DEIONIZATION

COST REDUCTION AND OPERATING RESULTS OF AN RO/EDI TREATMENT SYSTEM

Electrodeionization (EDI) uses electrical current, in lieu of acid and caustic chemicals, to regenerate cation and anion resin. Reverse osmosis/EDI systems are now widely used to replace conventional mixed-bed ion-exchange (IX) technology in a broad range of applications.

Proven effective at high flowrates, EDI has in recent years been incorporated in water treatment plants around the world, primarily in the power generation, chemical, electronics, and pharmaceutical industries. The benefits of EDI are well known. While conventional mixed-bed systems require batch regeneration of the resin beds, which leads to variations in water quality, EDI offers continuous operation. As a result, quality is consistent and predictable. Because no regeneration chemicals are required, compliance with stringent environmental and safety standards is simplified. The hazardous waste stream, common to all mixed-bed systems, is eliminated. The EDI reject water can be recovered by the system ahead of the RO, or sent directly to drain, with no neutralization infrastructure or permitting required. Electrodeionization systems also have a smaller footprint than mixed-bed IX systems of comparable capacity. The most widely used systems offer a modular design, with the flexibility to accommodate any height and space requirements.

As more companies make the move to EDI, the specific cost and performance benefits of this technology compared to mixed-bed systems are increasingly apparent. However, for the comparison to be accurate, it is important to look at the entire system. If the water treatment plant has already been specified, it will be necessary to take a step back and look at all the factors which affect system performance and payback. For many applications, EDI offers significant performance improvements while substantially reducing system infrastructure and operating costs. This article relates Fuji Photofilm's experience with the EDI technology.

When facility expansion at Fuji Photofilm in Greenwood, S.C., necessitated additional high-purity water production capacity, new water plant designs were evaluated. These design considerations included: initial capital cost, operating costs, physical space requirements, reliable performance, chemical usage, and waste disposal requirements.

The old plant consisted of an activated carbon filter pretreatment stage, an RO stage, and a mixed-bed deionization (DI) stage. The capability of the new system was to be similar to the old one, consisting of two trains, each producing 250 gallons per minute (gpm) of product water. The decision to upgrade mixed-bed technology with more efficient EDI was made based on the results of a pilot test, as well as the reduced capital and operating costs that could result from its use.

A key aspect of the manufacture of photographic emulsion is the formation and growth of silver halide crystals. This critical reaction between silver nitrate and halide is process sensitive, and requires close quality control of the chemical constituents. Pure water, used as a solvent, is a primary ingredient in producing the silver chloride and halide solutions. Trace contaminants in the process water can have deleterious affects on the silver halide crystal formation and growth. Pure water is used further throughout the process in the making of numerous sensitizing chemicals, preparation of the gelatin used to suspend the halide crystals, for chemical "washing" of the emulsion, and for post-batch clean in place.

In addition to the cost and performance considerations addressed below, Fuji had concerns about the reliability of mixed-bed technology. Upset conditions had previously been experienced causing process contamination and product loss. Electrodeionization offered fewer potential process problems with less possibility of contamination, and lower potential for operator exposure to hazardous chemicals. The new EDI system was installed in the spring of 2000.

Pilot Test

When considering the introduction of new technology for the production of pure water, a number of concerns were raised. Materials used in the construction of the EDI unit, methods used in the manufacture of the EDI unit, the EDI resin, specifics of regeneration, and other unknown factors raised cautious con-

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TABLE A
Pilot Test Results

Feed Conductivity (μS)	*Feed SiO_2 (ppb)*	*Product Resistivity (megohm-cm)*	*Product SiO_2 (ppb)*	*Silica Rejection*
1.9	1500	17.8	23	98.5%
1.92	567	18.0	10.6	98.1%
3.5	670	17.4	18	97.3%
1.4	312	18.0	7.8	97.5%
1.4	108	18.0	6.9	93.6%

TABLE B
Comparison Costs

System	*Cost*
RO/IX	
● Single-pass RO system, two trains rated at 265 gpm permeate rate. ● Granular activated carbon system, two parallel three-column trains rated at 330 gpm per train. ● Mixed-bed deionization system, three trains rated at 250 gpm.	$1,015,221
RO/EDI	
● Single-pass RO system, two trains rated at 265 gpm permeate rate ● Granular activated carbon system, two parallel three-column trains rated at 330 gpm per train. ● EDI system, two trains rated at 250 gpm.	$925,608

TABLE C
Ancillary Facilities Cost

System	*Cost*
● Bulk chemical supply for regeneration (i.e., sulfuric acid and sodium hydroxide).	$57,690
● Neutralization tank with pH monitoring and control	$18,350
● Regeneration skid, with sodium hydroxide heat exchanger for heating caustic, and sulfuric acid heat exchanger for cooling acid.	$43,950
● Total ancillary costs	$119,990

TABLE D
Mixed-Bed Cost per Year

Item	*Cost*
Acid	$2,102
Caustic	$13,140
Manpower	$4,088
Waste Water	$6,137
Resin	$5,820
Total:	$31,267

cern as to the effect the new process might have on water characteristics and quality. Fuji felt it necessary to invest the time and resources to commission a pilot test EDI unit, to process the RO water currently produced at the factory and normally fed to the existing mixed-bed unit. Pure water produced by the EDI system, along with pure water produced by Fuji's existing mixed-bed DI system, was used to make test emulsions that were otherwise identical. The emulsions were then examined for differences in photographic properties. The results showed no measurable differences. It was deemed that EDI technology could be applied to produce pure water to meet Fuji's process requirements.

The 12.5 gpm pilot test ran continuously for two weeks. Product water quality and silica content were monitored under various conditions. While the EDI manufacturer recommended not exceeding 500 ppb of silica, Fuji saw impressive results beyond the manufacture's claims. Temperature of the feedwater was consistently 33 to 34 °F, which is also outside the manufacturer's recommendations, due to the low ion mobility that occurs at colder temperatures. Table A shows data from the pilot test.

Cost Reduction: Mixed-Bed versus EDI

An accurate cost comparison between mixed bed and EDI required breaking costs down into three main areas: capital costs, facility costs, and operating costs, not to mention the intangible costs that relate to worker safety, environmental risks, and the increased liability surrounding the handling of acid and caustic chemicals. When the comparison was complete, the overall savings in favor of EDI technology were approximately 22%.

Capital costs for a traditional mixed-bed IX system would include not only the cost of the primary DI system, but additional costs for chemical storage, neutralization, and regeneration equipment.

Additionally, if conventional mixed-bed DI would be used at Fuji, then a substantial chemical regeneration system would have to be separately located and supplied with appropriate chemicals. Because the new plant was located away from the existing pure water system, regeneration chemicals would need to be supplied using chemical totes or bulk storage tanks. Provisions for loading and unloading trucks, containment infrastructure and the physical space for these peripheral process components would have to be made.

Because the off-line regeneration required by traditional mixed-bed technology necessitates a second, redundant system to ensure continuous pure water production, a third DI system would have been required to provide the necessary redundancy in the case of component failure. Because with EDI, continuous regeneration occurs on-line, only two EDI systems were required to meet production requirements.

The vendor[a] supplied Fuji with competitive pricing for both RO/EDI and RO/mixed bed systems. Table B compares the investment required for each.

Further consideration was given to the ancillary facilities required for mixed-bed polishing, which were not needed with the EDI system[b]. These considerations and the associated investment are highlighted in Table C.

The above costs include double containment for the tanks, as well as piping for carrying hazardous chemicals.

Combining the ancillary costs with the primary mixed-bed system costs brought the total investment to $1,135,211, a difference of $209,603 or approximately 18% more than a comparable EDI configuration.

Facility costs. The comparative footprints and related costs were also reviewed in the evaluation of the two systems. Aisleways a minimum three feet wide were required to allow for removing and installing components, and servicing for both systems. For the RO/mixed-bed option, the facility would have needed 3,490 square-feet (ft^2). The RO/EDI configuration would have required 2,880 ft^2.

TABLE E
Annual EDI Cost

	Estimated with Brine	*Estimated w/o brine*	*Actual w/o Brine*
Electrical	1.6 kw-hr/kgal	2.4 kw-hr/kgal	2.6 kw-hr/kgal
Consumption	$5,172	$7,758	$8,405
Cost of Brine	$234	$0	$0
Manpower	$2,044	$2,044	$2,044
Waste Water	$0	$0	$0
Stack Replacement	$16,800	$16,800	$0
Total:	$24,250	$26,602	$10,449

TABLE F
Predicted RO Permeate versus Actual RO Permeate

Parameter	*RO Feed*	*Predicted*	*Actual*
Conductivity	232.6 µS/cm	1.3 µS/cm	2.8 µS/cm
pH (25 °C)	7.1	n.a.	n.a.
TEA	92.7 ppm	2.2 ppm	2.7 ppm
TEC	88 ppm	0.6 ppm	1.3 ppm
SiO_2	n.a.	90 ppb	180 ppb

n.a. = not available

TABLE G
Predicted versus Actual EDI Quality at Fuji Plant

Parameter	*Specification*	*Predicted*	*Actual*
Resistivity	>5 megohm-cm	>16 megohm-cm	17.3 to 18.0 megohm-cm
Silica	<10 ppb	< 5 ppb	<1 ppb
Cl^-	<10 ppb	< 10 ppb	2.9 ppb
SO_4	<10 ppb	< 10 ppb	0.07 ppb
NO_3	<10 ppb	< 10 ppb	0.12 ppb
Ca	<10 ppb	< 10 ppb	<0.02 ppb
Na	<10 ppb	<1.4 ppb	0.43 ppb
Fe	<10 ppb	< 10 ppb	<0.02 ppb

Applying a price of $80/ ft^2 of finished wet processing area, the additional 610 ft^2 required for the mixed-bed system would cost $48,800, bringing the cost difference to $258,403 or approximately 22% less for the EDI configuration.

Operating costs. Conventional mixed-bed operating costs include chemical consumption, plus labor costs for regeneration, wastewater disposal and resin replacement. In contrast, operating costs for EDI include electricity, plus labor for maintenance and stack replacement.

Electrical consumption for EDI includes power required for the instrumentation, recirculation pump, and rectifier, as well as the electricity used by the EDI stacks for regeneration. Labor for EDI maintenance is significantly less than that required for a mixed bed. The EDI takes a few minutes, several times a week, to record data logs and make manual adjustments, whereas regenerating and cleaning a mixed-bed system takes several hours for each regeneration. The EDI wastewater is made up of a concentrate bleed and an electrode stream that can be recovered, combined with the RO concentrate, and used as industrial water to re-fill cooling towers and process vessel thermal baths. No separate wastewater disposal is required. Stack replacement occurs typically every 5 to 10 years.

Table D provides a breakdown of the annual cost for a mixed-bed system. The cost is estimated, based on proposed mixed beds operating at average 205 gpm usage, 24 hours per day, 365 days per year.

Table E illustrates the yearly cost for EDI. Electrical consumption is dependent upon the ability to conduct current throughout the stack. At Fuji, we evaluated the benefit of brine injection. To date, no stacks have been replaced.

Intangible costs. Fuji also considered the intangible costs of the chemical regeneration process required with mixed-bed technology, including issues of worker safety and general liability.

Operating Results

To date, performance of the specified EDI technology has exceeded requirements. Actual performance criteria were established according to the following specification, as shown in Table F. Table G shows the predicted versus the actual EDI water quality at the Fuji plant.

Conclusions

Performance criteria and results

achieved are rarely the same for any two industrial high-purity water systems. While the results discussed here cannot be directly applied in evaluating the potential performance of EDI in different applications where requirements might vary widely, it is evident from the data presented that Fuji's EDI system performed dramatically better than predicted.

In addition, cost savings were substantial: 22% in capital costs, and some 15% in projected annual operating costs based on the pilot test. In the previous pure water plant application, the process design and installation were assigned to a general design/build firm and their related sub-contractors. The original budget for this new project was developed based on this past experience. Fuji Photofilm teamed with engineering firm, O'Neal Inc., equipment supplier Trionetics Inc., and installer, Kajima - Process Mechanical Division to complete a new pure water system that performs better, is more environmentally robust, and cost 45% less overall than the projected budget.■

Endnote

[a]Trionetics Inc. of Twinsburg, Ohio, was the provider of prices for the RO/EDI and RO/mixed-bed equipment.

[b]E-Cell™ from E-Cell Corp. in Guelph, Ontario, Canada.

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