DEIONIZATION

POWER INDUSTRY EXPERIENCE USING MICRO-MEDIA FILTRATION AND SHORT-BED ION EXCHANGE

With the demand for higher efficiencies, lower maintenance and operating costs for boilers and turbines, high-purity water treatment systems are becoming more crucial to the operation of power plants. Modern power plants, operating at supercritical and ultra supercritical boiler pressures and temperatures, require high-purity water that approaches quality levels at the theoretical levels. High-efficiency gas-fired combustion turbines (CTs) use high-purity water for nitrogen oxide (NO_x) control and sprint mode. Heat recovery steam generators (HRSGs) and once-through steam generators (OTSGs) also require high-purity water for the same reasons as boilers and steam turbines.

The versatility and efficiency of counter-current regenerated short-bed ion exchange (IX) deionizer systems produce high-purity water from feeds of variable characteristics, with lower chemicals consumption and waste volumes, and without the need for final polishing using mixed beds.

Effective pretreatment for reverse osmosis (RO) and IX deionizer systems is a crucial requirement that not only contributes to the production of high-purity water, but also helps to reduce the operating and maintenance costs of the entire system.

This article discusses the use of short bed IX deionizer systems for the production of high-purity boiler feed make-up water, and condensate polishing. The article also examines the use of micro media filtration[a] (MMF) as a pretreatment for RO or IX systems. The experiences of several installations are outlined for applications in power generation and cogeneration plants.

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Background

In order to increase their efficiency, and reduce generation costs and emissions, modern coal-fired generating stations are improving heat recovery rates by operating their boilers at higher pressures and temperatures. These pressures and temperatures have reached supercritical and even ultra supercritical levels in the newest state-of-the-art generating stations.

As operating pressures and temperatures increase, so must the purity of the boiler feedwater to prevent, or at least minimize to the greatest extent possible, the introduction of corrosion and scaling products to the boilers, and through carry-over to the steam turbines. Scaling and fouling cause heat transfer efficiency losses in boilers, and generating efficiency losses in steam turbines, resulting in higher operating costs, while corrosion, scaling and fouling all lead to higher maintenance costs and potentially catastrophic failures. Losses from unplanned outages and increased costs can add up to hundreds of thousands of dollars, or more if a problem occurs during a peak generating period or becomes a long term event (1).

Higher-purity boiler feedwater also allows an operator to reduce the amount of blowdown required in drum boiler operations (2). This will further optimize operating costs by reducing the amount of make-up water required, and the heat needed to bring it to temperature and pressure. Likewise, for gas-fired combustion turbine generating stations, whether simple cycle or combined cycle operations, higher-purity water for turbine injection and boiler feed make up reduces the rates of scaling, fouling and corrosion.

The reliable and cost effective production of high-purity deionized water becomes more important as generating stations strive for greater efficiencies, and lower emissions, with lower operating and maintenance costs.

Short-Bed Deionizer

Counter-currently regenerated IX deionizer plants have been available since the 1950s, and the major advantages claimed for this technology are lower regenerant chemical consumption, higher demineralized water purity, and smaller

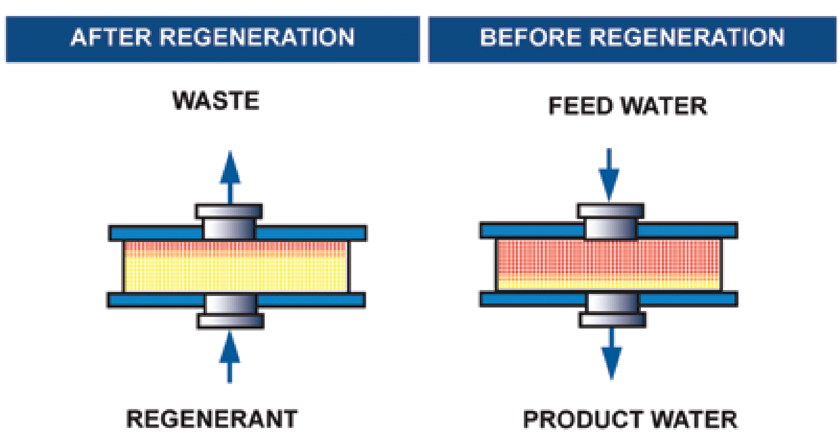

Figure 1. Water flow through the short bed after and before regeneration.

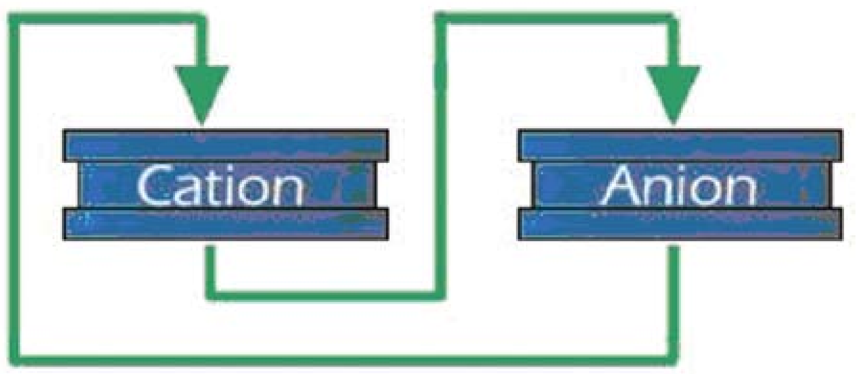

Figure 2. Circulation between vessels loaded with cation and anion resins after regeneration.

equipment (3).

The principles of the short-bed IX design date back to the late 1960s at the University of Toronto, and there are now more than 1,000 systems installed in more than 50 countries.

While a detailed explanation of the principles of the short-bed IX deionizer is beyond the scope of this article, it can be appreciated by reviewing several of the major design features incorporated into the system.

Fine mesh resin. The short-bed IX units use a fine mesh resin, which is about one fifth the size of conventional resins. This greatly increases the surface area to volume ratio, and decreases the diffusion path length, which dramatically enhances the kinetics of the IX process. The improved efficiency allows for much greater surface area flowrates of up to 35 gallons per minute per square foot (gpm/ ft^2). The smaller resin beads are also inherently stronger, and less susceptible to attrition because of osmotic shock and physical damage (4).

Short bed height/small resin volume. The resin beds depths of the short-bed IX units are either 6 inches in the deionizer configuration, or 3 inches in the polisher configuration, and the total resin volume is typically less than 10% that of conventional units. This dramatic reduction in the size of the resin beds makes it possible for the units to be preassembled and tested in the factory prior to shipping. This not only reduces the space requirements for the system, but also reduces the installation and start up time and costs.

Low resin loading. Unlike conventional IX units, which load the resin to the maximum extent possible in order to extend run times, the short-bed IX unit uses only 10% to 15% of the total exchange capacity of the resin. Using only the most accessible exchange sites near the surface of the resin beads further improves the exchange kinetics for both the service and regeneration cycles, reducing regenerant usage. By accepting a lower operating capacity, the regenerant usage can be further reduced, and it is possible to approach theoretical (i.e., stoichiometric) regenerant consumption. The low loading also decreases the resin volume change (i.e., swelling and shrinking) during each cycle, further reducing the attrition that occurs in conventional resins.

Counter-current regeneration. Regenerant passes through the resin bed in the opposite direction to the service flow, which maintains the cleanest resin as the last resin that the water comes into contact with at the bottom of the bed. With conventional counter-current regeneration, regenerant usage may be half that of co-current, and product water quality is maximized since the leakage of ions is much lower in counter-current units than in co-current vessels (5). Figure 1 illustrates the water flow through the short bed after and before regeneration.

Internal recirculation of rinse. Following the regeneration, which produces small volumes of waste, the final rinse is recirculated internally through the unit until the product water reaches the required quality. Only then is the outlet valve opened, and product water sent to the boiler (or storage tank). This further reduces the volume of waste compared to conventional units. Figure 2 shows the rinse circulation between vessels loaded with cation and anion resins after reeneration.

Compressed resin beds. By slightly compressing the resin inside the short bed IX unit, flow channeling is eliminated, and the resin is immobilized so that exchange profiles are maintained throughout the bed as the unit cycles, fully realizing the benefits of counter-current regeneration.

Shorter cycle times. The combination of high flowrates, low resin loading, and short bed heights result in short cycle times for both service and regeneration. Short service cycles of 20 to 60 minutes, and frequent regeneration cycles of 3 to 7 minutes (service-to-service, including rinsing) produces higher quality product water since leakage of ions and colloidal silica is virtually eliminated.

Feed forward conductivity control. With continuous monitoring of the feedwater conductivity, the ionic loading of the resin is constantly totalized by the programmable logic controller (PLC) as the cycle proceeds. The service cycle is automatically terminated prior to breakthrough when the loading reaches the programmed design level, and a regeneration cycle is initiated.

In addition to these design features, the short-bed IX unit uses an onboard direct injection system for concentrated regenerant chemicals, which simplifies the operation, and reduces the amount of peripheral equipment and operator interaction with the system.

As mentioned earlier, one of the major advantages of the short-bed IX deionizer system is the production of high-purity water without mixed-bed polishers. This further reduces the amount of equipment, chemical consumption and the complexity of operation and maintenance.

The one drawback of the short-bed IX system is the need for good pretreatment of the feedwater. Since it is not possible to backwash the compressed resin bed, it is necessary to have a prefiltration system upstream of the deionizer. It is fair to say that the short-bed IX system requires a level of prefiltration similar to that required by a reverse osmosis (RO) system (3).

Micro Media Filtration

The short-bed IX deionizer units use a fine mesh resin that is packed and compressed into place within the vessels. Since there is no freeboard within the vessels, the resin cannot be fluidized and backwashed to remove particulate matter that is not removed by pretreatment. Although this allows the short-bed IX systems to take advantage of the greater efficiencies of counter-current regeneration, it also requires a better filtration system to be used.

In order to address this requirement, and as a result of some of the features of the short-bed IX unit, a new dual media, backwashable filter was developed. This novel design uses a lower layer of very fine, high-density "micro media", along with an upper layer of standard anthracite. The main design features of this MMF are the following:

Coarse upper layer. The top layer consists of approximately 30 inches of coarse anthracite. This is similar to, but somewhat finer than that used in a conventional dual-media filter, and provides the bulk of the solids retention.

Micro media lower layer. The lower layer is a significant departure from conventional dual-media filter design, which typically uses 8 inches of silica sand with an effective size of about 0.35 millimeter (mm). The much higher density (almost 2X that of sand) micro media has an effective size of less than 0.1 mm. The higher density of the lower micro media causes it to settle out much quicker after backwash, creating a well-defined interface layer between the upper and lower media. This interface provides a barrier to any fine suspended solids not retained by the upper layer.

High service flowrate. Service flowrates for the MMF are significantly higher than conventional media filters. Typically, the MMF operate in the range of 12 to 16 gallons per minute per square foot (gmp/ft^2), compared to the maximum of 8 gmp/ft^2 of a conventional filter.

Smaller diameter vessel. Because of the higher service flowrate, a much smaller diameter vessel can be used to provide an equivalent capacity filter. This results in smaller equipment and less space.

Short ripening period. As a result of the defined interface layer between the media, the rinse to quality is much shorter for the MMF following a backwash cycle. Often the filtrate quality is achieved with less than one vessel volume of rinsing.

Backslip. Since the micro media provides an effective barrier to suspended solids, any fine particulate not retained by the upper layer remains on the interface, and does not penetrate into the micro media layer. As a result, a patented process called a backslip was developed to extend the service cycle of the MMF between full backwashes. In the backslip, the flow is reversed for a short interval to push, or burp, the suspended solids back up into the upper layer, cleaning the interface layer. After a quick rinse to quality, the filter can operate for another service cycle. Up to 7 backslips have been achieved before a full backwash is required. However, this is typically restricted to 3 to 5 backslips.

Power Industry Experience

MMF. At a public utility generating station in the southwestern United States, an existing ultrafiltration (UF) system was not able to meet the demands of filtering clarified lake water to feed the water treatment system because of maintenance and reliability issues. The utility hired a major engineering firm to find the best filtration solution for their needs. After a thorough evaluation of the technologies available, and pilot testing of each, the engineer recommended micro media filtration as the best option. Table A shows performance data from the use of the MMF.

MMF and Short-bed IX. A gas-fired, combined cycle combustion turbine generating station in Mexico uses tertiary treated municipal effluent as their feed source for boiler make up and turbine injection water. The original water treatment system, consisting of multimedia sand filters, RO, and electrodeionization (EDI), was having difficulty meeting the capacity and quality requirements of the plant. Following a thorough evaluation by a major EPC, the decision was made to expand the capacity and address the quality issues using MMF, and short-bed IX polishers, along with higher capacity elements in the existing RO. After more than 8 years of continuous service, the system is still consistently meeting the quality and capacity requirements. Table B provides data showing the system's performance.

Short-bed IX. A coal-fired power plant in the Midwestern United States was experiencing many maintenance and reliability issues with their existing RO followed by an EDI system. Based on their requirement to expand their deionized water production capacity, and the recommendations of a major engineering firm hired for the project, the plant replaced the EDI system with short-bed IX deionizer units. An additional single-pass RO train was added to increase their overall capacity to meet the new requirements. Based on the small size of the equipment, the new water treatment system was installed on the turbine deck. After more than 2 years of consistent operation, the plant chemist reported that the system produces between 0.05 and 0.07 microsiemens per centimeter (µS/cm) water.

MMF and short-bed IX. A major expansion at a coal-fired, supercritical power plant in the Midwestern United States required effective filtration to treat a blend of river well water, and recycled cooling water after a clarifier to provide service and cooling water, and a water treatment system to produce high-purity boiler make up from the service water. The EPC selected MMF to produce the 2,000 gpm of service and cooling water (< 0.2 Nepholemetric Turbidity Units [NTU]), and a system consisting of single-pass RO followed by short-bed IX deionizer/polishers for the 200-gpm of < 0.1 µS/cm make-up water. Following some initial difficulties with unknown organic contaminants, the system was successfully started up and the new generating unit went online.

Short-bed IX. The expansion of a coal-fired power plant in the Midwestern United States required a new water treatment system to produce high purity (< 0.1 µS/cm) boiler feed make up from well water. The EPC selected a system consisting of cartridge filters (CF), two-pass RO, and short-bed IX polishers. Following the successful start up and consistent operation of the Unit 2 water treatment system, the plant owner has decided to upgrade the Unit 1 water treatment system by replacing the existing conventional IX columns, which follow CF and single-pass RO, with the short-bed IX polishers. Reliability, product water quality, and the automated operation of the short-bed IX units were cited as the key factors in the decision.

MMF and short-bed IX. A new coal-fired, supercritical power plant was being built in Texas. Tertiary treated municipal wastewater would be used as the feed source for the water treatment system (WTS) to produce high-purity (< 0.1 µS/cm) boiler make up. After a thorough evaluation of the available technologies, along with the performance of a similar system at a combined cycle gas-fired plant in Mexico, the EPC selected a water treatment system consisting of MMF, single-pass RO, and short-bed IX deionizer units.

The start up of the WTS was completed in December 2010, and the system has met all performance expectations. The WTS is currently being used to provide washing and flushing water for the completion of the rest of the power plant. Steam blows are expected to begin in summer 2011.

Short-bed IX for condensate polishing. At a new cogeneration plant and an existing heat and process steam plant, both located in Ontario, Canada, returning condensate is polished prior to being returned to the boiler feed tanks. By treating the condensate prior to returning it to the boilers, both plants are able to reduce boiler maintenance and minimize blowdown by virtually eliminating contaminants being introduced due to tube leaks and concentration from evaporative losses. At both locations, the decision was made to use the versatility and robustness of the short-bed IX polishers with counter-current regeneration for this application. After several years of continuous operation, both units are maintaining a consistent condensate quality of < 0.1 µS/cm.

MMF and short-bed IX. After 10 years of continuous and consistent operation at an 8-reactor nuclear generating station, a water treatment system consisting of MMF, single-pass RO, and short-bed IX deionizer and polisher units continues to produce high-purity feed water from a shallow intake on the Great Lakes. The strict quality and capacity requirements (> 16.7 megohm-cm, 66 liters per second [L/s]) are actually being surpassed as the WTS is producing an average of 18.0 megohm-cm. Organics, silica, and sodium are of particular concern with this plant. Table C provides performance data for this facility. Current regenerant consumptions for this system are the following:

Deionizer: Sulfuric acid (H_2SO_4) (93%) = 0.0195 gal/1,000 gal deionized water
Sodium hydroxide (NaOH) (50%) = 0.0403 gal/1,000 gal deionized water

Polisher: H_2SO_4 (93%) = 0.00004 gal / 1,000 gal deionized water
NaOH (50%) = 0.00007 gal/1,000 gal deionized water❑

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Endnote

[a]The micro media filtration (MMF) discussed in the text is based on the Spectrum Micro Media Filters™ product line developed and sold by Eco-Tec Inc., which is based in Pickering, Ontario, Canada.

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TABLE A
Pilot Data Showing Micro Media Filtration Performance

Parameter	*Specified Feed*	*Proposed Filtrate*	*Actual Feed*	*Actual Filtrate*
Turbidity (NTU)	< 10.0	< 0.2	0.72 – 3.52	0.13 – 0.16
SDI (15)		< 5		4.0 – 4.7
Net flowrate (gpm)		184		198

TABLE B
Data for Using MMF and Short-Bed IX Together

Parameter	*Specified Performance*	*Proposed Performance*	*Actual Performance*
Conductivity (µS/cm)	< 0.10	< 0.10	0.07
Silica (ppb)	< 10	< 5	< 3
Net Flowrate (m^3/hr)	40	40	41

TABLE C
Performance Data for Water System at Nuclear Power Plant

Parameter	*Specified Performance*	*Proposed Performance*	*Actual Performance*
Feed turbidity (NTU)	20	20	1 – 150+
Filtrate turbidity (NTU)		< 0.2	< 0.2
Product conductivity (µS/cm)	< 0.06	< 0.06	0.055 – 0.057
Silica (ppb)	< 2	< 2	0.1 – 0.7
Sodium (ppb)	< 0.2	< 0.2	0.02 – 0.06
Net flowrate (gpm)	1,050	1,050	450 – 1,100
Acid consumption (gal/kgal)			0.0195
Caustic consumption (gal/kgal)			0.0403