Power generation: Continuous electrodeionisation for power plants

The use of deionised water in power plants is an accepted technology, but the usage of hazardous chemicals can create problems. Jonathan Wood of Siemens Water Technologies explains how recent advances in electrodeionisation are helping with the chemical issue as well as cost reduction.

Introduction

Power plants use deionised 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 deionisation. This is a widely accepted technology that has been in use for 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 neutralisation before it can be discharged.

Over the past decade the power industry has increasingly utilised reverse osmosis (RO) as a roughing demineraliser to remove the bulk of the mineral, organic and particulate contaminants, and reduce the chemical consumption of the ion-exchange system. In the past few years, improvements in continuous electrodeionisation (CEDI) technology have caused a movement towards chemical-free deionisation systems, as RO/CEDI has become more 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 deionisation.

Recent improvements in electrodeionisation 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.

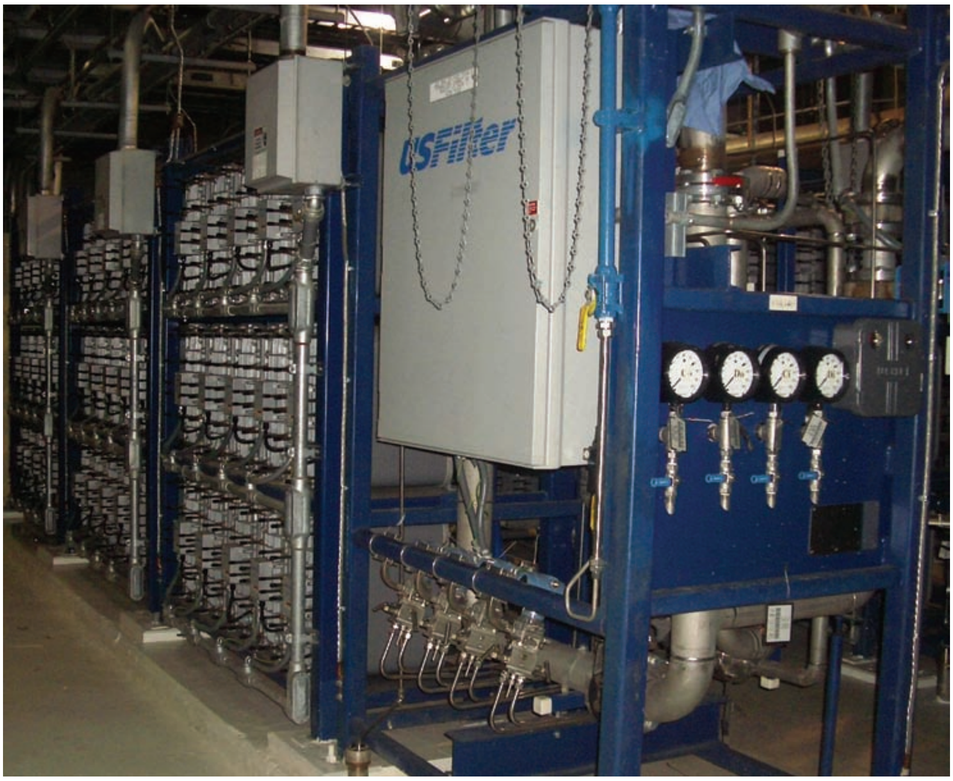

Figure 1: 1500 m^3/h CEDI System at East River Generating Station (1 of 10 skids).

In addition to describing the recent advances in electrodeionisation technology, this article 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.

Table 1: Typical makeup water specifications for high pressure boiler

Conductivity	≤ 0.1 µS/cm
Silica	≤ 10 µg.kg^{-1}
Sodium	≤ 5 µg.kg^{-1}
Chloride	≤ 5 µg.kg^{-1}
Sulfate	≤ 5 µg.kg^{-1}
TOC	≤ 100 µg.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 µg.kg^{-1} as Cl_2)
Temperature	5-45°C
TOC	< 500 µg.kg^{-1} as C
Heavy metals	<10 µg.kg^{-1}
Silica	1 mg.kg^{-1} as SiO_2

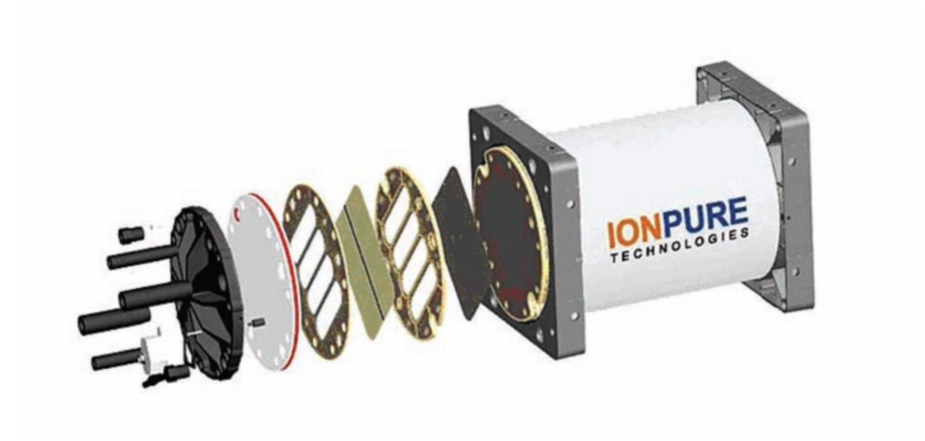

Figure 2: Stacked-disk CEDI module – exploded view.

CEDI module design

The process of continuous electrodeionisation was first commercialised in 1987 (1) by the Process Water Division of Millipore Corporation (now part of Siemens Water Technologies). This process has been described extensively in the literature and is now a widely accepted water purification process(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 more extensive use in higher flow applications such as power and microelectronics.

Ion-exchange also produces a considerable amount of chemical waste, which requires neutralisation before it can be discharged.

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 is 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 incorporate 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 a decade, 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 not possible 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 system plumbing, using RO-like interconnectors to manifold together CEDI stacks in parallel. The vessels can then be stacked or mounted on a frame like RO pressure vessels, resulting in systems that take up considerably less floor space than a conventional ion-exchange deionisation system. Examples of such a vessel-based stacked-disk CEDI system are shown in Figures 2 and 3.

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 megajoule of electricity per cubic meter of product water, compared to 20-50 MJ/m^3 for the high pressure RO pump.

If there is a problem with one particular 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.

CEDI systems often use multiple smaller modules in parallel to attain high product flow rates. This type of modularity in itself provides redundancy. If there is a problem with one particular 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.

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 is cost-effective for small and medium sized systems (up to about 100 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

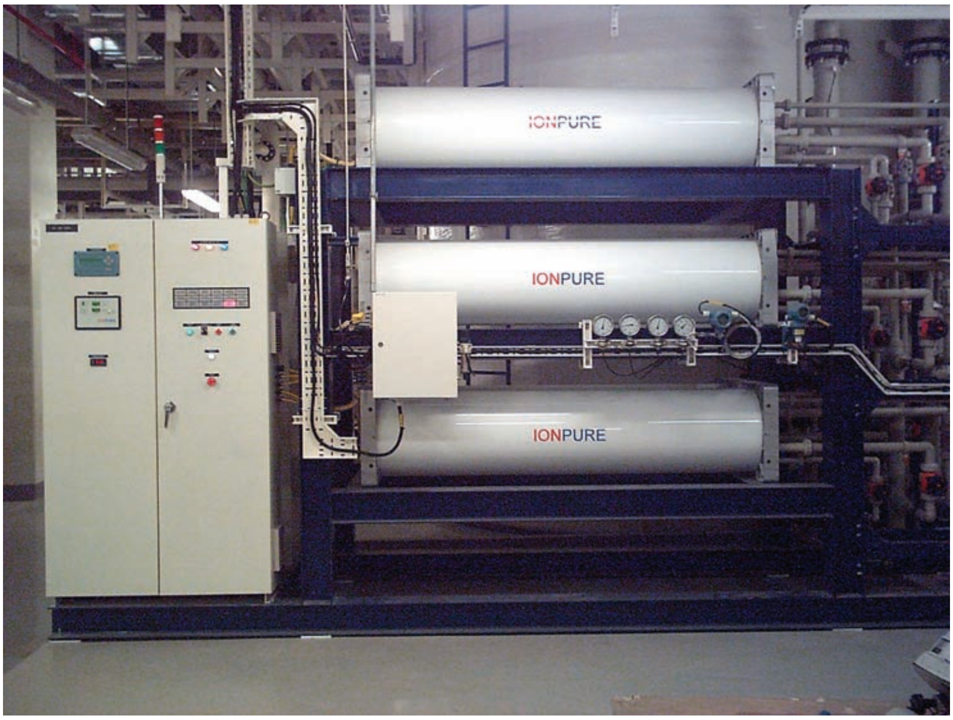

Figure 3: 70 m^3/h CEDI system using stacked-disk modules.

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.

RO/CEDI process considerations

Since its introduction in 1987, continuous electrodeionisation has gradually evolved into a polishing demineralisation 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 reverse osmosis 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 1). In addition the RO removes organics that could foul the ion exchange resins in the CEDI modules, and removes 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 from manufacturer to manufacturer, but are usually close to the values listed in Table 2.

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

1. whether to use single-pass or two-pass reverse osmosis (usually dictated by raw water quality);
2. optimum water recovery (usually depends on hardness, but typically ranges from 90 to 95%);
3. how to prevent a slug of poor quality reverse osmosis permeate from contaminating the CEDI when the RO starts up from a standby condition (either a pre-service flush to drain or post-service flush with permeate);
4. ensuring that the pretreatment system achieves complete removal of chlorine, which could oxidise the resin in a CEDI module;
5. whether or not to recycle the CEDI reject to the reverse osmosis feed (can reduce the CEDI quality in the absence of a CO_2 removal step); and
6. how to prevent buildup of the hydrogen gas generated by the CEDI module (a simple atmospherically vented drain is usually sufficient).

These topics have been discussed in more detail in a recent paper (5).

Conclusions

New 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 an 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 deionised water systems based on reverse osmosis/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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