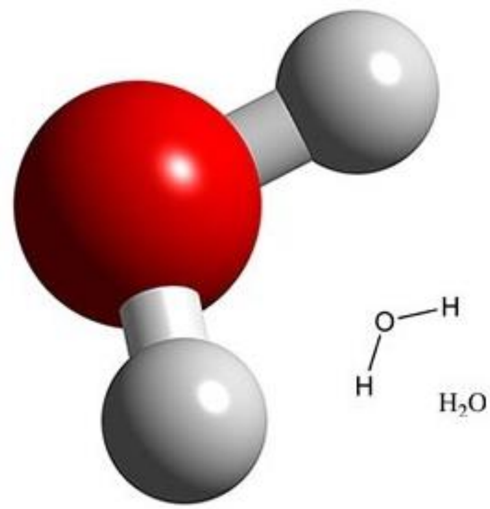
Industrial Water Treatment
Part One: An Overview

An ADF Engineering white paper written by Rakesh Patel, P.E.

Background

Water in its purest state has no color, taste, or smell, and consists only of two hydrogen molecules and one oxygen molecule, shaped roughly like Mickey Mouse's head. Water is often called a universal solvent due to its ability to dissolve almost every naturally-occurring element on earth. This ability to dissolve substances is a major benefit for human use, but it also poses a great challenge for industrial and process usage. Dissolved minerals can cause scale deposition and corrosion on equipment and piping, poor taste and odors, toxicity, and can harbor viruses, bacteria and other parasites that thrive in water systems. These are just some of the reasons that water used in industrial applications almost always goes through some type of onsite treatment before it is used.



Industrial Water Sources in The United States

Industrial water is delivered from either a public supplier such as a municipal water treatment plant or is self-supplied through lakes, rivers, or underground wells when needed in larger quantities. Per the U.S. Geological Society, roughly 90% of all industrial water is self-supplied, with 83% of that coming from surface water sources such as rivers, lakes and oceans, while the remainder comes from ground water. More specifically, fresh water from lakes and rivers accounts for more than 90% of surface water withdrawals.

1. **Surface Water:** Surface water quality depends on the type of water shed, eutrophication, climate conditions, agricultural practices, dams, and pollution in surrounding regions. Surface water sources are replenished by rain and snow, and as water runs along the ground it collects suspended particles of dirt, sand, leaves, nutrients, and variety of life forms such as algae, fungi, bacteria, and other organic matter. Surface water quality is also greatly impacted by seasonal changes throughout the year, with occurrences like sudden rainstorms quickly and dramatically changing in the composition of source water. Surface water chemistry also varies over longer periods of time due to cycles of floods and droughts. This much variability needs careful consideration during the design of industrial water treatment plants.

2. **Well Water:** Water from wells typically has uniform quality year round, allowing for simple, consistent water treatment processes that can be utilized year round. However, excessive concentrations of dissolved minerals such as calcium, magnesium, carbonates, iron, chloride, manganese, and sulfides do exist in well water and could require an expensive treatment plan.

3. **Sea Water:** A small percentage of industrial facilities use sea water, primarily for cooling water needs. Desalinating sea water is an energy intensive, expensive process but fresh water scarcity may dictate usage of sea water despite the challenges that have to be overcome.

The table below gives a quick comparison between surface that and ground water for common contaminants that need treatment.

Impurity	Surface Water	Ground Water
Turbidity (ability of light to pass through)	High	Low
Dissolved minerals	Moderate	High
Dissolved Gases	Moderate	Low
Organics & Microorganisms	High	Low
Constituent Variability	Excessive	Low

Water Impurities
The impurities in untreated source water can be broadly categorized into four different types.

1. **Organic Matter:** Organic constituents occur in water from plant matter, decaying organisms, farm waste, industrial effluent, and domestic sewage. Organics deplete the available dissolved oxygen in water and increase turbidity. Organic chemicals are made up of naturally occurring carbon, hydrogen, nitrogen, and oxygen, but may also contain sulfur, phosphorous, chlorine, iodine, and bromine discharged from industrial sources. Organics cause disagreeable tastes and odors in drinking water, some of the industrial organics are well known carcinogens. Organics are mostly present as suspended solids in water and need to be removed using appropriate filtration techniques.

2. **Dissolved Gases:** Oxygen, carbon dioxide, and hydrogen sulfide are the most common gases that exist naturally in water. Rain water stored in clouds is one of the purest states of water but as rain travels through the atmosphere it absorbs gases and other impurities, with cold water having higher concentrations of dissolved gases than warm water. The extent of treatment to remove dissolved gases depends on end user's requirements. Water with hydrogen sulfide smells like rotten eggs and municipal treatment plants have to remove it from drinking water to make it palatable. Dissolved oxygen is vital to sustain aquatic life in fresh water bodies but it increases the rate of corrosion in boilers and hot water storage tanks dramatically and must be stripped before usage. The presence of dissolved gases also adversely impacts the effectiveness of removing other impurities in water treatment plants. Dissolved gases are removed using mechanical deaerators, membranes, aeration, chemical oxidation reduction, and steam stripping.

3. **Dissolved Minerals:** The chemical characteristics of water is greatly influenced by the presence of dissolved minerals, which naturally dissolve as water slowly passes through rocks and sediments in the Earth's crust. Hardness and scale build up from calcium and magnesium are

the most well-known dissolved minerals but other minerals such as potassium, sodium, bicarbonates, chlorides, silica, and sulfates are also fairly common.

4. **Heavy Metals:** Metallic chemical elements with relatively high density that are toxic at even very low concentrations are commonly referred to as heavy metals. Mercury, cadmium, arsenic, copper, chromium and lead are well known heavy metals present in water. These elements are natural components of the Earth's crust and are dissolved by water as it passes through sediments. Heavy metals do not degrade or destroy easily and can bioaccumulate in human bodies causing chronic poisoning. Heavy metals leaching from industrial waste, landfills, vehicle emissions, fertilizers, and paints can exacerbate the concentration of these elements in surface water sources, so must be treated using membrane technology, ion exchange, and chemical precipitation.

Effects on Processing

Though there are countless minerals and impurities found in all incoming water sources, most major problems can be traced back to a handful of culprits. Scaling and corrosion are the biggest concerns from presence of dissolved minerals in water. Scaling occurs when mineral deposits build up into a salt-like residue, which then enables a chemical reaction within pipes and tanks that leads to localized, uneven corrosion. Just a small amount of scaling can increase energy costs due to loss of proper heat conduction, until widespread scaling eventually builds up enough to cause corrosive leaking and drainage problems. Often, these conditions necessitate a costly, unplanned replacement of piping and storage systems.

The table below captures the adverse effect of many of these minerals on water storage, treatment, and distribution systems.

Impurity	Common Name	Effect on Processing Systems
Calcium Carbonate	Chalk; Limestone	Soft Scale
Calcium Sulfate	Gypsum; Plaster of Paris	Hard Scale
Calcium Chloride	Ice Bite	Corrosion
Magnesium Sulphate	Magnesite	Corrosion
Sodium Chloride	Epsom Salt	Galvanic Corrosion
Sodium Carbonate	Soda; Washing Soda	Alkalinity
Sodium Bicarbonate	Baking Soda	Priming; Foaming
Sodium Hydroxide	Caustic Soda; Lye	Alkalinity; Embrittlement
Sodium Sulfate	Glauber Salt	Alkalinity
Silicon Dioxide	Silica	Hard Scale

Types of Industrial Process Water

To prevent major problems like scaling, corrosion, and microbiological growth, you need an optimized water processing and treatment plan. Water can be treated to meet several grades of purity, but all filtration methods are based on a simple idea – the water must pass through increasingly stringent filters to catch smaller and smaller particulates that effect water purity.

1. **Filtered Water:** Raw water contains suspended impurities such as dirt, organics, iron and other impurities that are undesirable for industrial process use. The allowable limit for suspended particles in treated water, usually expressed in parts per million (ppm), dictates the water treatment technology deployed for filtering a given raw water stream. Sand filters have been used for centuries and are very effective at removing coarse particles. Modern water treatment equipment use a variety of natural and manmade porous media for filtration. Cartridge and bag filters are fairly inexpensive and can filter out particles as small as 1 micro meter in nominal size. Membrane-based Ultra and Nano filters can be used to remove impurities as small as 1/100 of a micro meter, but such equipment is expensive and energy intensive. Chemical coagulation and flocculation agents are routinely used to coalesce smaller particles into larger sizes before passing the water through filtration media. Filtered water is primarily used for cleaning, drinking and other sanitary purposes.

2. **Softened Water:** Dissolved calcium and magnesium salts are primarily responsible for scale build up in pipes and tanks, which impacts the available flow area, heat exchange capacity, and can ultimately destroy metallic pipes and tanks. Water is classified as hard if these minerals are present at a concentration greater than 75 parts per million as $CaCO_3$. The solubility of different elements in water is generally temperature-dependent and for most salts, the solubility increases with temperature.

   Hardness elements, on the contrary, has inverse solubility which means calcium and magnesium drops out of water solution more readily as the water temperature increases. This property is especially detrimental to industrial hot water systems such as boilers, as the rate of scaling increases significantly in these high temperature systems. The primary methods used for water softening are chemical precipitation, sodium cycle resin ion exchange, and Nano filtration.

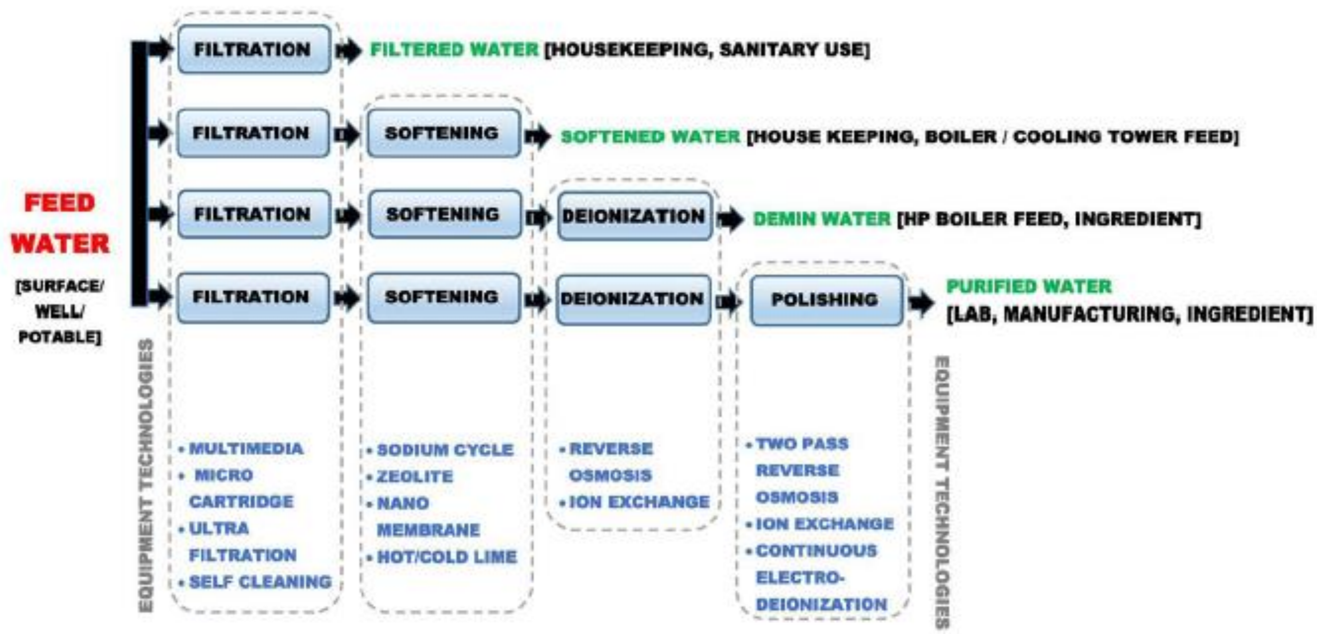
   Chemical precipitation water softening is based on the fact that the solubility of calcium and magnesium salts is very low in water with a pH greater than 9. The dissolved calcium and magnesium drops out of the water in the form of solid calcium carbonate and magnesium hydroxide. The precipitated solids are either gravity separated or filtered out fairly easily. Calcium hydroxide (lime) is added to remove carbonate hardness while sodium carbonate (soda ash) is used to remove sulfate hardness. Water is sometime heated in the range of 120 - 140°F in a process called warm lime softening to more effectively remove hardness from water source that is very hard or if higher quality effluent treated water is required. Softened water is mostly used for utilities such as cooling towers and boiler feeds, but is also used frequently as cooling water and as ingredient water.

3. **Demineralized Water:** Demineralization is used to remove the majority of inorganic salts from water by the process of ion exchange or reverse osmosis. Demin water is primarily used to feed high pressure boilers, as an ingredient in food and pharmaceutical manufacturing, for lab uses and for washing chips in microelectronics industries.

Ion exchange demineralizer equipment typically uses two types of ion exchange resins. The cation resin (positive charge) converts dissolved salts to their corresponding acids and the anion resin (negative charge) removes these acids through adsorption. Mixed bed ion exchange columns are used to produce a high purity water with minimal amounts of dissolved salts.

Reverse osmosis removes dissolved ions from water by forcing it through a semipermeable membrane using high pressure. A semipermeable membrane allows certain molecules to pass (based on atomic size) but not others. Osmosis is a naturally occurring phenomenon where a weaker solution will migrate through a semipermeable membrane to a stronger solution on the other side to equalize the salt concentration in both solutions. Reverse osmosis essentially reverses this natural phenomenon by driving water from stronger solution (feed water) to weaker solution (treated water) using high pressure to work against natural osmotic pressure. The dissolved salts present in feed water do not pass through the membranes. Concentrated salts are continually rejected through a split stream. Reverse osmosis can produce super low conductivity water with minimal amounts of inorganic salts with a water purity level that is comparable to ion exchange process but at significantly lower costs.

4. **Purified Water:** The demineralized water can be further refined to reduce the amounts of impurities in water to a magnitude of only a few parts per billion. Multi pass reverse osmosis, multi pass ion exchange and advance distillation techniques are used to purify water to such a level. Purified water requires special piping and storage tank to prevent contamination during conveyance and storage. Requirements and treatment specifications are often driven by regulatory requirements when used in pharmaceutical industries for applications such as manufacturing of sterile injections. Purified water is also used for things like laser cutting and laboratory testing.



Various industrial water types and treatment technologies used to produce the treated water.

What it Means to You

In your facility, having the right process water treatment design is essential to the quality and consistency of your production. From the water you use in manufacturing your products to the water you use for cleaning and sanitization, it is important to have the right treatments applied at the right steps of your processes to yield the best benefits and efficiencies.

This white paper will be followed by an Industrial Water Treatment series in 2017.

References

1. http://water.usgs.gov/
2. Betz Handbook of Industrial Water Conditioning

About ADF Engineering

ADF Engineering is a leading provider of process and facility engineering solutions. We have a reputation for providing cutting edge, high quality and cost effective engineering solutions to industrial clients throughout the United States, as well as internationally. We understand that every project is unique, therefore, having a strong set of core competencies combined with experience is essential to our success. ADF assembled a sizeable team of extremely talented engineers in all critical engineering disciplines at three strategic U.S. locations. Contact ADF Engineering at (937) 847-2700, or visit us on the web at www.adfengineering.com.

About the Author

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