Continuous Electrodeionization for Water Treatment at Power Plants

By Jonathan Wood, Siemens Water Technologies

Power plants have for many years used deionized water as makeup to high-pressure boilers and for producing steam to drive turbines and generate electricity. Although this technology has been popular for half a century, it requires the use of hazardous chemicals to regenerate the ion exchange deionizers. Additionally, ion exchange produces chemical wastes that require neutralization before being discharged.

During the past 10 years, power plants have increasingly used reverse osmosis (RO) as a roughing demineralizer to remove the bulk of the mineral, organic and particulate contaminants, thus reducing the chemical consumption of the ion exchange system. Recent improvements in continuous electrodeionization (CEDI) technology have resulted in the move toward chemical-free deionization systems, because RO followed by CEDI has become more cost competitive with conventional ion exchange. Another advantage of RO/CEDI is that it offers better removal of colloidal silica and dissolved organics than conventional deionization. Recently, CEDI module and system costs fell still more due to module construction improvements. Increased acceptance of RO/CEDI technology has resulted in some large steam generation installations, like the one shown in the upper photo on page XXX.

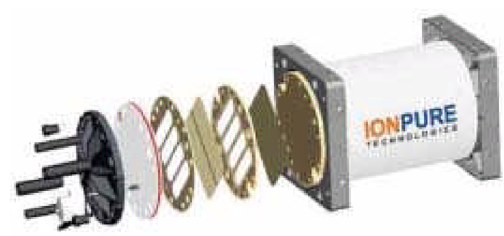
CEDI Module Design

Millipore Corp. (now part of Siemens Water Technologies) first commercialized the CEDI process in 1987. For the first 10 years, almost all commercial CEDI units were of a plate-and-frame design and used what can be described as "thin cell" product water compartments (about 2.5 mm between ion exchange membranes) with a mixed-bed ion exchange resin filter. These devices were used primarily for producing pharmaceutical-grade water.

Since then, several new designs have emerged, including different module configurations (spiral wound), thicker product cells (8 mm to 9 mm inter-membrane spacing) and different resin configurations (clustered bed, layered bed and separate bed). CEDI is now used more extensively in higher flow applications such as power and microelectronics.

Using thicker cells reduces the ion exchange membrane area.

FIGURE 1 STACKED-DISK CEDI MODULE, EXPLODED VIEW.



This results in lower cost, as well as greater mechanical strength and the ability to incorporate o-ring seals to prevent both internal and external leaking. In most early CEDI designs, a screen with some type of gasket was used in the concentrate compartment. In these devices, the amount of salt in the concentrate streams controls the module's overall electrical resistance. Some CEDI suppliers incorporate concentrate recirculation and/or salt injection. This approach increases the conductivity of the

1500 m³/h CEDI system at East River Generating Station (one of 10 skids)

70 m^3/h CEDI system using stacked-disk modules

concentrate and reduces the module's electrical resistance. However, lowering the module's resistance without resorting to these measures is better. This can be done by using ion exchange resin in the concentrate and electrode cells as well as in the dilute cells, so that the resistance is independent of the concentrate water conductivity.

Although spiral-wound CEDI devices have been around for over a decade, the plate-and-frame configuration still accounts for more than 90 percent of the CEDI systems installed. Plate-and-frame devices offer the advantage of equal water flow and DC current distribution among the cells, which are hydraulically in parallel and electrically in series. This is possible because all the product compartments are identical to each other, as are the reject compartments. By contrast, in a spiral-wound device the outer leaves have more membrane area and thus lower current density than the inner ones. Also, in spiral-wound devices, the cell cross-section tapers near the end of the leaf, which may cause uneven current distribution across the cell.

A recent CEDI design includes a plate-and-frame device in a "stacked disk" configuration inside a fiberglass reinforced plastic (FRP) vessel (Figure 1). In this case, the vessel is used to provide mechanical support and simplify system plumbing using RO-like interconnectors to manifold together the CEDI stacks in parallel. The vessels can be stacked or mounted on a frame like RO pressure vessels (the lower photo on page XXX) so the CEDI system takes up much less floor space than conventional ion-exchange deionizers.

CEDI Systems Design

With the "all-filled" module construction described above, salt injection or recirculation pumps are not necessary, therefore reducing system complexity and potential maintenance downtime. The operating cost is also lower because a concentrate recirculation pump can use nearly as much electricity as the CEDI modules themselves. The modules typically use only about one megajoule (MJ) of electricity per cubic meter (m3) of product water, compared to 20 to 50 MJ/m3 for the high-pressure RO pump.

CEDI systems often use smaller modules in parallel to obtain high product flow rates. Therefore, if a problem occurs with one particular module, that module can simply be isolated from the system and the other modules can process a slightly higher flow until a replacement can be installed. Following the same approach, the rectifier can be designed to operate each module individually. Individual DC power controllers allow some degree of operational flexibility and additional individual module monitoring capabilities. The controllers are cost-effective for small and medium sized systems up to about 100 m3/hour. The CEDI control system's main requirement is that the DC power be shut off if insufficient water flow occurs. This feature prevents overheating and potentially permanent damage to the CEDI modules and can be accomplished by using flow switches on both the product and concentrate streams, as well as a "run signal" from the RO system or CEDI feed pump.

Process Considerations with RO/CEDI

The CEDI process has gradually evolved into a polishing demineralization step that is almost always used downstream of an RO system. This has occurred mainly because CEDI devices are susceptible to hardness scaling, organic fouling and physical plugging by particulates and colloids. It also occurs because CEDI product water quality is somewhat dependent on feed water quality. While some CEDI devices may be able to produce "two-bed quality" water directly from softened feed water, most power plant applications now require "mixed-bed quality" water. This typically cannot be produced by CEDI alone. By using RO as pretreatment to the

TABLE 1 TYPICAL MAKEUP WATER SPECIFICATIONS FOR HIGH-PRESSURE BOILER

Conductivity	≤0.1 mS/cm
Silica	≤10 $mg.kg^{-1}$
Sodium	≤5 $mg.kg^{-1}$
Chloride	≤5 $mg.kg^{-1}$
Sulfate	≤5 $mg.kg^{-1}$
Total Organic Carbon (TOC)	≤100 $mg.kg^{-1}$

TABLE 2 TYPICAL FEED WATER SPECIFICATIONS FOR CEDI MODULES

Hardness	<1 $mg.kg^{-1}$ as $CaCO_3$
CO2	<10 $mg.kg^{-1}$ as CO_2
Chlorine	Non-detectable (<20 $mg.kg^{-1}$ as Cl_2)
Temperature	5-45°C
TOC	<500 $mg.kg^{-1}$ as C
Heavy Metals	<10 $mg.kg^{-1}$
Silica	1 $mg.kg^{-1}$ as SiO_2

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CEDI, the dissolved solids are reduced to a level that allows the CEDI to meet the feed water quality requirements of a high-pressure boiler (Table 1). Also, RO removes organics that could foul the ion exchange resins in the CEDI modules and it removes particulates that could clog the narrow flow channels in the resin compartments (spacers) or the resin bed itself.

The feed water to the CEDI system must always meet the specifications outlined by the CEDI module manufacturer. These specifications may vary slightly from one manufacturer to another, but they are usually close to those listed in Table 2.

In addition, some issues relating to the design of pretreatment/RO/CEDI processes for boiler feed exist and must be considered to ensure long-term system performance and reliability. These include:

- Determining whether to use a single-pass or two-pass RO (usually dictated by raw water quality)
- Recovering optimum water (usually depends on hardness, but typically ranges from 90 percent to 95 percent)
- Preventing a slug of poor quality RO permeate from contaminating the CEDI when the RO starts up from a standby condition (either a pre-service flush to drain or a post-service flush with permeate)
- Ensuring that the pretreatment system completely removes chlorine, which could oxidize the resin in the CEDI module
- Determining whether or not to recycle the CEDI reject to the RO feed (can reduce the CEDI quality in the absence of a CO_2 removal step)
- Preventing a buildup of the hydrogen gas generated by the CEDI module (a simple atmospherically vented drain is usually sufficient).

Recent improvements in CEDI module construction have improved the physical integrity and module reliability while enabling process simplification, such as eliminating concentrate recirculation, as well as salt injection into the concentrate stream. However, reliable long-term operation of a RO/CEDI system requires careful attention to process design, particularly, hardness and chlorine. With good module and system design, RO/CEDI-based deionized water systems can be designed that consistently meet the makeup water quality requirements for high-pressure boilers without the use of hazardous chemicals and without creating regenerate waste. pe

Editor's Note: This article is based on an original version that appeared in Filtration + Separation *magazine, June 2008.*

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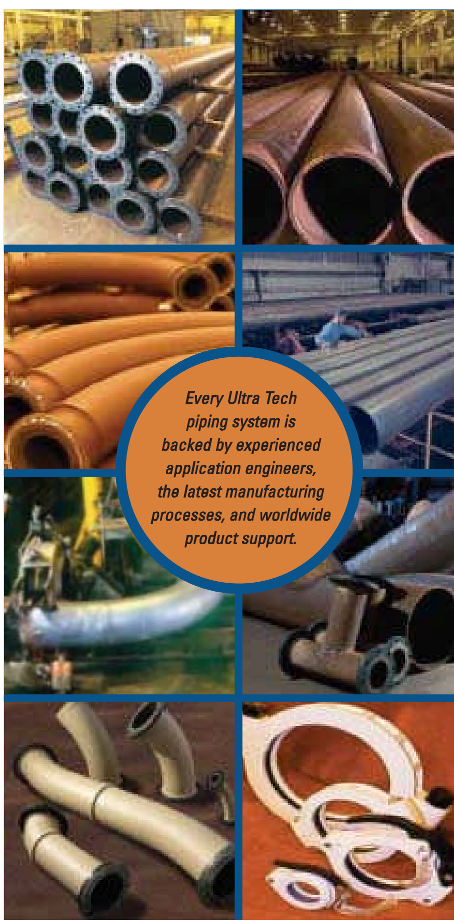

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