By Jeff Tate

For more information on this topic, go to **www.watertechonline.com** and enter keyword(s): **Electrodeionization, ultrapure, ion exchange**.

Electrodeionization basics

EDI provides a significant advantage to ultrapure water users.

Electrodeionization (EDI) is an ultrapure water treatment process that polishes reverse osmosis (RO) permeate without chemical regeneration. EDI has been in existence for over 55 years, and has been commercially available for more than 23 years. It has become a proven and acceptable technology for all industrial water treatment users who require high purity.

The process of operating an EDI system is extremely simple. Electrodeionization is sometimes referred to as continuous electrodeionization (CEDI). Since electrodeionization is continuous in nature, we will refer to the technology simply as EDI. While there are several different commercially available EDI products with varying design, all operate using the same principles of chemistry.

Electrodeionization modules are electrochemical devices. Since each EDI module is driven by electrical energy from an outside power supply, more specifically it is an electrolytic cell. Each EDI module consists of five primary components: Ion exchange resin, two ion exchange membranes and two electrodes.

Figure 1 (page 25) shows a diagram of the internal process of an electrodeionization device. Two electrodes are on either side of multiple EDI compartments, which are known as diluting chambers and concentrating chambers. As water flows through the EDI module and power is applied, there are three processes occurring simultaneously: The deionization process where the water is purified by ion exchange; ion migration where the ions are removed from the resin; and continuous regeneration of the resin.

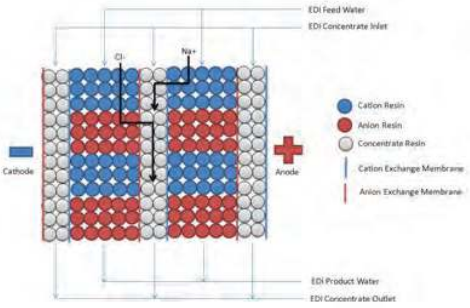

Figure 1

In Figure 1, we see there are two types of chambers in an EDI device. Diluting chambers (D-chambers) are the portion containing mixed bed ion exchange resin where water is purified or diluted of ions. Concentrating chambers (C-chambers) are the areas where water is concentrated of ions, and becomes waste water. The D-chambers contain both cation exchange resin and anion exchange resin. There are several different concentrate chamber designs; however the most efficient EDI devices contain resin-filled concentrate chambers, known as an "all filled" EDI design.

The D and C chambers are separated by ion exchange membranes. The membranes are similar in material and charge to the ion exchange resin. For example, cation exchange membranes only allow cations to pass, and anion exchange membranes only allow anions to pass. Water and oppositely charged ions may not pass across the ion exchange membrane used in EDI.

Deionization

Deionization is the removal of ions — both positively charged cations and negatively charged anions. Cations are positively charged ions because they have a loss of one or more electrons, very small negatively charged particles. For example, the sodium ion (Na^+) is positive because the ion lost one electron. Calcium (Ca^{++}) has twice the positive charge of sodium because it has lost two electrons. Anions contain a negative charge because they contain one or more additional electrons. The chloride ion (Cl^-) is formed when chlorine gains one electron, and oxide (O^{--}) has gained two electrons.

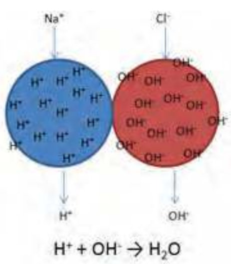

Figure 2

Figure 2 shows the ion exchange process. This is typical of all high purity resin, including electrodeionization. The cation exchange resin is in the regenerated hydrogen (H^+) form as the charged exchange sites are bonded with hydrogen ions. As the feed water contacts the resin, the contaminant cations such as calcium, magnesium, sodium, potassium and ammonium have a higher affinity to the site charges on a resin bead than a hydrogen ion. The cation exchange resin releases a hydrogen ion to bond with the cation. Likewise, anion exchange resin is in the regenerated hydroxide (OH^-) form as the charged exchange sites are bonded with hydroxide ions.

The contaminant anions — such as carbonate, bicarbonate, chloride, sulfate, nitrate, fluoride, silica, boron and carbonic acid — have a higher affinity to the anion exchange resin than hydroxide. The anion exchange resin releases a hydroxide ion to bond with the anion. The released hydrogen and hydroxide ions bond to form water. Water is purified, or deionized, by the removal of the cations and anions as it flows through the mixed resin bed.

Ion migration

The second process in electrodeionization is ion migration. This differs from chemically regenerated ion exchange as EDI continuously removes the ions from the resin. Conventional ion exchange resin becomes exhausted until chemical regeneration occurs. EDI power sources supply a DC electrical current between the two electrodes. The electrical current is the movement of electrons between the electrodes, from the anode to the cathode. The electrode with a negative charge is the cathode, where reduction of the oxidation number occurs (electrons are available). The electrode which oxidizes (takes electrons) is the anode and has a positive charge. As the ions are removed from the feed water, cations that have lost electrons are attracted to the negative cathode where electrons are supplied, or the oxidation number is reduced. Likewise, anions are attracted to the negative anode where electrons leave the cell or oxidation number increases.

Once on the resin, positively charged ions will migrate through the cation resin bed,

(Concluded on next page)

(Continued from prior page)

through the cation exchange membrane and into the concentrate chamber due to their attraction to the cathode. Negatively charged ions will migrate through the anion resin bed, through the anion exchange membrane and into the concentrate chamber due to their attraction to the anode. Once the ions are in the concentrate stream, they are not able to continue their migration to the electrode as they encounter an oppositely charged ion exchange membrane which does not permit entry to the adjacent diluting chamber. Concentrate water exits the EDI module and is most often sent directly to drain since this is typically only 5-10 percent of the feed water. EDI waste water can be recovered by sending it to a ventilated raw water storage tank, sometimes advantageous with larger systems.

Resin regeneration

The third process that occurs as the ions are removed and migrate to the concentrate chamber is resin regeneration. With conventional ion exchange, the resin is regenerated with acid and caustic chemicals. Hydrochloric acid (HCl), or sometimes sulphuric acid (H_2SO_4), is applied to cation exchange resin to regenerate. When this is done, the massive concentration of H^+ displaces the cations on the resin. Sodium hydroxide (NaOH) is applied to anion exchange resin and the massive concentration of OH^- displaces the anions from the resin. EDI does not require acid to regenerate the cation exchange resin, nor does it require caustic chemicals to regenerate the anion resin. Instead, it takes advantage of the electrical current that is applied across the EDI module.

In the presence of the electrical field, a phenomena known as "water splitting" occurs. The electricity causes a small percentage of water molecules to split into hydrogen and hydroxide ions which continuously regenerate the resin bed: $H_2O \rightarrow H^+ + OH^-$.

Therefore, EDI operation is continuous. The ions are continuously removed, and the resin is continuously regenerated without chemicals. This provides a significant advantage to ultrapure water users over either onsite or offsite chemically regenerated ion exchange. The operation of the EDI system is as simple as operating a reverse osmosis system and the results of EDI are more reliable than chemically regenerated ion exchange. **WT**

Jeff Tate is president of Agape Water Solutions Inc. Based in Harleysville, Pennsylvania, Agape Water Solutions is the Master Service Provider in North America for Ionpure Technologies, a leading manufacturer of electrodeionization modules. Recognized worldwide as an expert in reverse osmosis and electrodeionization, Tate has written numerous technical articles and has delivered presentations at several conferences. He can be reached via e-mail at jtate@agapewater.com or www.agapewater.com.