Short-Bed Demineralization: An Alternative to Electrodeionization

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ABSTRACT

To be competitive in the deregulated market, power producers are looking for ways to lower operating costs while maintaining a reliable supply. To this end, many plants have investigated innovative technologies for boiler make-up water treatment. One such technology is the combined reverse osmosis (RO) and electrodeionization (EDI) system. While this system offers several benefits, its operating costs and lack of operating experience in power plant applications make it unattractive in certain cases. Another water treatment technology, short-bed demineralization, combines the low cost, proven reliability, and high performance of conventional mixed-bed ion exchange with many of the benefits of RO/EDI systems.

INTRODUCTION

Deregulation of government controlled power markets is forcing utilities and independent power producers to take a closer look at their production costs. In the almost risk-free monopoly days, a utility could maintain profitability by simply passing the operating costs to the customers. However, survival in the new competitive era depends upon remaining profitable when the price of electricity is determined by the open marketplace rather than by cost-plus pricing. The main focus is therefore on operational efficiency and the ability to provide a reliable power supply when it is required. One area that has been identified by many power plants for operating cost savings is the boiler feed water treatment system. Two water treatment technologies that are coming to the forefront are electrodeionization (EDI) and short-bed demineralization.

ELECTRODEIONIZATION

While the first related patent was issued in 1957, it was not until 30 years later when the first electrodeionization product was marketed. Millipore commercialized its CDI™ (continuous deionization) product in 1987 through Ionpure, with the first system installed in 1988. The expansion of the technology continued through U.S. Filter Corp. which bought Ionpure in 1993. Since the technology became commercially viable, a number of companies have offered similar products. Early installations were primarily in low flow applications, such as laboratories and pharmaceutical plants, where the flows were generally less than 50 gpm. Efforts are now underway to market much larger systems with acceptable materials of construction for power generation and semiconductor applications.

The EDI units are modules that may be operated individually, or in series if a greater flowrate is desired. Each module has the capacity to treat 10 to 15 gpm, depending upon the design. The inside of the module, as shown in Figure 1, consists of a series of cell pairs that are arranged to form flow-through compartments. Each cell pair consists of a cation permeable membrane on one side and an anion permeable membrane on the other side. The space between the two membranes is filled with a mixture of cation and anion resin and is often referred to as the "diluting compartment". There are also two additional compartments on the other side of the membranes, often called the "concentrating compartments".

As water flows through these three chambers, ions are exchanged onto the resin in the diluting chamber. A DC electric potential, applied by an external power supply, will cause ions to move from the resins and across the membranes into the concentrating compartments. As shown in Figure 1, a cathode will drive positively charged cations across the cation membrane while an anode will remove the negatively charged anions through the anion membrane. The selective membranes will allow only the passage of the appropriately charged ions, i.e., only cations can be transported across the cation membrane and only anions can be transported across the anion membrane. The electric current therefore maintains the resins in a highly regenerated state, making it unnecessary to use acid or caustic for regeneration. The treated water exits the diluting chamber while the water from the concentrating compartments is recirculated to promote mixing. To prevent ion concentration from reaching the point of precipitation, a small stream is bled from the concentrated stream loop. A small portion of concentrated stream is also used to flush the electrodes to remove any build-up of gases.

The EDI unit is capable of producing water with a resistivity of up to around 16 megohm•cm, but requires a very high quality feed water, as shown in Table 1. A reverse osmosis (RO) system is therefore almost always used prior to the polishing EDI units.

The intricate design of the stacks makes on-site maintenance very difficult. For replacement, the complete stack is usually sent back to the manufacturer for exchange. A typical stack life is claimed to be 5 years.

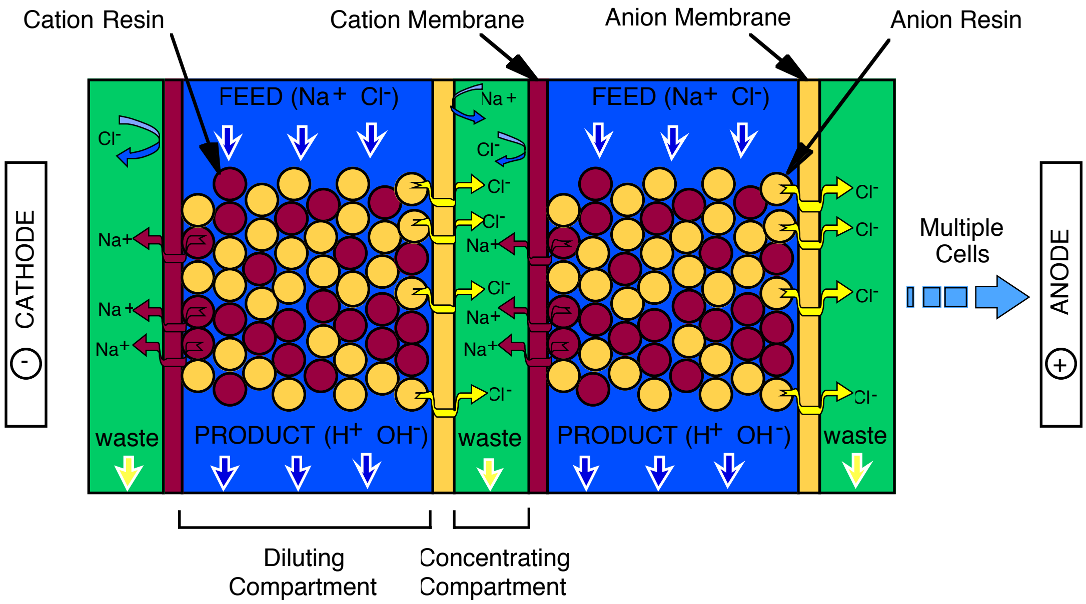

Figure 1 - Ion transfer in a typical EDI stack

Feed Characteristic	Value
Total Dissolved Solids	<5.0 ppm
Hardness (as $CaCO_3$)	<1.0 ppm
Total Organic Carbon	<0.5 ppm
Free Chlorine (Cl_2)	<0.05 ppm
Iron (Fe), Manganese (Mn)	<0.01 ppm
Silica (SiO_2)	<0.4 ppm
Hydrogen Sulfide (H_2S)	<0.01 ppm
pH	4 to 9
Temperature	5 to 40 °C

Table 1 - Typical feed water requirements for EDI stacks

RO/EDI offers certain advantages over standard deep-bed demineralization; most notable is the elimination of the infrastructure and operator exposure associated with the acid and caustic regenerant chemicals. Cleaning chemicals and pretreatment chemicals prior to the reverse osmosis system, such as acid or antiscalant addition, are often still a requirement. Furthermore, the membranes in the EDI unit have to be periodically cleaned with peracetic acid or some other disinfectant to remove biological foulants. Other benefits include continuous operation, constant water quality, modular design, small space requirements, rapid installation, and the elimination of the regenerant waste stream.

For boiler feed applications, RO/EDI systems have several drawbacks including a relatively high capital cost, high EDI stack replacement costs, high energy consumption, and the difficulty in removing weakly ionized contaminants such as silica, carbon dioxide, and organics. The system is susceptible to fouling by colloidal silica or organic material typically found in surface waters, such as humic, fulvic, or tannic acids. In addition, EDI systems are only available with plastic piping due to the danger of accelerated corrosion from stray currents.

SHORT-BED DEMINERALIZATION

The Short-bed demineralizer was first commercialized as the Recoflo® Demineralizer by Eco-Tec Inc. in the 1970s (Figure 2). The first unit was installed in 1978 to provide high purity rinse water in a chrome plating facility. Hundreds of units of been installed since, primarily in boiler feed applications.

A short-bed demineralizer employs two shallow beds (down to 3") of ion exchange resin (one cation bed and one anion bed). This is in contrast to deep-bed units in which the bed heights are typically greater than 3 feet. The small resin volume translates into relatively inexpensive resin replacement costs. In order to ensure proper distribution of water and regenerant through the shorter resin beds, the vessels are fully packed with fine mesh resin such that no freeboard exists. The fine mesh resin beads are approximately one-quarter of the diameter of other ion exchange resins. Fine resins improve ion exchange kinetics, allow for more efficient rinsing, and are physically stronger than their larger counterparts. Elimination of the freeboard reduces liquid dilution and intermixing in the bed and consequently reduces rinse volumes. Packed resin beds also ensure that the exchange zone profile is not disturbed to allow for the most efficient usage of regenerant chemicals.

The operation of a short-bed demineralizer is also distinctive. Whereas conventional deep-bed demineralizers load the resins to near exhaustion (i.e., around 90%), short-bed units will use less than 20% of the total exchange capacity of the resin. By using only the most accessible exchange sites, kinetics of ion uptake and regeneration are improved, and regenerant usage is minimized since the sites that most readily accept an ion are those that are most easily regenerated. Furthermore, the low resin loading does not force the resin beads to undergo large changes in size which is the main cause of resin fragmentation. The chemical usage efficiency of the unit is further improved through counter-current operation in which the regenerant chemicals are passed through the bed in the opposite direction to the onstream flow.

Figure 2 - Recoflo® short-bed demineralizer

With feeds containing up to around 100 ppm of total dissolved solids (TDS), the rapid ion transfer kinetics allows a single two-bed unit to produce high quality water (e.g., 10 megohm•cm with less than 10 ppb silica). Deep-bed demineralizers would require a mixed-bed polisher for this purpose. An RO primary unit or a two unit configuration can be employed to produce better quality water (i.e., 10 to 18 megohm•cm with less than 5 ppb silica) from feeds with higher TDS concentrations.

The combination of small resin volume and low exchanger loadings results in short onstream and regeneration cycle times. Depending on the feed dissolved solids concentration, the total cycle time is approximately 10 to 120 minutes. During offstream, regeneration and rinsing takes around 4 minutes, and this is followed by an internal recirculation to the desired product quality which takes approximately 1 to 3 additional minutes. These cycle times are drastically different from those of deep-bed systems that are typically onstream for around 20 hours and require 2 to 4 hours for regeneration. The shorter cycle times result in the production of small "slugs" of wastewater throughout a day rather than one large volume of wastewater. These small "slugs" allow for a much smaller waste holding tank and waste treatment facility.

The shorter cycles also aid in identifying and resolving operational problems. It typically takes a full regeneration cycle to assess the operation of any demineralizer. If the specified product quality is not being produced, then the cause must be identified and remedied, and the unit must be regenerated once again. This procedure, which is continued until the required water quality is produced, can take a long time with most demineralizers since each regeneration cycle can take 3 to 4 hours to complete. The shorter regeneration time of the short-bed unit (around 6 minutes), however, allows for several regenerations cycles to be conducted in a short period of time.

COMPARISON BETWEEN RO/EDI AND SHORT-BED DEMINERALIZATION

Short-bed demineralization combines the benefits of the RO/EDI and conventional deep-bed demineralization technologies, as summarized in Table 2.

Proven Reliability -Short-bed demineralization technology, like its deep-bed counterpart, has been successfully employed for over two decades in numerous installations for the production of high purity water. The use of EDI outside of low flow applications has been somewhat limited. In fact some EDI products have been on the market for less than their claimed lifespan of 5 years. As such the long-term reliability of the EDI technology and the actual life of many of the EDI brands are yet to be verified.

Space Requirement - The low resin inventory of the short-bed demineralizer results a space requirement that is as small or smaller than an EDI system; typically half the space of a conventional demineralization system.

Installation and Commissioning - As with the EDI stacks, installation of the short-bed demineralizer is expedited by loading the resin in place prior to shipment. To reduce commissioning time, the unit can even be operated to produce the specified quality of product at the manufacturer's facility. A short-bed demineralizer can be commissioned in several days. This is in contrast to a conventional deep-bed system that requires one to two weeks to load the resin into the beds and troubleshoot the unit on-site. Both the EDI and short-bed systems require minimal civil work for installation.

PARAMETER	MIXED-BED DEMINERALIZATION	REVERSE OSMOSIS/ ELECTRODEIONIZATION	SHORT-BED DEMINERALIZATION
RELIABILITY	• Proven reliability in many installations	• limited number of installations and short-term operating experience in power plants • susceptible to scaling by hardness and silica that leak through RO	• proven reliability in many installations
EQUIPMENT	• stainless steel piping available • complex auxiliary equipment • complex regeneration sequence	• plastic piping only, no stainless steel • skid-mounted, compact, small footprint • complex EDI stacks • stacks prone to leaking	• stainless steel piping available • skid-mounted, compact, small footprint • simple two bed configuration
WASTE HANDLING	• large waste volume generated (waste handling issues)	• no need for waste treatment	• small "slugs" of waste generated *(easy to handle)*
INSTALLATION, COMMISSIONING	• on-site construction, assembly of parts (labor and time intensive) • resin must be loaded on-site • unit must be troubleshot on-site	• easy to install, pre-assembled	• pre-assembled and pre-tested • resin already installed, conditioned, and ready for service • easy to install, and commission (lower installation costs)
SERVICEABILITY	• long cycle times may require more time/supervision to identify and ensure system errors have been corrected • deep beds (feet) require longer downtime for re-bedding; long downtime (days) for brine squeeze to remove organics from the resin	• EDI stacks are not serviceable on-site; must be sent back to the manufacturer	• short cycle times facilitate troubleshooting • short beds (inches) allow easy re-bedding; short downtime (hours) for brine squeeze
OPERATING COSTS	• high volume of chemicals required • large volumes of resin to replace	• high energy consumption • high replacement costs for stacks • EDI stack membrane cleaning required	• uses less regenerant chemicals • small volume of resin to replace

Table 2 - Comparison of water treatment technologies

Chemical Requirement - A main benefit of the EDI system is the elimination of the need for on-site storage of concentrated acid and caustic regenerants. This benefit translates into a reduction in capital cost since the infrastructure required to hold and convey these chemicals is no longer required (e.g., storage tanks, waste neutralization facility). In addition, the risk of exposure of plant personnel to these hazardous chemicals is also eliminated.

While short-bed demineralization requires the acid and caustic for regeneration, the short cycle operation and regenerant dosing design minimizes required infrastructure and risk of exposure. For regeneration, concentrated chemical can be drawn from small totes (e.g., 220 gal) and diluted in-line directly below the resin bed, thus reducing the risk of operator exposure and the need for bulk storage tanks. Totes of concentrated acid and caustic are available from numerous chemical suppliers across North America and Europe. In installations with a primary reverse osmosis system, each tote can last as long as 3 months, depending upon the product flowrate. In addition, the short cycles of the unit result in the generation of small "slugs" of wastewater throughout the day. The waste neutralization facility for a short-bed demineralizer is therefore much smaller than the facility for a deep-bed demineralizer system that must be designed for a large volume of wastewater at one time. In many cases, the low flow waste stream can be recycled directly in front of the reverse osmosis unit to recover a portion of the wastewater.

Operating Cost - A comparison of the operating costs of an EDI stack and a short-bed polisher for a typical make-up water application is given in Table 3. The costing is for the production of 400 gpm of 10 megohm•cm water from a reverse osmosis permeate containing a TDS concentration of 4 mg/L as $CaCO_3$. The operating costs for pretreatment, the primary reverse osmosis system, and O&M labor are assumed to be the same for both cases. The short-bed system offers a savings of approximately $45,000 per year. Even if the wastewater from the EDI was recycled back to the plant for another purpose (e.g., cooling or pump seal water), the annual operating cost for the short-bed demineralizer would still be around $37,000 less.

The influence of EDI stack life is far greater on the overall operating cost than the influence of resin life. As shown in the sensitivity analysis in Figure 3, a reduction in resin life has a minimal effect on operating cost. A one year decrease in resin life has almost no effect on the normalized annual operating costs of the short-bed demineralizer (1% increase), but the same decrease in EDI stack life would increase the operating costs by 11%. Even in the extreme case of having to change both the cation and anion resin beds every year, the annual operating costs would increase by only around $5,400 or 27%. This in stark contrast to the $127,400 increase or almost threefold increase that would be incurred if the EDI stacks had be replaced annually. The risk is further compounded by the lack of long-term operating experience of the EDI system in power plat applications.

Operating Cost ($/1000 gal)	Short-Bed Demineralization	Electrodeionization
Electricity	0.060	0.118
Steam	0.003	
Sulfuric Acid	0.003	
Caustic	0.011	
Resin Replacement	0.007	
EDI Stack Replacement		0.152
Wastewater	0.010	0.040
Total Cost ($/1000 gal)	**0.094**	**0.31**
Total Annual Cost ($/yr)	**$19,762**	**$65,174**
Design Basis: electricity ($0.05/kWh), steam ($2.50/1000 lb), sulfuric acid ($0.04/lb), caustic ($0.18/lb), EDI stack ($5000/stack), raw water ($2.00/1000 gal), sewerage ($2.00/1000 gal), resin life (5 years), EDI stack life (5 years), waste neutralization included		

Table 3 - Operating cost comparison between EDI and short-bed demineralization (400 gpm net flow, 10 megohm•cm product with < 0.010 mg/L silica)

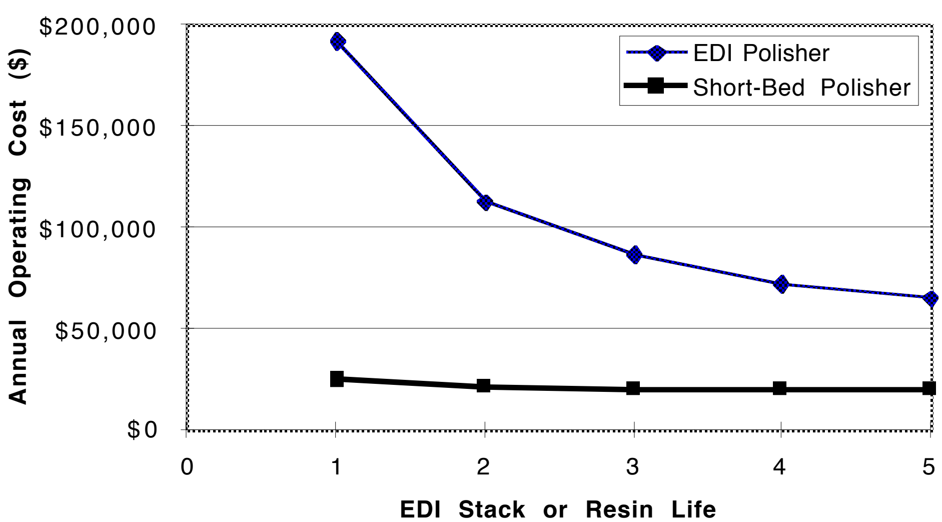

Figure 3 - Effect of resin life and EDI stack life on annual operating cost (400 gpm net flow, 10 megohm•cm product with < 0.010 mg/L silica, see Table 2 for design basis)

SUMMARY

Electrodeionization technology for water treatment offers several benefits; most notable is the elimination of the on-site bulk storage and operator exposure associated with the use of acid and caustic regenerants. Other benefits include continuous operation, small space requirements, rapid installation, low labor requirements, and the elimination of the regenerant waste stream. For boiler feed applications, EDI systems have several drawbacks including a relatively high capital cost, high energy consumption, and the inability to effectively remove weakly ionized contaminants such as silica, carbon dioxide and organics. Also, as the technology is relatively new, its long-term reliability in power plant applications is unknown.

Short-bed ion exchange technology appears to combine the low cost, proven reliability, and high performance of standard mixed-bed ion exchange with the low chemical exposure, low maintenance, rapid installation, and small space requirements of EDI.