

# Analytical Measurements for Makeup Water in Power Plants

*Improve Plant Efficiency and Reduce Capital Costs*



## Background

Power plants that burn fossil fuels or produce nuclear reactions for the generation of electricity require almost 150 billion gallons of water per day for steam production and cooling purposes. In order to keep these plants as efficient as possible, the quality of the water is vital. Ultra-high-purity water is required for makeup in highpressure steam-generating systems. However, relatively high concentrations of impurities can be tolerated in makeup water for open recirculating cooling systems. These plants require a constant intake of water to replace water lost through sampling systems, steam losses, evaporation from cooling, and blowdown.

## The Problem

Sources of water can vary from the local water authority to a local river to a nearby ocean. Each water source has unique characteristics, including organic growth, dissolved minerals, and chemical contaminants. Each of these inherent characteristics/contaminants can cause difficulties in a power plant. The water must be treated to minimize potential problems, since these problems often result in either reduction of plant efficiency or large capital costs. Table 1 lists a number of the characteristics and contaminants, the difficulties that they can cause, and the means of treatment for each type. The process of preparing water for use by a plant is known as “makeup water treatment.” Analytical measurements such as conductivity, ORP, sodium ion, and pH play an important part in ensuring that the various components necessary for water purification are operating at maximum efficiency at all times.

## The Pretreatment Stage

The first stage of treating the water can vary significantly, depending upon the source of the water. This stage, typically known as pretreatment, usually consists of chlorination, multimedia filters, and carbon filters. The purpose of this stage of treatment is to remove most of the organics, suspended solids, color, turbidity, iron, and manganese present in the water. The pretreatment stage must also ensure that the water has the best characteristics and minimal contaminants to ensure optimal efficiency in the later stages.

Water can be a breeding ground for many types of microorganisms, such as algae, fungi, or bacteria, as well as many types of macroorganisms, such as zebra mussels, Asiatic clams, or barnacles. These organisms create quite a difficulty for power plants, which must purify the water to ensure that clogging is minimized and heat transfer is maximized. Historically, the micro- and macroorganisms have been controlled by adding an oxidizing biocide, such as chlorine, bromine, or ozone, to effectively limit the microbial activity.

| <b>Table 1: Common Impurities in Water and Means of Treatment</b>   |   |   |
|---|---|---|
| <b>Chemical/Characteristic</b>  | <b>Difficulties Caused</b>  | <b>Means of Treatment</b>   |
| <b>Turbidity</b>  | Imparts unsightly appearance to water. Deposits in water lines, process equipment, etc. Interferes with most process uses.  | Coagulation, settling, and filtration.  |
| <b>Color</b>  | May cause foaming in boilers. Hinders precipitation methods such as iron removal and softening.   | Coagulation and filtration. Chlorination. Absorption by activated carbon.   |
| <b>Hardness</b><br>Calcium and magnesium salts<br>Expressed as CaCO <sub>3</sub>  | Chief source of scale in heat exchange equipment, boilers, pipelines, etc.  | Softening. Demineralization. Internal boiler water treatment. Surfaceactive agents.   |
| <b>Alkalinity</b><br>Bicarbonates (HCO <sub>3</sub> ),<br>Carbonates (CO <sub>3</sub> ),<br>and Hydrates (OH)<br>Expressed as CaCO <sub>3</sub> | Foaming and carryover of solids with steam. Embrittlement of boiler steel. Bicarbonates and carbonates produce CO <sub>3</sub> in steam, a source of corrosion in condensate lines. | Lime and lime-soda softening. Acid treatment. Hydrogen zeolite softening. Demineralization. Dealkalization by anion exchange. |
| <b>Free Mineral Acid</b><br>H <sub>2</sub> SO <sub>4</sub> , HCl, etc.<br>Expressed as CaCO <sub>3</sub>  | Corrosion.  | Neutralization with alkalis.  |
| <b>Carbon Dioxide (CO<sub>2</sub>)</b>  | Corrosion in water lines, particularly in steam and condensate lines.   | Aeration. Deaeration. Neutralization with alkalis.  |
| <b>pH</b><br>Hydrogen ion concentration, $\text{pH} = \log \frac{1}{[\text{H}^+]}$  | pH varies according to acidic or alkaline solids in water. Most natural water has a pH of 6.0 to 8.0.   | pH can be increased by alkalis and decreased by acids.  |
| <b>Sulfate (SO<sub>4</sub><sup>2-</sup>)</b>  | Adds to solids content of water, but in itself is not usually significant. Combines with calcium to form calcium sulfate scale.   | Demineralization.   |
| <b>Chloride (Cl<sup>-</sup>)</b>  | Adds to solids content and increases corrosive character of water.  | Demineralization.   |

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| <b>Chemical/Characteristic</b>  | <b>Difficulties Caused</b>   | <b>Means of Treatment</b>  |
| <b>Nitrate</b> ( $\text{NO}_3^-$ )                                      | Adds to solids content, but is not usually significant industrially. Useful for control of boiler metal embrittlement.   | Demineralization.  |
| <b>Silica</b> ( $\text{SiO}_2$ )  | Scale in boiler and cooling water systems. Insoluble turbine blade deposits because of silica vaporization.  | Hot process removal with magnesium salts. Absorption by highly basic anion exchange resins, in conjunction with demineralization.            |
| <b>Iron</b><br>$\text{Fe}^{++}$ (ferrous)<br>$\text{Fe}^{+++}$ (ferric) | Discolors water on precipitation. Source of deposits in water lines, boilers, etc.   | Aeration. Coagulation and filtration. Lime softening. Cation exchange. Contact filtration.   |
| <b>Manganese</b> ( $\text{Mn}^{++}$ )                                   | Same as iron.  | Same as iron.  |
| <b>Oxygen</b> ( $\text{O}_2$ )  | Corrosion of water lines, heat exchange equipment, boilers, return lines, etc.   | Deaeration. Sodium sulfite. Corrosion inhibitors.  |
| <b>Hydrogen Sulfide</b> ( $\text{H}_2\text{S}$ )                        | Cause of "rotten egg" odor. Corrosion.   | Aeration. Chlorination. Highly basic anion exchange.   |
| <b>Ammonia</b> ( $\text{NH}_3$ )  | Corrosion of copper and zinc alloys by formation of complex soluble ion.   | Cation exchange with hydrogen zeolite. Chlorination. Deaeration.   |
| <b>Dissolved Solids</b>   | This is a measurement of total amount of dissolved matter, determined by evaporation. High concentrations of dissolved solids are objectionable because of foaming in boilers. | Various softening processes, such as lime softening and cation exchange by hydrogen zeolite, will reduce dissolved solids. Demineralization. |
| <b>Suspended Solids</b>   | This is a measurement of undissolved matter, determined gravimetrically. Suspended solids cause deposits in heat exchange equipment, boilers, water lines, etc.                | Subsidence. Filtration, usually preceded by coagulation and settling.  |

A typical makeup water system (Figure 1) will treat raw water entering the system with a biocide. The typical oxidant used is chlorine, although sodium hypochlorite is finding more widespread use in smaller systems. The chlorination is done as early as possible to immediately reduce organic growth to acceptable limits.

A large residual is typically maintained as long as possible in order to discourage any further growth. This process is called hyperchlorination. Unfortunately, the amount of oxidant feed necessary can shift with changes in flow, raw water organism content, or even varying oxidant levels already present if the raw water is from a municipality.

## Analytical Monitoring for Pretreatment

The basis for traditional chlorination control has been laboratory screening procedures coupled with maintaining a residual level of the biocide to ensure the maximum kill rate. This method has typically resulted in a periodic underfeed, leading to organism growth, or overfeed, adding unneeded expense and potential component damage. The measurement of oxidation-reduction potential (ORP) has been shown to consistently control the biocide addition, effectively destroying the organisms while maximizing cost savings and component life. An ORP feedback loop can be placed into the makeup water system where oxidant addition is required, typically at the raw water inlet point (ORP #1 in Figure 1). Typical control points are site specific, but usually reside within the +600 mV range or higher for the oxidant addition. Control points should be determined by lab analysis for microbiological activity and level of oxidant present.

## Softener Stage

Calcium and magnesium are usually present in all waters. Essentially, water hardness is due to calcium and magnesium ions. Softening of the water is the process of removing these water hardness ions to improve water quality in order to reduce the tendency to scale or foul process equipment. The softening process is typically the next stage in the makeup water treatment process after the pretreatment (Figure 1).

There are two methods used for softening a plant's feedwater. The first method, known as the lime-soda process, involves precipitation of calcium and magnesium as their carbonate and hydroxide forms by the use of calcium hydroxide and sodium carbonate, respectively. However, this method increases the total dissolved solids in the water. The second method, which is more commonly used, performs the softening by exchanging the hardness ions for sodium ions. This ion exchange is a widely accepted method of eliminating impurity ions. The process consists of placing chemically processed resin beads of varying materials into a tightly cross-linked network known as a bed (Figure 2). The resin beads are then chemically treated to produce cationic (positive) or anionic (negative) sites where the targeted ions can become attached. In the case of sodium cation exchange, the hardness ions of magnesium and calcium are exchanged for sodium ions.

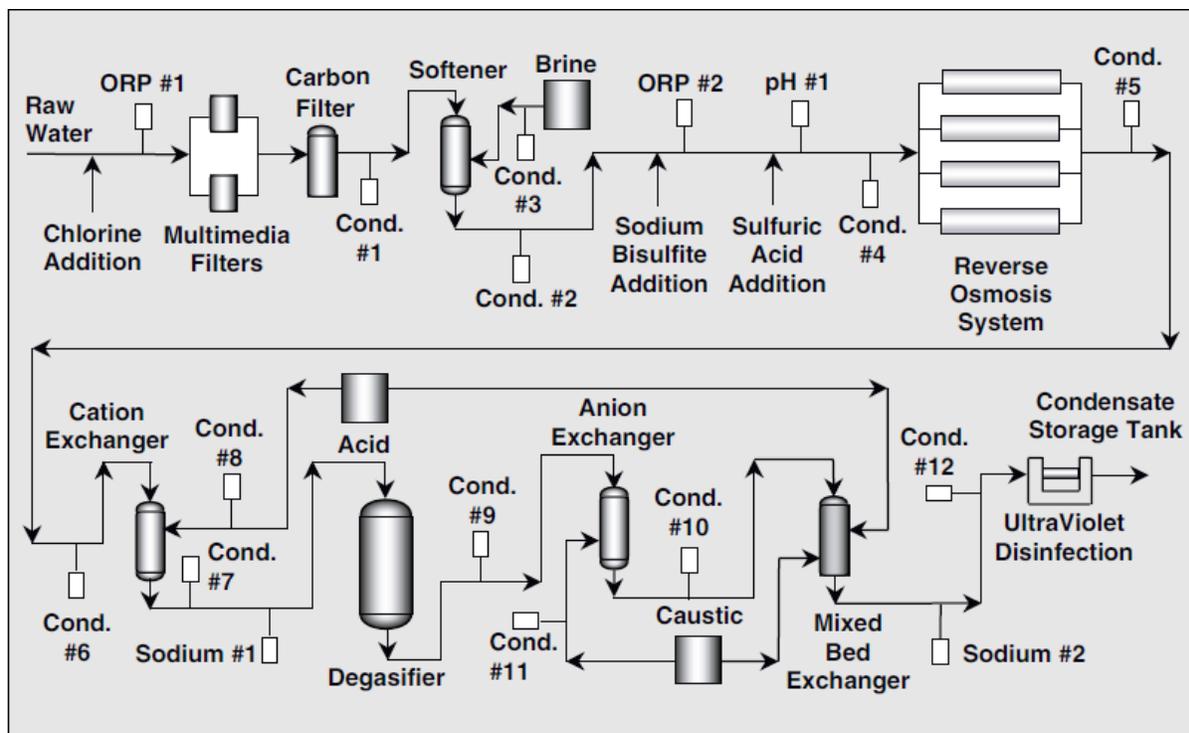


Figure 1: Makeup Water Process Diagram with Measurement Locations

After a period of time, the ion exchange resin becomes spent and must be regenerated. This regeneration process typically consists of three steps. The first step involves a strong backwash of flow through the bed to remove any foreign particulates as well as to loosen and regrade the bed. The second step involves a recharging of the resin beads with a sodium chloride solution, typically referred to as brine, to restore the sodium driving force for the ion exchange. The third step consists of a rinse with raw water to wash away excess brine along with the displaced calcium and magnesium.

Since the water softening operation can provide opportunity for proliferation of organisms in the water processing system, the softening process is usually done after the chlorine addition, ultraviolet light treatment, and multimedia filtering to minimize organism growth (Figure 1). For the same reason, the softening process will typically precede dechlorination of the feedwater in order to prolong the biocidal action of the chlorine throughout the makeup water as long as possible. The substitution of sodium ions for the hardness ions will make subsequent deionization by ion exchange more difficult, since sodium ions are more difficult to remove than other ions. The cation exchanger, which is discussed later, can remove the calcium and magnesium ions in place of the softener. However, ion exchange softening is used prior to reverse osmosis systems to prevent fouling of the membranes.

### Analytical Monitoring at the Softener Stage

Many ion exchange softeners are regenerated based on time or totalized water flow. However, this is a predictive technique with no feedback, and does not take into account variation in hardness of the water supply. The most sensitive method would be to monitor the hardness of the treated water, but continuous instrumentation for this is costly and maintenance-intensive. A more economical method is to monitor the conductivity ratio across the softener (Figure 1). Cond. #1 can be used to determine whether the inlet water's hardness is deviating from normal conductivity levels. Since sodium is typically more conductive than the hardness minerals it replaces; a higher conductivity at the outlet (Cond. #2) is expected. As the ratio of Cond. #2 to Cond. #1 approaches unity, hardness ions are breaking through and regeneration is needed. Typical ranges for the ratio measurement will be from 1 to 2. Brine concentration is important for economical and consistent regeneration. This concentration of the sodium chloride solution can be monitored by conductivity as well. The range can vary significantly depending upon the resin type, but ranges of 5 to 25 percent are common.

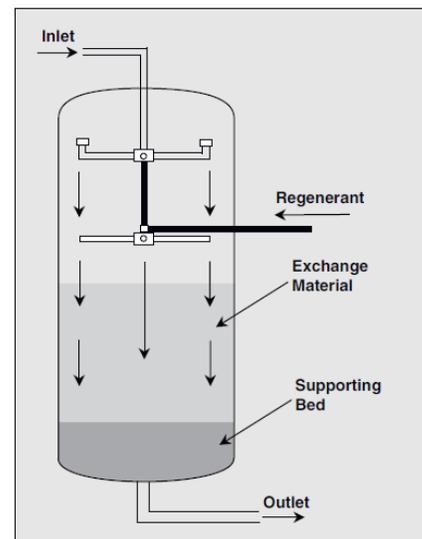


Figure 2: Ion Exchange Bed Diagram

### Reverse Osmosis Stage

When a semipermeable membrane separates solutions of different concentrations, the natural flow of the more diluted water to the more concentrated water is called osmosis. In water purification by reverse osmosis (RO), sufficient pressure is applied to the concentrated side to force the water to flow through the membrane in the other direction (Figure 3). The water is purified, since dissolved solids cannot easily pass through the membrane. Reverse osmosis can remove 85 to 98 percent of dissolved salts in one pass. Multiple passes can improve purity. The purified water is called permeate, or product. A continuous flow of the concentrated water is discharged to prevent an excessive buildup and is called concentrate, or reject.

Today power plants are increasingly using reverse osmosis systems for a number of reasons. They do not use hazardous regeneration chemicals, do not require large amounts of energy, and are easy to maintain and service. Since the ion exchange systems must be regenerated often because of the level of contaminants that must be removed, the reverse osmosis system is an excellent means of easing the burden on the ion exchange systems. This will help guarantee higher-purity water and will reduce costs for chemical regeneration. Some common RO membrane types are thin film composite (TFC, the most popular), cellulose acetate (CA), aromatic polyamides (PA), and polysulfonated polysulfone.

Cellulose-based membranes typically cost less, but they are susceptible to biodegradation and require a narrow pH range (typically 4 to 6 pH) to avoid hydrolysis.

Noncellulose membranes typically have a wider pH range, such as 2 to 11 pH for thin film composites or 4 to 9 pH for polyamides. pH considerations go beyond maximizing the life expectancy of the RO membranes, however. Minerals in the water will have varying solubilities at different pH levels. For instance, passing water with a pH of 8 to 8.5 through an RO membrane will allow good rejection of the bicarbonate ion, but the membrane will be more susceptible to calcium carbonate scaling. Acid dosing can prevent the scaling, but bicarbonate ions will not be rejected very well. The type of membrane chosen and the pH level of the water must be decided based upon the characteristics of the water and the desired levels for contaminant removal

Oxidants such as chlorine or bromine added in the pretreatment stage to prevent organic problems can be helpful or harmful in the reverse osmosis and later stages. The presence of a strong oxidizer such as chlorine can degrade ion-exchange resins, resulting in the need for more frequent regeneration, which can be costly. In addition, some reverse osmosis systems (such as those made of thin film composite or polyamide membranes) are typically very susceptible to water treated with chlorine and quickly degrade upon exposure. Other membrane types, such as cellulose acetate, are highly resistant to oxidants. In fact, the CA-based reverse osmosis systems are actually helped by the presence of chlorine since microorganisms can quickly foul and destroy the membranes. The type of membrane used in the RO system will determine whether dechlorination (or removal of another oxidant) must be performed. However, many plants will dechlorinate the makeup water before it enters any reverse osmosis or ion exchange units in the system.

There are typically two ways that this may be done—activated carbon beds or chemical injection with sulfur dioxide ( $\text{SO}_2$ ) or sodium bisulfite ( $\text{NaHSO}_3$ ).

Activated carbon beds can serve two purposes within a makeup water system—to dechlorinate the water and to adsorb any organics that remain in the water. Efficiency of the carbon beds in removing the chlorine depends on a number of things, including pH, temperature, and organic load in the water. Unfortunately, carbon beds can become a nurturing environment for organic growth and therefore need to be sanitized often. The pH levels necessary for the carbon beds to effectively dechlorinate can often be harmful to components downstream. In addition, carbon fines can be released from the bed, causing problems downstream with other components.

Because of the number of problems associated with carbon beds, many makeup water systems are employing chemical injection to dechlorinate and using special anion-exchange resins for removal of organics.

Dechlorination by means of chemical injection involves adding a reducing agent such as sulfur dioxide or a form of bisulfite, such as sodium bisulfite. The bisulfite (or sulfur dioxide) is oxidized, and the chlorine reduced, thus removing the harmful effects of chlorine in the water. The bisulfite ions are converted to sulfate ions, which are removed in the anion exchanger. The chlorine ions are converted to chloride ions, which are also removed by the anion exchanger. Failure to completely dechlorinate can result in hydrolytic destruction of some reverse osmosis membranes and/or damage to ion exchange resins. However, overfeed of the reducing agent can result in unneeded chemical costs and increased anionexchange resin regeneration

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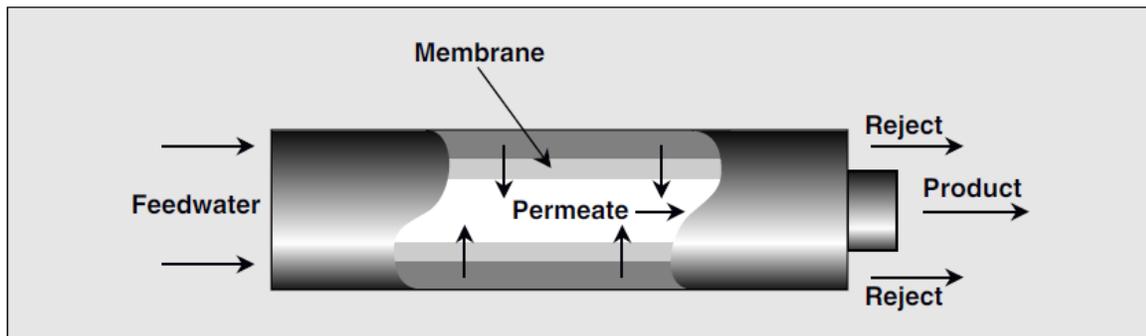


Figure 3: Reverse Osmosis Diagram

### Analytical Monitoring for Reverse Osmosis

In the example illustrated in Figure 1, ORP was used with feedback control in the pretreatment stage for the addition of an oxidant, such as chlorine. ORP can be used again just prior to the reverse osmosis stage for better control of the addition of the sodium bisulfite or sulfur dioxide (ORP #2 in Figure 1) when dechlorination must be performed.

Once again, an ORP feedback loop along with flow proportioning can be used, with the control point at +200 mV or less. The actual ORP control setpoint should be decided by wet chemistry tests to determine when the chlorine has been fully reduced. ORP could also be used after an activated carbon bed to determine when chlorine breakthrough is occurring. This can allow full utilization of the carbon, avoiding premature regeneration or replacement.

If the pH of the water must be decreased for protection of the reverse osmosis membranes, sulfuric acid can be added by flow proportioning along with a pH feedback loop (typically using PID control) to ensure consistent pH control.

The optimal level will depend largely upon the type of membrane chosen and the characteristics of the mineral content of the water.

The efficiency of reverse osmosis operations is usually monitored by comparing inlet and outlet conductivity (Cond. #4 and #5, respectively, in Figure 1). This measurement is sometimes reported in terms of TDS—total dissolved solids. Calculations of percent passage or percent rejection can be used for this comparison. This gives a reading of either the amount of total dissolved solids getting through the membrane or the amount being rejected. The equations for these are as follows:

$$\% \text{ Passage} = (\text{Cond. \#5} / \text{Cond. \#4}) \times 100$$

$$\% \text{ Rejection} = (1 - \text{Cond. \#5} / \text{Cond. \#4}) \times 100$$

When the percent passage number rises too high or the percent rejection number drops too low, the reverse osmosis system is not removing the dissolved solids as well as it should. Typical ranges for percent passage are 0 to 20 percent, and typical ranges for percent rejection are 80 to 100 percent.

From operating experience and flow rate data, abnormal readings can be interpreted as membrane fouling, incorrect flow rates, or membrane failure. A good cleaning of the membrane is usually necessary when the salts are not being removed efficiently.

### **Cation and Anion Deionization Stage**

The prominent ions found in water are calcium, magnesium, and sodium (the cations), as well as sulfate, bicarbonate, and chloride (the anions). Deionization by ion exchange is an effective treatment method to remove these undesirable ions, as discussed in the earlier section on water softening. Another traditional name for this step is the demineralization stage, but demineralization has now come to refer to the reverse osmosis, cation and anion deionization, and mixedbed deionization stages.

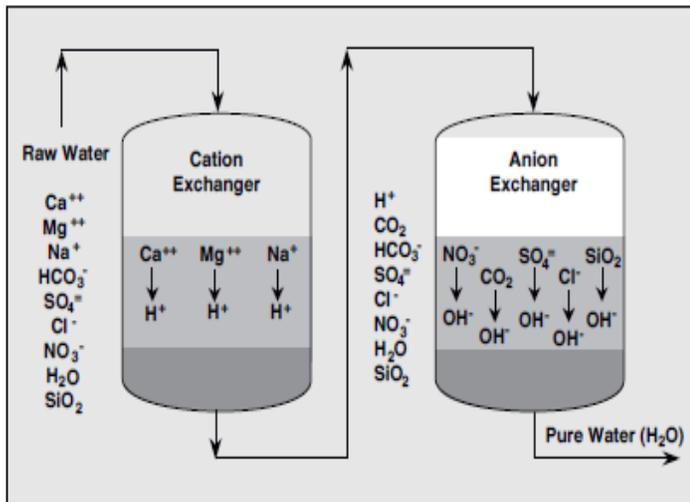
A column packed with insoluble cation-exchange resin beads is the heart of this first stage of the ion exchange process (Figure 2). An industrial ion exchange unit along with its resin is referred to as a bed. The first stage will typically be a hydrogen ion exchanger, often referred to as the cation exchanger (Figure 1). When the column is packed with hydrogen cation resin, the calcium, magnesium, and sodium cations in hard water are absorbed (Figure 4). Simultaneously, the water is softened when the cations (hydrogen), originally charged on the resin, are released into the water. Specific resins are chosen to optimize performance in treating a particular water composition. When the resin's capacity to retain the hardness cations is exhausted, regeneration by passing an acid (hydrochloric or sulfuric) solution through the column recharges the resin.

The bicarbonate, chloride, or sulfate anions may be removed in an anion column, known as the anion exchanger, placed in series after the cation exchanger (Figure 4). Anionic resins, previously charged with hydroxyl ion, are capable of exchanging hydroxyl ions for anions such as chloride and sulfate, as well as non-ions such as carbon dioxide and silica. Regeneration is accomplished by passing an alkaline solution (sodium hydroxide) through the anion resin bed. The effluent from a two-column system is essentially pure water, typically in the conductivity range of less than 10 microsiemens/cm.

### **Analytical Monitoring for Cation and Anion Deionization Stage**

The efficiency of ion exchange operations is most commonly monitored by conductivity, although sodium ion analyzers may be used as well. Comparing inlet and outlet conductivity (commonly referred to as measuring conductivity across the bed) identifies breakthrough of unwanted ions and the need for bed regeneration. However, comparing conductivity at measurement points within the bed can give warning before the need for regeneration by identifying depletion in the resin before breakthrough. But measurement within the bed requires access for the conductivity cells, with screening to prevent resin beads from entering and shorting the cells.

One consideration when performing this monitoring is the temperature of the water at the measurement point. The ionic characteristics of the water vary at different stages of deionization treatment, requiring specialized conductivity temperature compensation to provide consistent monitoring performance. Raw water generally contains neutral minerals with one set of conductivity temperature characteristics. Cation exchanged water is acidic and has different temperature characteristics. Product deionized water is also close to the neutral salts compensation, but requires state-of-the-art high-purity temperature compensation to accommodate its high and variable temperature coefficients.



**Figure 4: Cation and Anion Exchange Chemistry**

More precise control can be achieved in cation and anion beds by using conductivity ratio measurement. In a cation exchange bed, mineral cations are exchanged for hydrogen ions, which are much more conductive. The increase in hydrogen ions in cation exchange produces an acidic solution at the outlet. Because the temperature coefficient of acids is different from that for neutral solutions, the cation temperature compensation should be selected for the cell placed immediately at the outlet of the cation exchanger, Cond. #7. The conventional neutral salts temperature compensation is appropriate for the inlet cell, Cond. #6. The conductivity at the outlet of the cation exchanger (Cond. #7 in Figure 1) will be considerably higher than at the inlet (Cond. #6 in Figure 1). A high conductivity ratio of Cond. #7 to Cond. #6 indicates good mineral ion removal, while a ratio approaching unity indicates no removal. Typical ranges for the ratio measurement will be from 1 to 4.

If the first cell is placed within the bed (near the bottom) during normal operation, both cells will see full mineral exchange for hydrogen ions. Since both points are measuring an acidic solution, cation temperature compensation is selected in both cells. Conductivities are high, and the ratio of Cond. #7 to Cond. #6 is near unity. As the resin depletes from the top down or by channeling, the cell in the bed will sense the less conductive mineral cations first, and the ratio will increase above unity. A high ratio should be the trigger for regeneration before mineral breakthrough reaches the outlet. Typical ratio numbers would be a range of 1 to 1.5.

When the resin in a cation bed becomes spent, the sodium ion will be the first to break through. If even better accuracy is required to determine when the cations are beginning to break through from the cation bed, a sodium ion analyzer can be used (Sodium #1 in Figure 1). A 0.1-ppb sodium ion concentration (equivalent to a 0.25-ppb sodium chloride increase) would yield a conductivity increase of 0.0005 microsiemens/cm. This is beyond the sensitivity of existing conductivity meters. However, this level of increase would be detectable by a sodium ion analyzer. Thus, a sodium ion analyzer is used on demineralizing systems to achieve the greatest selectivity and sensitivity for detecting impurity ions.

In the anion exchange bed, similar conductivity principles to those used with the cation exchanger can be applied. Monitoring can be done at the inlet (Cond. #9 in Figure 1) and the outlet (Cond. #10 in Figure 1) of the anion exchanger. However, the results obtained from the ratio measured across the bed will be reversed from that of the cation bed. This is because the conductivity at the outlet of the anion exchanger will be much lower than that of the inlet. A ratio of Cond. #10 with respect to Cond. #9 will yield a number much less than unity. As the number approaches unity, anion breakthrough is occurring, and regeneration should be triggered. The range for the ratio measurement would be expected to be between 0.25 and 1.

If in-the-bed monitoring is performed, both cells will see full anion removal in normal operation, and the ratio will be near unity. Since both points are normally measuring a neutral solution, high-purity salt temperature compensation is selected for all points of measurement. As the resin is depleted from the top down or by channeling, the cell nearer the inlet will sense the conductive anions first, and the ratio will decrease below unity. A low-ratio alarm can then trigger regeneration before anion breakthrough reaches the outlet. A typical range for the ratio measurement would be from 0.5 to 1.

### Mixed-bed Deionization Stage

In many systems, another step in the purification process is required to obtain the purity of water needed for the plant. This step is commonly known as polishing, and it utilizes a mixed-bed ion exchanger (Figure 1). A mixed bed contains a mixture of cation and anion resins, and is capable of producing water of the highest purity. The mixed-bed ion exchanger can be thought of as an infinite number of cation and anion exchangers in series.

Typically, conductivity of effluent water from a mixed-bed exchanger is less than 0.5 microsiemens/cm. During regeneration, the resins are separated, regenerated with the respective acid or caustic, and then recombined. This makes the regeneration stage much more difficult for the mixed-bed exchanger than that of just a single-ion exchanger.

### **Analytical Monitoring for the Mixed-bed Deionization Stage**

An absolute conductivity value from the cell at the outlet of the anion exchanger (Cond. #10) can also provide outlet monitoring—a primary indicator of system performance prior to the polishing step. A conductivity cell placed after the polisher (Cond. #12 in Figure 1) is ultimately used to determine whether the water is pure enough for use in the plant's steam/water cycle. Similar principles of ratio measurement between the cells at the inlet and outlet of the mixed-bed exchanger can be applied to determine when regeneration is necessary. Since the sodium ion will be one of the first ions to break through the mixed-bed exchanger, sodium measurement can also be used at the outlet of the mixed bed (Sodium #2 in Figure 1) to detect the need for regeneration slightly before conductivity will.

Ion exchange regeneration uses acids and bases to periodically remove accumulated mineral ions from the resin. Since these reagents are normally supplied at too high a concentration for regeneration, they must be diluted. Typical dilution strengths are 1 to 5 percent for acids and 3 to 6 percent for caustic. The dilution concentration can be monitored by high-range conductivity measurement with special temperature compensation and conductivity-to-concentration conversion specifically for these reagents.

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