using EDI to meet the needs of pure water production

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Note: SUEZ purchased Ionics in 2005.

summary

This report describes the advantages of using EDI for ultrapure water production for power plant boiler makeup water and microelectronics fabrication rinse water. Operating data is presented showing the advantages of EDI for these applications.

introduction

The three industries of power, pharmaceutical and microelectronics have different needs and specifications for high-purity water. This report will describe the use of electrodeionization (EDI) technology for the production of pure water in the power and microelectronics fields. Two of the field installations described are in the power industry and use EDI to produce high-quality water for boiler makeup. The third installation of interest applies EDI technology in the microelectronics industry for microchip fabrication rinse water.

Although the EDI technology is being used in two different types of applications, the data presented demonstrates that EDI meets and exceeds the specifications of both the microelectronics and power industries. Because of this, EDI has grown in popularity and continues to be accepted as a standard method of water treatment.

Data is presented in this report demonstrating the flexibility, reliability and quality of the continuous EDI process.

EDI process

High-purity water production has traditionally used a combination of membrane separation and ion exchange processes. One well-known membrane separation concept is electrodialysis (ED), which uses an electrical potential to transport and segregate charged aqueous species.

EDI is a further refinement of electrodialysis in that it combines the semi-permeable membrane technology with ion-exchange media to provide a high-efficiency demineralization process. While the fundamental concept is somewhat simple with the basic desalting unit being an ED dilute cell filled with mixed-bed ion-exchange resin, some complex chemical reactions take place within the resin-filled cell. It is these reactions that help to produce the very high purity water required.

When flow enters the resin-filled diluting compartment of an EDI stack, several processes are set in motion. Strong ions are scavenged out of the feed stream by the mixed bed resin. Under the influence of the strong DC field applied across the stack of components, charged ions are pulled off the resin and drawn toward the respective, oppositely charged electrodes, cathode or anode. As these strongly charged species, such as sodium and chloride, migrate toward the ion-exchange membrane, they are continuously removed and transferred into the adjacent concentrating compartments (see Figure 1).

As the strong ions are removed from the dilute process stream, the conductivity becomes quite low. This relatively pure water helps to set the stage for further chemical reactions. The electrical potential splits water at the surface of the resin beads, producing hydrogen and hydroxyl ions. These act as continuous regenerating agents of the ion-exchange resin. These regenerated resins, in turn, act as micro-regions of high or low pH permitting

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ionization of neutral or weakly ionized aqueous species such as carbon dioxide or silica. Once these species acquire a charge through this ionization process, they become subject to the influence of the strong DC field and are removed from the diluting compartment through the ion-exchange membranes (see Figure 2). The membranes used in EDI stacks are flat sheet, homogeneous, ion exchange membranes which help to provide efficient ion transfer.

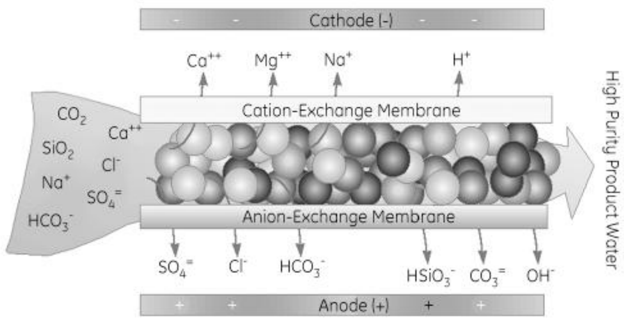

Figure 1: EDI Flow Schematic

Resin in hydrogen and hydroxide forms

Removal of weakly ionized compounds by ionization reactions

$CO_2 + OH^- \rightarrow HCO_3$ - pKa = 6.4

$HCO_3- + OH^- \rightarrow CO_3$ = pKa = 10.3

$SiO_2 + OH^- \rightarrow HSiO_3$ - pKa = 9.8

$H_3BO_3 + OH^- \rightarrow B(OH)_4$ - pKa = 9.2

$NH_3 + H^+ \rightarrow NH_4$ + pKa = 9.2

Figure 2: Ionization Reactions in EDI Diluting Compartments

description of sites

Power Plant 1

This water treatment system supplies ultrapure water to a small-scale, fossil fuel, municipal power plant. Total treated water flow is just below 100 gallons per minute on a continuous basis for high-purity steam makeup water.

The plant is a land-based unit and includes the following train of water treatment unit operations: multi-media filters (MMF), sodium zeolite softeners (NaZe), followed by cartridge filters (CF), reverse osmosis (RO), electrodeionization (EDI) and ion-exchange polishing resin (IE). Feed water for this unit is well water. (Figure 3)

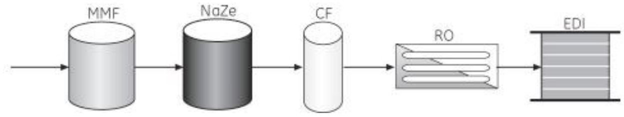

Figure 3: Power Plant 1: Train of Unit Operations

The multimedia filters are backwashed manually based on pressure drop through the filter. Dual softeners are regenerated by salt on a volume throughput basis. Cartridge filters are rated at five micron, and the dual filter system enables cartridge filter replacement without having to shut down the system, as is true with the other pretreatment operations. The RO system is a single-pass RO system composed of a 3:1 array with 6M vessels (6 elements per vessel). The EDI system contains two EDI stacks each with a 50 gpm (0.2 m^3/h) capacity. The EDI is operated at 95% recovery.

This unit has operated continuously since late 1997 and has consistently produced in-spec, high purity water for the power plant boiler makeup requirements. No chemical cleanings have been required for the EDI or RO process streams during the 2,300 hours of operation.

Power Plant 2

This trailer-mounted build-own-operate (BOO) ultrapure water treatment system has been supplying all of the ultrapure water requirements for a nuclear power plant located in the southeastern United States. The 120 gpm (0.5 m^3/h) of ultrapure water is used for steam generator makeup water. Feed water comes from a surface water source.

The triple membrane trailer (TMT) design is configured as ultrafiltration (UF), reverse osmosis, and EDI. The capacity of this system is 360 gpm (1.4 m^3/h). Downstream from the TMT is mixed bed ion-exchange resin, deoxygenation via catalytic oxygen reduction system (CORS) as well as total organic carbon (TOC) destruct systems.

This TMT is set to operate continuously in automatic mode. A customer start signal will enable production of ultrapure water.

The EDI unit capacity is set 100 gpm (0.4 m^3/h) product. EDI performance, measured as product resistivity, has remained consistently high. The exception to this is a decline in product resistivity late in 1999. This was addressed by performing a dilute stream clean-in-place (CIP). Full product quality was recovered after the CIP. Among the reasons for product quality decline include biofouling. This CIP will be discussed in more detail.

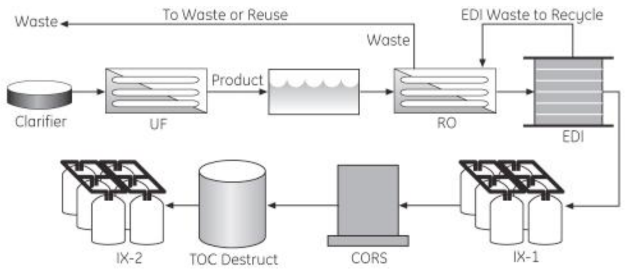

Figure 4: Power Plant 2: Train of Unit Operations

Microchip Manufacturing Plant

The water treatment plant for this microchip manufacturing plant has been online for approximately 18 months. The process train consists of multimedia filters, cartridge filters, two-pass reverse osmosis, electrodeionization, ion-exchange polishing (IX) and TOC control. (Figure 5)Feed to this system is from surface water sources. Ion-exchange is normally used as a final polishing step.

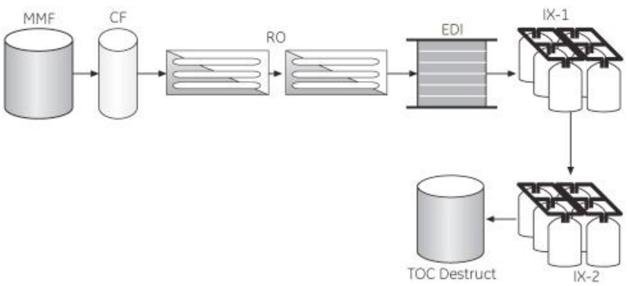

Figure 5: Microchip Plant Water Treatment System

This EDI unit is composed of four separate skids each with a product flow of 200 gallons per minute for a total capacity of 800 gallons per minute. Normally all four units are in operation due to high plant demand.

Immediate pretreatment for the EDI units consists of multimedia filters, followed by cartridge filters and a large array of double-pass reverse osmosis. When an EDI unit is ramped down for service or other reason, one of four RO units also automatically switches off. Downstream from the EDI unit are primary and secondary mixed-bed ion exchange, TOC destruct and polishing ultrafiltration.

This set of four identical EDI units has operated continuously since start-up and produced consistently high meg-ohm/cm product. Silica removal has also remained very high. No chemical cleanings have been required in the EDI dilute process stream. Other process streams have received low pH flushes as a preventative maintenance measure.

data presentation and discussion

Power Plant 1

This plant has performed consistently well since initial startup. Figure 6 shows EDI product resistivity versus time. Operating hours total approximately 2,300 hours. EDI product resistivity begins with an average of 13.5 megohm-cm, but it quickly climbs to a long-term average of 15.5 megohm-cm. Over the final thousand hours, product quality continues to increase to the 16 to 18 megohm-cm range.

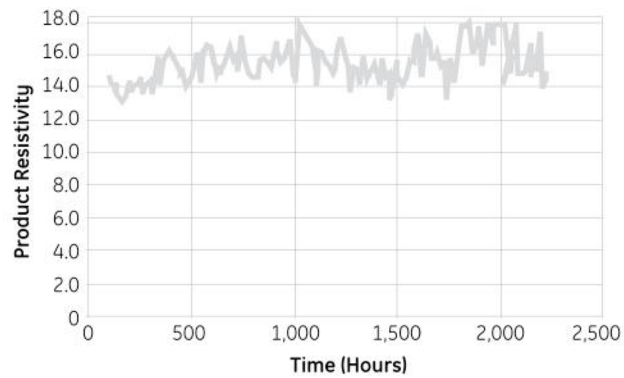

Figure 6: Power Plant 1:EDI Product Resitivity vs. Time June 1998 - Present

This resistivity data shows periodic spikes, an artifact of the randomly chosen data points and the variability in feed water quality. No RO cleanings have been required. There have also been no EDI process stream cleanings.

Figure 7 shows long-term silica rejection vs. time. Silica reduction is shown to be consistently in the 99 percent range with hardly any deviation over the entire operating life of the EDI unit. Silica feed to the unit is typically 400 ppb with silica in the product averaging a consistent 2-3 ppb. Table 1 shows EDI product quality.

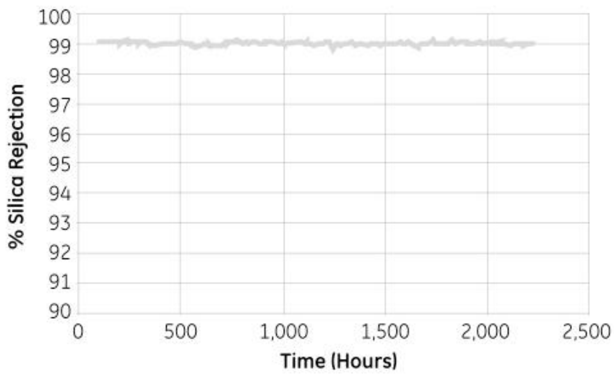

Figure 7: Percent Silica Rejection vs. Time June 1998 - Present

Table 1: Power Plant 1 Performance

Parameter	Feed (PPB)	Product (PPB)	% Removal
Silica	310	2.9	99.1
Conductivity (units in µS/cm)	3.54	0.067	99.9
Sodium	758	14	98.2
TOC	191	91	52.4

Power Plant 2

This EDI unit has operated over 20,000 hours since installation. EDI was installed as part of an equipment upgrade. The TMT trailer was altered from a UF-EDR-RO trailer into a UF-RO-EDI unit, saving both operating and labor costs. (EDR is electrodialysis reversal technology.)

Figure 8 shows EDI performance data as product resistivity vs. time. This data represents the initial six months of 2000. There are several inflection points in product quality. The first drop in product quality was a result of seasonal variation in temperature. As a result amperage was also low. Salt addition to the brine stream had an immediate beneficial effect in raising product quality to the 17 megohm-cm ranges. The next decline in product quality was a result of biofouling. A low concentration of free chlorine was fed to the brine stream to combat biofouling, but a further incremental drop in product quality was observed. When chlorine injection was halted, product resistivity began to recover. EDI product quality completely recovered when EDI stack differentials were increased further. (Note: The EDI unit was retrofitted into this plant around the 20,000-hour mark.)

Another decline in product quality was noted around 34,000 hours, also as a result of EDI stack fouling and biofouling. In this instance the EDI stack pressure drop also began to increase. To stop the pressure increase and decline in product quality, a dilute stream cleaning was initiated. While a brine stream cleaning does not require stopping high purity water production, a dilute stream cleaning necessitates a complete shutdown of the EDI unit. The dilute stream process cleaning completely recovered EDI product quality and pressure drop to a current average of 16 Megohm-cm.

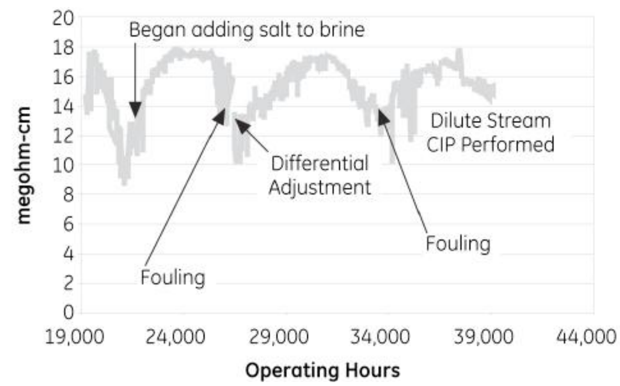

Figure 8: Power Plant 2: TMT EDI Product Resitivity

Figure 9 demonstrates the long-term silica removal of this EDI unit. Prior to salt addition to the EDI brine stream, silica removal ranged from 90% to 95%. After salt addition, silica removal averaged 98% to 99% for a long period of operation. Interestingly enough, the silica removal was not affected by the second decline in product resistivity. During this period, product resistivity declined, and stack pressure drop increased. Silica rejection also began to drop. The dilute stream CIP recovered silica removal to previous long-term values of 98% to 99% removal. Table 2 shows EDI performance.

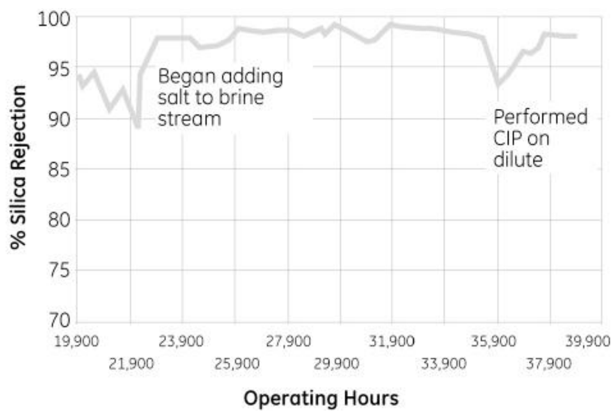

Figure 9: Power Plant 2 TMT3 EDI Silica Rejection Recovery Post CIP

Table 2: Power Plant 2 Performance

Parameter	Feed (PPB)	Product (PPB)	% Removal
Silica	110	< 2	99.1
Conductivity (units in μS/cm)	4.56	0.0625	99.9
Sodium	849	< 1	99.9
Chloride	135	< 1	99.3
Boron	14	0.40	97.1

Microchip Manufacturing Plant

The third water treatment unit is a microchip manufacturer. Total on-line time for this EDI unit is close to 10,000 hours. This EDI system is composed of four separate units each with a capacity 200 gpm (0.8 m^3/h). All four units are on-line nearly 100% of the time.

Figure 10 illustrates consistent high EDI product quality over the entire operating period. Product quality stayed in the 16-17 MΩ range in the first thousand hours. As a result of careful system adjustments such as amperage and differential pressure, the product quality was brought up to the 17-18 MΩ range, where it has remained. In spite of a significant increase in EDI feed conductivity from 3 μS/cm up to 6 μS/cm, product quality has remained constant.

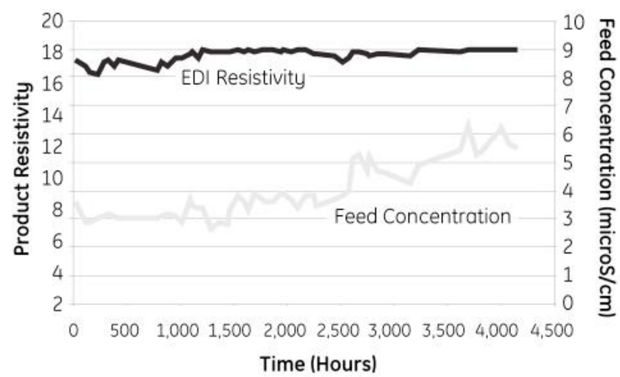

Figure 10: Microelectronics Plant Unit A Product Resistivity vs. Time

Typical silica removal has remained above 95%. Feed silica is in the 30-ppb range with product silica consistently in the 1-3 ppb range.

This high-volume EDI system has not required a cleaning over the life of the plant, although some minor chemical addition to the brine stream has been performed as preventative maintenance. EDI performance can be seen in Table 3.

Table 3: Microelectronics Plant Performance

Parameter	Feed (PPB)	Product (PPB)	% Removal
Silica	42.5	< 2	97.6
Conductivity (units in μS/cm)	3.4	0.057	99.9
Sodium	553	< 1	99.8
Chloride	62	< 1	98.4
TOC	61.5	39	36.6

conclusions

Since installation, all three of these EDI units have performed quite reliably, providing the customers with high-purity product water for either power plant boiler feed or microchip rinse water. The water produced has met or exceeded customer high-purity water specifications. In addition, when a dilute stream cleaning was required as a result of fouling, product quality was completely recovered.

references

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2. Fleming, L.; Prato, T.; Zhang, L.; Hernon, B., "Improvement in an UPW System by Utilizing EDI," International Water Conference, Pittsburgh, PA, October 1999.