Continuous electrodeionization for boiler feed water

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INTRODUCTION

Power plants use deionized water as makeup to high pressure boilers, for producing steam to drive turbines and generate electricity. The conventional means of purifying boiler feed water has been to use chemically regenerated ion-exchange deionization. This is a widely accepted technology that has been in use for over half a century but has the disadvantage of requiring the use of hazardous chemicals for regeneration of the ion exchange resins. Ion-exchange also produces a considerable amount of chemical waste, which requires neutralization before it can be discharged.

Over the past decades the power industry has increasingly utilized reverse osmosis (RO) as a roughing demineralizer to remove the bulk of the mineral, organic and particulate contaminants, and reduce the chemical consumption of the ion-exchange system. More recently, improvements in continuous electrodeionization (CEDI) technology have caused a movement towards chemical-free deionization systems, as RO/CEDI has become cost competitive with conventional ion-exchange technology. Another reason for incorporation of the RO/CEDI process is that it offers better removal of colloidal silica and dissolved organic matter than conventional deionization.

Recent improvements in electrodeionization module construction have led to further cost reductions both at the module and system level. The increase in acceptance of RO/CEDI technology has led to the installation of some very large installations for steam generation, such as the one shown in Figure 1.

In addition to describing the recent advances in electrodeionization technology, this paper will discuss some of the process design issues applicable to the use of RO/CEDI systems for reliable production of feed water for high-pressure boilers.

Figure 1 6,750 gpm (1500 m^3/h) boiler feed water CEDI system (1 of 10 skids). USFilter is now part of Evoqua Water Technologies.

CEDI MODULE DESIGN

Continuous electrodeionization was first commercialized in 1987[1] by the Process Water Division of Millipore Corporation (now Evoqua Water Technologies) and is now a widely accepted means of water purification[2]. For the first ten years, nearly all commercial CEDI devices were 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 filler. The principal application for these devices was in the production of pharmaceutical-grade water. In recent years a variety of new designs have emerged, including different module configurations (spiral wound), thicker product cells (8–9 mm inter-membrane spacing), and different resin configurations (clustered bed, layered bed, separate bed). CEDI is now seeing

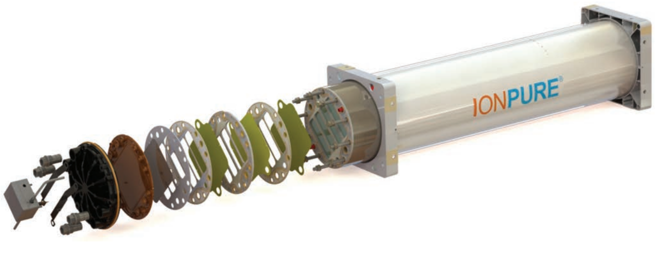

Figure 2 Stacked-disk CEDI module—exploded view

more extensive use in higher flow applications such as power and microelectronics.

The employment of thicker cells offers the advantages of reduced ion exchange membrane area and thus lower cost, as well as greater mechanical strength and the possibility of incorporating O-ring seals to prevent both internal and external leaking. In most early CEDI devices, the concentrate compartment was some type of gasketed screen. In such devices, the amount of salt in the concentrate streams controls the overall electrical resistance of the module. Some CEDI suppliers incorporated concentrate recirculation and/or salt injection to increase the conductivity of the concentrate and reduce the electrical resistance of the module. It is preferable to lower the module resistance without resorting to such measures. This can be accomplished by using ion exchange resin in the concentrate and electrode cells as well as the dilute cells, to make the resistance independent of the concentrate water conductivity(3).

While spiral wound CEDI devices have now been around for over two decades, the plate-and-frame configuration still predominates, estimated at over 90% of the installed base of CEDI systems. One advantage of the plate-and-frame arrangement is that because all the product compartments are identical to each other (as are the reject compartments), the water flow and the DC current is equally distributed among the cells, which are hydraulically in parallel and electrically in series. This is much more difficult to accomplish in a spirally-wound device, where the outer leaves have more membrane area and thus lower current density than the inner ones, and the cell cross-section tapers near the end of the leaf, which could cause uneven current distribution across the cell.

A recent development is the use of a plate-and-frame device in a “stacked disk” configuration inside an FRP vessel(4). In this case the vessel is used to provide mechanical support and to simplify skid assembly, allowing the vessels to be stacked or mounted on a frame like RO pressure vessels. This results in systems that take up considerably less floor space than a conventional ion-exchange deionization system. An example of such a vessel-based stacked-disk CEDI module is shown in Figure 2. Table 1 gives an example footprint comparison of typical CEDI and MBDI systems.

TABLE 1—FOOTPRINT COMPARISON: CEDI AND MIXED-BED DEIONIZER (TYPICAL 260 GPM)

CEDI Equipment	ft^2	MBDI Equipment	ft^2
CEDI skid	55	Resin vessels skid	60
Access aisles	119	Air compressor	9
		Acid regeneration skid	32
		Caustic regeneration skid	50
		Acid storage tote	2 x 20
		Caustic storage tote	2 x 20
		Access aisles	106
		Waste neutralization tank*	80
		Waste neutralization skid*	60
Total	174	Total	477

*If not already present at site

CEDI SYSTEM DESIGN

With the “all-filled” module construction described above, there is no need for salt injection or recirculation pumps, reducing system complexity and potential downtime for maintenance. This also lowers the operating cost, since a concentrate recirculation pump may use nearly as much electricity as the CEDI modules. The CEDI modules themselves typically use only about 1 kwh of electricity per thousand gallons of product water (0.26 kwh/m^3), compared to 20–50 kwh/kgal (5–13 kwh/m^3) for the high-pressure RO pump.

CEDI systems often use multiple smaller modules in parallel to attain high product flow rates. This type of modularity provides some redundancy. If there is a problem with one module, it can simply be isolated from the system and the other modules can process a slightly higher flow until a replacement can be installed.

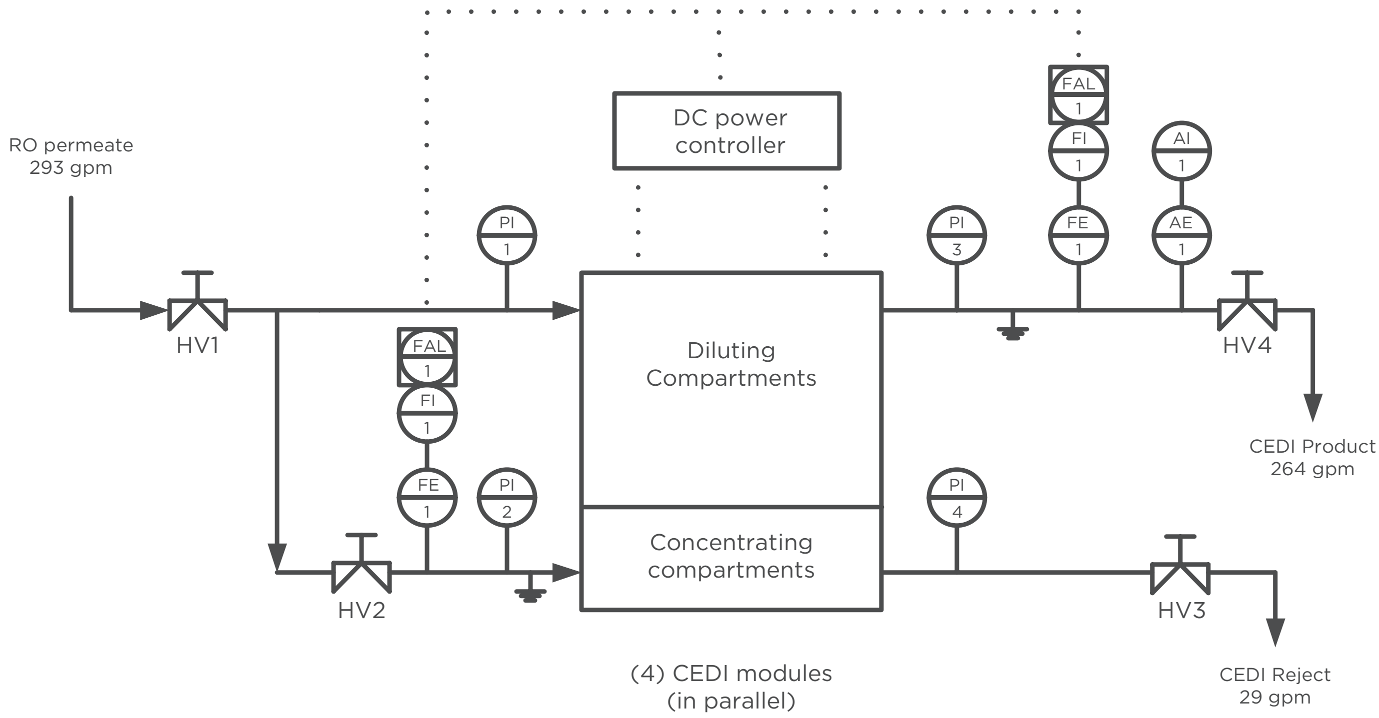

Figure 3 P&ID of 264 gpm (60 m^3/h) CEDI system

Following the same approach, the rectifier can be designed to operate each module individually. Having individual DC power controllers offers some degree of flexibility in operation and additional monitoring capabilities of the individual modules and has been shown to be cost-effective even for very large systems—over 4400 gpm (1000 m^3/h).

The main requirement of the CEDI control system is to ensure that the DC power is shut off in the event of insufficient water flow. This is necessary to prevent overheating and potentially permanent damage to the CEDI modules. It is usually accomplished through flow switches on both the product and concentrate streams as well as a "run signal" from the RO system or CEDI feed pump. Aside from the individual module power control mentioned above, CEDI systems generally use a design philosophy like that of RO systems, where instrumentation and control are provided at the skid or system level, not at the module level. This makes for easier operation and maintenance while lowering the capital cost of the system. The piping and instrumentation diagram of Figure 3 illustrates how simple the controls can be for a typical CEDI skid. Compare this to all the automatic valves, pumps, and sequencing controls required to regenerate a conventional demineralizer and then neutralize the spent regenerant. Figure 4 is a photo of a typical CEDI system.

Figure 4 264 gpm (60 m^3/h) CEDI system using stacked-disk modules

RO/CEDI PROCESS CONSIDERATIONS

Since its introduction in 1987, continuous electrodeionization has gradually evolved into a polishing demineralization process which is almost always employed downstream of a reverse osmosis system. There are several reasons for this: the CEDI devices are susceptible to hardness scaling, organic fouling, and physical plugging by particulates and colloids. In addition, the CEDI product water quality is somewhat dependent on the feed water quality. While some CEDI devices may be able to produce "two-bed quality" product water directly from a softened feed water, most power plant applications now require "mixed-bed quality" water, which would typically not be produced by CEDI alone.

Using RO pretreatment ahead of the CEDI reduces the dissolved solids to a level that allows the CEDI device to meet the feed water quality requirements of a high-pressure boiler (Table 2). The RO also removes organics that could foul the ion exchange resins in the CEDI modules and takes out particulates that could clog the narrow flow channels in the resin compartments (spacers) or the resin bed itself.

It is very important that the feed water to the CEDI system always meet the specifications set forth by the CEDI module manufacturer. These specifications may vary slightly between manufacturers but are usually close to the values listed in Table 3.

There are also some issues relating to design of pretreatment/RO/CEDI processes for boiler feed that must be considered in order to ensure long-term performance and reliability of the system[5]. Examples include:

- Whether to use single-pass or two-pass RO. This is usually dictated by raw water quality such as the amount of hardness and/or silica, as well as the boiler feed water specifications.
- The optimum CEDI water recovery, which usually depends on the amount of hardness in the RO permeate, but typically ranges from 90 to 95%.
- How to prevent the initial slug of poor-quality RO permeate from contaminating the CEDI every time the RO starts up from a standby condition. This is more important for CEDI systems than for regenerable mixed beds, which have the benefit of frequent aggressive chemical cleaning. It is easily accomplished with either a pre-service RO product water flush to drain or a post-service flush of the RO with permeate water. It is crucial to understand that a low-pressure feed water flush of the RO does not address this issue.
- Ensuring that the pretreatment system achieves complete removal of chlorine, which could oxidize the resin in a CEDI module. It is important to prevent oxidation of the resin in a CEDI module because the damaged resin is not as easily removed and replaced as with a tank full of ion exchange resin.
- Whether or not to recycle the CEDI reject to the RO feed. Because the RO does not remove CO_2, in the absence of a CO_2 removal step this can result in concentrating the CO_2 and causing a significant increase in the ionic load on the CEDI system. Since that can cause a subsequent decline in the CEDI product water quality, it may be preferable to find another use for the CEDI reject, which from a TDS standpoint is better quality than the raw water.

TABLE 2—TYPICAL MAKEUP WATER SPECIFICATIONS FOR HIGH PRESSURE BOILER

Conductivity	≤ 0.1 μS/cm
Silica	≤ 10 ppb
Sodium	≤ 3 ppb
Chloride	≤ 3 ppb
Sulfate	≤ 3 ppb
TOC	≤ 100 ppb

TABLE 3—TYPICAL FEED WATER SPECIFICATIONS FOR CEDI MODULES

Hardness	< 1 ppm as $CaCO_3$
CO_2	< 10 ppm as CO_2
Chlorine	Non-detectable (≤ 20 ppb as Cl_2)
Temperature	5-45°C
TOC	< 500 ppb as C
Heavy metals	< 10 ppb
Silica	< 1 ppm as SiO_2

- How to prevent buildup of the hydrogen gas generated by the cathode reaction in all CEDI modules (a simple atmospherically vented drain is usually sufficient).

CONCLUSIONS

Recent developments in CEDI module construction have improved both physical integrity and module reliability while simultaneously enabling process simplification such as elimination of concentrate recirculation and elimination of salt injection into the concentrate stream. However, reliable long-term operation of a RO/CEDI system requires careful attention to process design, and in particular hardness and chlorine. With good module and system design, it is possible to design deionized water systems based on RO/CEDI that will consistently meet the makeup water quality requirements of high-pressure boilers without the use of hazardous chemicals and without creating regenerant waste.

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