[illegible]	68.0	1.19	37	98.4	0.69
4	[illegible]	[illegible]	[illegible]	69.8	1.15	38	100.4	0.67
5	[illegible]	[illegible]	[illegible]	71.6	1.11	39	102.2	0.65
6	[illegible]	[illegible]	[illegible]	73.4	1.08	40	104.0	0.63
7	44.6	2.22	24	75.2	1.04	41	105.8	0.61
8	46.4	2.11	25	77.0	1.00	42	107.6	0.60
9	48.2	2.00	26	78.8	0.97	43	109.4	0.58
10	50.0	1.89	27	80.6	0.94	44	111.2	0.56
11	51.8	1.78	28	82.4	0.91	45	113.0	0.54
12	53.6	1.68	29	84.2	0.88	46	114.8	0.53
13	55.4	1.61	30	86.0	0.85	47	116.6	0.51
14	57.2	1.54	31	87.8	0.83	48	118.4	0.49
15	59.0	1.47	32	89.6	0.80	49	120.2	0.47
16	60.8	1.39	33	91.4	0.77	50	122.0	0.46
17	62.6	1.34	34	93.2	0.75			

NOTE: This table is dependent on the membrane used, and should be used only for a guideline on how temperature effects permeate production. Other factors including mechanical design and water quality will affect the RO system performance.

Temperature correction factor indicates almost double the capacity at 77 °F (25 °C), compared to at 50 °F (10 °C).

TFC membranes are susceptible to oxidation from chlorine in the water, so chlorine must be removed from the supply water prior to the water coming in contact with the membranes. A carbon filter is used to remove the chlorine. For small systems, a cartridge-type carbon filter can be used and changed as needed. Larger systems use tank style carbon filters/dechlorinators that are sized comparable to softeners they are used with in order to maintain similar flows.

DriSteem RO systems come with a pressurized storage tank as standard equipment. An atmospheric storage system with UV light and pump is also available on a skid as an option. DriSteem's Vapor-logic controller is used to control every system.

400 Series RO systems are designed for larger loads from 250 pph to 5500 pph and use from one to twelve 4″ x 40″ low-energy membranes.

200 Series RO systems are designed for smaller loads up to 300 pph and use from one to three 2½″ x 21″ low-energy membranes.

DEIONIZATION (DI) WATER TREATMENT

Deionization is a form of water purification that removes dissolved ionic compounds—such as calcium, magnesium, sodium, chlorides, sulfates, and silica—through the use of ion exchange resins. These resins exchange hydrogen and hydroxide ions for cations and anions in the water, respectively, resulting in ultrapure water with minimal conductivity. Deionized water is commonly used in applications requiring high water quality standards, such as in laboratory settings, electronics manufacturing, and increasingly, in commercial and industrial HVAC systems—particularly for steam humidification.

Several market solutions for deionization are available. Cartridge-based systems are typically used for smaller applications or point-of-use systems, offering simplicity and ease of replacement. Serviceable DI bottles, which are exchanged and regenerated offsite by a water service provider, are widely used for mid-sized systems where a high purity water source is needed without the investment in permanent infrastructure. For large-scale or continuous operations, onsite regeneration systems can be employed, allowing for continuous use and recharging of resin beds through acid and caustic chemical handling—ideal for high-demand facilities looking for long-term cost control.

The benefits of DI water in HVAC systems, particularly in steam humidifiers, are substantial. By removing scaling ions such as calcium and magnesium, deionized water prevents the formation of mineral deposits on heating elements, nozzles, and distribution piping. This not only prolongs equipment life but significantly reduces maintenance frequency and downtime. Additionally, the absence of corrosive anions like chlorides and sulfates lowers the risk of corrosion in downstream components, improving system reliability. Overall, using deionized water helps maximize the uptime of humidifiers and other sensitive equipment, while supporting the consistent delivery of clean steam or mist into the conditioned space. Proper system sizing and monitoring of resin exhaustion are essential to maintaining consistent performance and water quality.

TESTING THE WATER QUALITY

Water quality is an important factor in RO system product lifespan:

- Membranes can scale up or plug up in RO systems treating water that is high in TDS.
- Membranes can oxidize and fail in RO systems treating water containing chlorides.

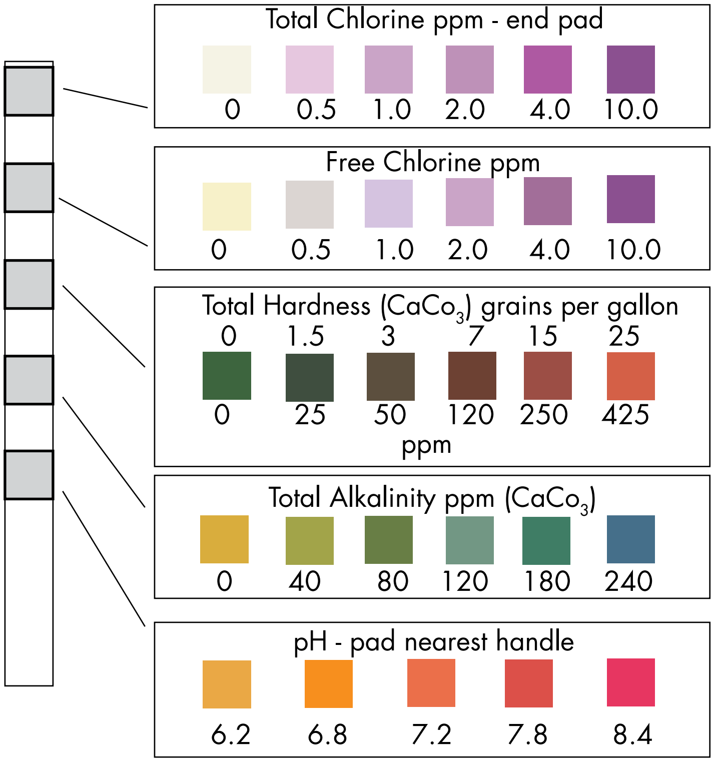
Knowing what to test for is also important. Typical tests of municipal water include the following:

- Chlorides
- Alkalinity (carbonate)
- TDS
- Total hardness
- pH
- Conductivity

Page 54 provides instructions for obtaining and properly using water quality test strips.

WATER QUALITY TEST STRIPS

- Carbon filters in the water treatment system should be changed regularly to maintain proper pressure and flow and water quality.
- The carbon filter removes chlorine. Change the carbon filter when chlorine from supply water starts to pass through. Check regularly for chlorine pass through.
- To check for chlorine, obtain a water sample from the RO inlet line and test the water. If chlorine is present, change the carbon filter and record the interval to estimate the next carbon filter change.
- For best results, test water chlorine every two weeks. If not checking the carbon efficiency, a preventative maintenance change out every six months is advised.
- To order Water Quality Test Strips, contact your local DriSteem rep, or call 1-800-328-4447.



DIRECTIONS:

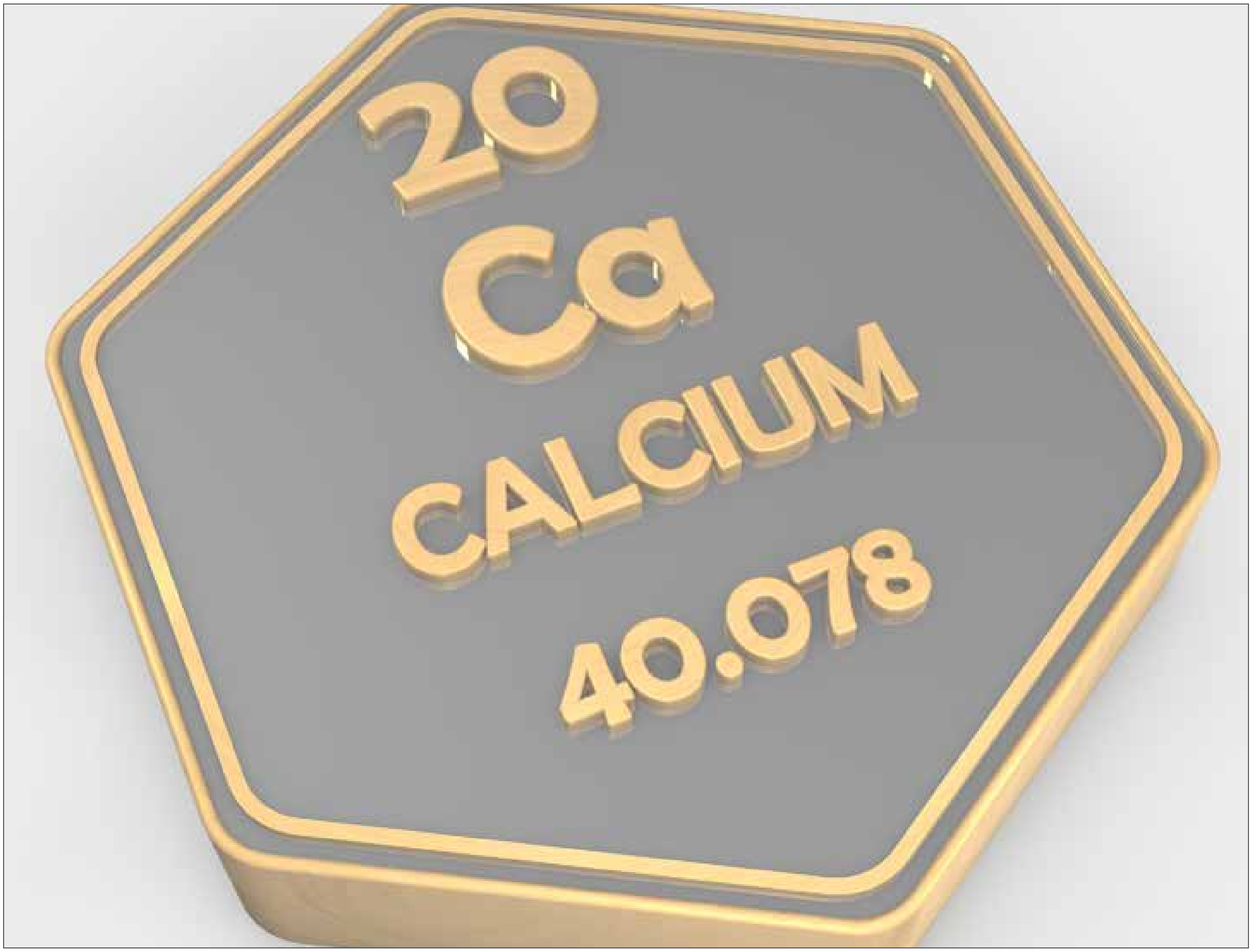
1. Dip entire strip into water for 1 second (or pass under water stream), remove. Do not shake excess water from the test strip. Hold the strip for 30 seconds.
2. Compare TOTAL HARDNESS, TOTAL ALKALINITY and pH pads to color chart to the left.
3. Dip strip into the water again and move back and forth for 30 seconds (or hold two chlorine pads under water stream for 10 seconds).
4. Compare CHLORINE pads to color chart to the left.
5. Track results in the chart below.
6. Change the carbon cartridge filter once chlorine is detected in the concentrate water of the water treatment system.

Table 54-1:
Water quality test log

Date tested	Total chlorine ppm	Free chlorine ppm	Total hardness	Total alkalinity	pH
Week 1 ________					
Week 3 ________					
Week 5 ________					
Week 7 ________					
Week 9 ________					
Week 11 ________					

Notes

Section VI: Terminology



ALKALINITY

The capacity water has to neutralize an acid.

Made up from ionic species such as CO_3-2 (carbonate), HCO_3- (bicarbonate), and OH-.

These accept (or give off) H+ ions, stabilizing the pH of the water solution when acidic or basic chemicals (buffers) are added.

These ions are the substances that account for the formation of scale with calcium and magnesium.

ATOM

The basic unit of matter

The term "atom" is derived from the Greek "atomos" which was meant to describe the smallest indivisible particle for any given substance. Obviously, we have since learned how to split the atom with a process called nuclear fission.

An atom is made up of a dense, central nucleus which contains protons (positively charged) and neutrons (neutral) and surrounded by a "cloud" of electrons (negatively charged).

Note: The nucleus of a hydrogen atom contains one proton and no neutrons.

A neutral (uncharged) atom has the same number of protons as electrons.

ATOMIC WEIGHT

Every individual atom has a specific weight that corresponds to the number of protons and neutrons that make up that atom. Electrons have very little weight and contribute essentially nothing to the atomic weight. The atomic weight for any atom can be found on the Periodic Table of the Elements. For example, calcium has an atomic weight of 40. There are 20 protons and 20 neutrons in the nucleus of a calcium atom. So, the atomic weight for calcium is 40.

ANION

Negatively charged ion. The number of electrons is greater than the number of protons.

CATION

Positively charged ion. The number of protons is greater than the number of electrons.

COVALENT BOND

Unlike ionic bonds where the participants are anions and cations and have a full charge, (the anions take on electrons giving them negative charges and the cations give up electrons giving them positive charges).

Covalent bonds exist by sharing two electrons between two atoms. Neither atom has a full positive or negative charge. However, electrons making up a covalent bond may or may not spend more time nearer to one atom than the other. If they do, it will result in partial negative and partial positive characteristics making that bond polar, like a magnet. This is the case in a water molecule where there are two covalent bonds between hydrogen and oxygen atoms.

HARDNESS

Technically, the sum of all polyvalent cations (positive ions).

Practically, the sum of Ca+2 and Mg+2 ions (these are usually the predominant constituents). Ca+2 typically accounts for 70 – 90%.

Typically reported as $CaCO_3$ equivalents using equivalent weights of each species.

Expressed as mg/l or ppm, grains (ppm/17.1), French degrees (ppm/10), German degrees (ppm/17.8), Clark degrees (ppm/14.3)

ION

A charged atom, or atom in which the total number of protons and electrons are not equal.

IONIC BOND

The strong electrostatic force that holds positive and negative ions together in a lattice structure.

Positives and negatives attract each other. In chemistry this attraction occurs between positive and negative ions that are held together by this electrostatic force. When several of the same positive and negative ions come together, they form a lattice structure that is held together by this electrostatic force.

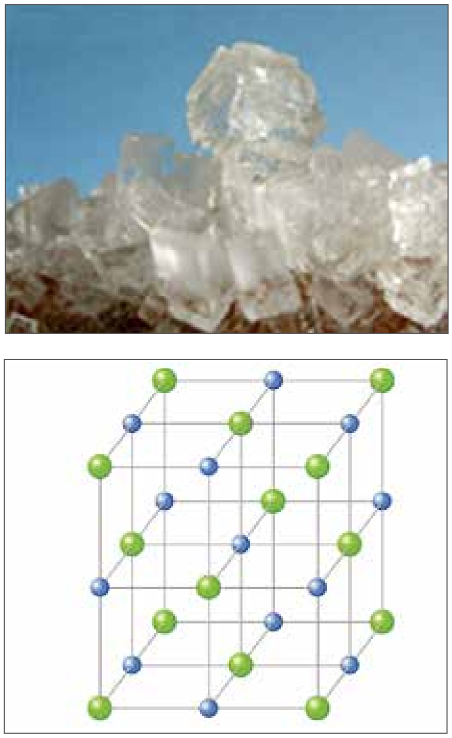
IONIC COMPOUND

A chemical compound in which positive and negative ions are held together in a lattice structure by ionic bonds.

The lattice structure is made up of positively charged ions and negatively charged ions.

Sodium chloride (table salt), shown in Figure 59-1, is an ionic compound. The sodium ions have a positive charge and the chloride ions have a negative charge.

FIGURE 59-1: SODIUM CHLORIDE



MOLE

Term similar to a dozen except that the number of things in a dozen is 12, and the number of things in a mole is 6.023×10^{23}. Avagadro figured out that this is the number of atoms (or molecules) in the atomic (molecular) weight of that substance expressed in grams. For example, the molecular weight of water is 18 so, a mole of water molecules has a weight of 18 grams (18 g/mole).

MOLECULE

At least two atoms held together by covalent bonds. Molecules are neutral because they do not have a net charge like ions. Water (H_2O) is a molecule.

MOLECULAR WEIGHT

Molecular weight is determined by adding the atomic weights of each element in a molecule. The atomic weight for hydrogen is 1 (its nucleus contains only 1 proton), and oxygen's atomic weight is 16 (its nucleus contains 8 protons and 8 neutrons for a total of 16). So, H_2O has a molecular weight of 18.

PH

pH is a measure of the acid or base levels of the water.

H+ is acidic and OH- is basic.

The pH range is 0 to 14. The number is technically the negative $\log_{10}$ of the H+ ion concentration.

7 is neutral (hydrogen ions and hydroxyl ions are equal).

> 7 is basic (hydroxyl ions are greater than hydrogen ions).

< 7 is acidic (hydrogen ions are greater than the hydroxyl ions).

POLYVALENT ION

An ion that has a charge greater than one.

TOTAL DISSOLVED SOLIDS (TDS)

All substances that are dissolved in the water.

Principal TDS contributors: calcium and magnesium carbonates and bicarbonates (principal scale forming substances) among others.

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