Water TECHNOLOGY

Add polish to high-purity water with EDI

Systems combine RO and ion electrochemistry

By Jeff Tate

Electrodeionization (EDI) has recently gained widespread acceptance by water treatment companies and end users alike for almost all applications requiring high-purity water.

EDI has proven to be a reliable, cost-effective solution for both end users and water treatment companies. End users purchasing capital equipment can eliminate on-site chemical regeneration. Water treatment companies selling capital equipment can provide this benefit to their customers. Service exchange companies can eliminate chemical regeneration on their own premises and sell water by the gallon using a system that requires less maintenance than traditional service exchange.

Historically, ultrapure water systems were based completely on ion exchange. These systems consisted of cation units, followed by anion units, followed by mixed-bed units. While these systems provide high-quality water, they also require significant amounts of chemical regeneration.

Over the last 20 years, reverse osmosis (RO) has gained industry acceptance to replace the two-bed cation and anion vessels. Now EDI has replaced the mixed-bed, ion-exchange unit used for polishing. In combination with RO, EDI provides a continuous, chemical-free system.

EDI eliminates hazardous regeneration chemicals and the need to transport, store or handle acid and caustic. The continuous, simple operation eliminates the complicated mixed-bed regeneration process and requires less labor.

The process also eliminates the need for auxiliary equipment, such as regeneration skids, storage tanks, pH neutralization system and associated infrastructure. The process produces no hazardous waste streams, making special discharge permits unnecessary. In fact, most of the EDI waste can be recovered back into the water treatment system inlet.

In many cases, using EDI will result in lower operating and capital costs. The main consumables for mixed beds are chemicals, replacement resin, labor and wastewater. The main consumable in EDI is electricity. Replacement stacks may need to be refurbished or replaced from time to time. Labor and wastewater costs are significantly lower in EDI than for a mixed bed with a comparable flow.

The electrical cost of running an EDI system is usually between 0.5 to 3.0 kilowatts an hour for every 1,000 gallons of product water, depending on feedwater quality and product water specifications. In many cases, this results in lower operating costs compared with mixed-bed ion exchange.

Software is available from EDI manufacturers that compares the operating cost of EDI to mixed beds by incorporating application and site-specific requirements and costs. RO effluent projections serve as input to EDI process software.

How EDI works

EDI stacks are the heart of an EDI system. A single EDI stack consists of two oppositely charged electrodes and

EDI maintenance requirements

Electrodeionization (EDI) systems require little maintenance in a well-designed water treatment system. The instrumentation may require calibration once or twice a year.

It is recommended that data such as flows, pressures and electrical characteristics be recorded in logs several times a week. Over time, the data recorded is reviewed to indicate possible scaling or fouling problems.

Scaling and/or fouling can be caused by pretreatment upset or a poorly designed pretreatment system. When scaling or fouling is suspected, on-site cleaning can restore the performance in most cases.

Pharmaceutical systems are cleaned and sanitized on a scheduled basis at the same time the pretreatment is sanitized. Cleaning procedures and chemicals are similar to those for reverse osmosis systems.

EDI stacks may last five to 10 years or longer. The actual life of the stack will depend primarily on the water source, pretreatment and maintenance, and ultimately on the intrinsic chemical stability of the strong-base anion resins used. In a modular design, single-problem stacks may be isolated and replaced in a few minutes, sometimes without even shutting the system down.

— J.T.

multiple cell pairs in a plate-and-frame design. A cell pair consists of a dilute chamber (d-chamber) filled with cation and anion exchange resin, a cation membrane, an anion membrane and a concentrate chamber (c-chamber). The EDI stacks contain multiple cell pairs.

Inside each EDI stack are two electrodes that apply up to 600 volts in order to pass the requisite DC current to each stack. The cathode at one end of the stack applies a negative voltage while the anode at the opposite end applies a positive voltage. The current flows through the 30 cell pairs in between the cathode and the anode.

Each d-chamber is a miniature ion-exchange bed approximately 8 millimeters thick, containing both cation and anion resin. A cation membrane separates the d-chamber from the c-chamber on the side toward the cathode. On the other side, an anion membrane separates the d-chamber from the c-chamber.

The membranes used in EDI are far different from those used in RO, microfilters or ultrafilters where the membrane allows the passage of water and small amounts of ionic and molecular contaminants. In EDI, the membranes are made of polystyrene-based material similar to ion-exchange resin and allow only the ions with proper charge and almost no water to pass.

The resin is continuously regenerated by water splitting. Inside the electrical field, a few H_2O (or HOH) molecules in the feedwater are separated into hydrogen (H+) and hydroxyl (OH-) ions. Attracted to the opposite charge, hydrogen ions will migrate through the cation resin in the direction of the cathode. Similarly, hydroxyl ions migrate through the anion resin in the direction of the anode.

The migration of the hydrogen and hydroxyl ions regenerates the resin. The cation membrane allows the hydrogen ions to pass through into the concentrate chamber because hydrogen ions have a positive charge. The anion membrane allows the hydroxyl ions to pass through into the concentrate chamber because hydroxyl ions have a negative charge. The hydrogen and hydroxyl ions will combine inside the concentrate chamber to yield water.

While water splitting is occurring, simultaneously the resin removes the ions in the feedwater by the process as conventional ion exchange. Once the cations and anions are trapped onto their selective resin site, they are attracted to the oppositely charged electrode and join the migration of hydrogen and hydroxyl ions through the resin and the membranes and into the concentrate chamber.

The concentrate chamber has its own flow stream and will collect the cations and anions and sweep them out of the stack. Oppositely charged membranes prevent the trapped ions

How to design a system using EDI

Along with electrodeionization (EDI) stacks, a complete EDI system will include a rectifier, controls, instrumentation, piping, valves and a recirculation pump all mounted on a skid.

These components are similar to those found on a reverse osmosis (RO) system, with the exception of the rectifier and the stacks. Rectifiers convert a three-phase, AC input to a DC output, which powers the stacks.

EDI manufacturers standardize a specific flow rate for each stack. A modular design offers flexibility to the original equipment manufacturer to design a system based on a specific application, similar to how RO systems are designed and built. Some systems include RO and EDI on a common skid.

Capacity is easily expanded or reduced by adding or removing additional stacks. Most single-skid systems are designed from 5 to 900 gallons a minute. Additional capacity can be made available by using multiple skids.

EDI is a polishing technology. It will use pure RO permeate or equivalent water as feed and purify it further. It is critical that the pretreatment is designed to meet the necessary feedwater requirements.

The table at the right shows typical feedwater requirements for an EDI system. Various configurations can be used to achieve these requirements, depending on the source of the water. A typical configuration for city water may be: Multimedia filter → activated carbon filter → single-pass RO → EDI

In the case of high-hardness water, a softener may be added to the train: Multimedia filter → activated carbon filter → softener → single-pass RO → EDI

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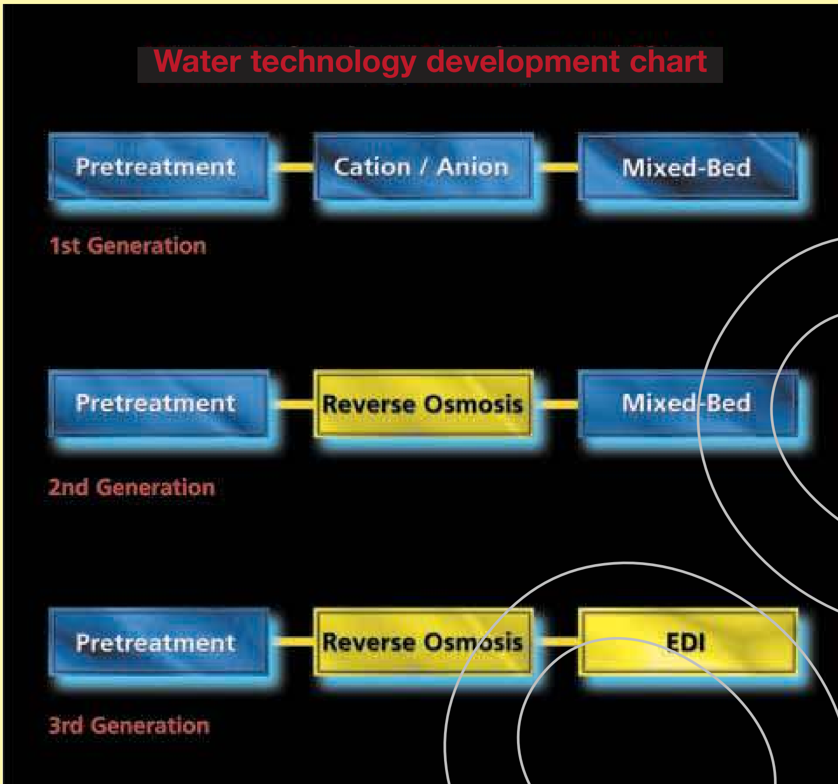
Feedwater requirements

Constituent	Range
TEA including CO_2	<25.0 ppm $CaCO_3$
pH	5.0 to 9.0
Hardness	<0.5 ppm $CaCO_3$
Silica (reactive)	<0.5 ppm
TOC	<0.5 ppm
Free chlorine	<0.05 ppm
Fe, Mn, H_2S	<0.01 ppm

from entering the adjacent d-chamber. As the process water flows through the d-chambers, additional ions are removed by the resin, resulting in pure water on the effluent side of the stack.

Recirculation an important step

In an EDI system, 90 to 95 percent of the feedwater flows through the dilute chambers. This flow can be sent to one or more stacks in parallel, each stack with multiple dilute chambers in parallel. The water flows through the d-chambers in a once-through design and is collected at the outlet as high-purity water.



The remaining 5 to 10 percent of the feedwater is sent into the concentrate chambers as makeup water for the 3 to 8 percent that is bled out of the EDI system and the 2 percent that is flushed over the electrodes.

Recirculation of the concentrate allows the conductivity of the concentrate flow to increase and increases the electrical efficiency of the EDI stack by passing more current. The pH of the EDI waste depends on the feedwater characteristics, but is usually near neutral and of good quality.

The concentrate bleed can be recovered by returning the concentrate back to the water treatment system inlet.

For high-silica water, a double-pass RO may be required:

Multimedia filter → activated carbon filter → double-pass RO → EDI

In some cases, there is a preference to substitute sodium metabisulfite in place of the carbon filter to control free chlorine levels:

Multimedia filter → softener → chemical feed → single-pass RO → EDI

Carbon dioxide (CO_2) also plays a critical role in system design. Molecular CO_2 will pass through the RO membranes and presents an anionic load to the anion exchange resin in conventional mixed bed or EDI units.

When it enters the EDI system, it is removed as both carbonate and bicarbonate, depending on the pH distribution inside the ion exchange resin. The additional CO_2 load requires additional electricity into EDI to reach quality requirements.

Low pH applications will increase the CO_2 in the feed. In some cases, a caustic feed may be used to increase pH, converting CO_2 to the ionic bicarbonate and carbonate forms, effectively improving its rejection by the RO:

Multimedia filter → activated carbon filter → caustic feed → single-pass RO → EDI

In some cases, acid is used to prevent hardness scale on RO membranes. In this case, a decarbonator or degasification membranes may be used to reduce CO_2, or antiscalant may be used in place of the acid feeder.

Multimedia filter → activated carbon filter → acid feed → RO → degasification → EDI

or:

Multimedia filter → antiscalant → (caustic feed) → RO → EDI

If EDI feedwater requirements are met, 16 megohms per centimeter (meg-ohm/cm) or better product water can be guaranteed. In some cases, even better quality water (18 or 18.2 meg-ohm/cm) is required and a nonregenerable mixed bed can provide a final polish.

The load on the ion exchange resin in a polishing mixed bed is so low that the resin may last one or two years. The resin is then removed and replaced with freshly regenerated resin, allowing the system to remain effectively chemical-free.

Pretreatment → RO → EDI → nonregenerable mixed bed

While mixed-bed systems require a minimum of two trains, no redundancy is required by EDI. The regeneration is continuous and a modular design provides additional built-in redundancy.

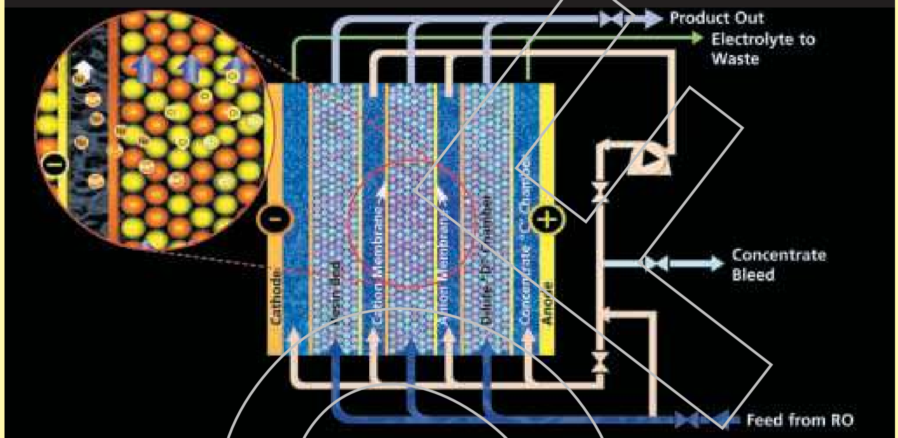
However, in semiconductor and other capital-intensive plants, it can cost the end user thousands of dollars every minute the water treatment system is not operating. In these cases, the end users are comfortable matching the EDI redundancy with that of the preceding RO train.

— J.T.

The electrode flush will contain extremely low levels of hydrogen, oxygen and chlorine gases and can be sent to drain in a well-ventilated area.

In the past three years, EDI has become well acceptable in many areas of water treatment. Today, nearly half of all new power plants and semiconductor water treatment systems and about 75 percent of all pharmaceutical systems include EDI.

Recent research developments are paving the path for new EDI stack improvements. In the coming months, the market will see continued reductions in electrical consumption and improved performance, particularly in silica and boron removal. In the next few years, expect even better water quality and higher feedwater tolerances for hardness and silica. □



An EDI system

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