Field Experience with a New CEDI Module Design

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Abstract: A new continuous electrodeionization (CEDI) module design employs advances such as O-ring seals, layered resin beds, and resin-filled reject compartments to prevent external leaking, reduce electrical resistance and simplify system design. This report describes a system operating at a power plant for about two years in place of a counter-current demineralizer.

INTRODUCTION

A new continuous electrodeionization (CEDI) module design was reported at the IWC in 2000. This device, manufactured by USFilter (and now sold under the Ionpure brand name), employs advances such as O-ring seals, layered ion exchange resin beds, and resin-filled concentrate/electrode compartments. These prevent external leaking, reduce module electrical resistance and simplify overall system design by eliminating concentrate recirculation and brine injection. Systems have now been in operation at several power plants for about two years. This progress report will focus on an installation where a CEDI system was retrofit in place of a chemically-regenerated counter-current separate-bed demineralizer system.

POWER PLANT DESCRIPTION

Located on the Mississippi River in Cassville Wisconsin, the Nelson Dewey Generating Station consists of two coal-fired units that produce a net total of 220,000 kilowatts of electricity. Power was initially produced at Nelson Dewey in 1959, when the plant's first unit was completed. This consists of a Babcock & Wilcox cyclone-fired boiler and an Allis Chalmers turbine generator. In 1962, a second unit was finished, using a Babcock & Wilcox boiler and a Westinghouse generator. This added another 100,000-plus kilowatts to the total generating capacity. Owned and operated by Wisconsin Power and Light Co. (a utility subsidiary of Alliant Energy), Nelson Dewey provides energy to homes, businesses, farms and industries around southwestern Wisconsin.

The Nelson Dewey Generating Station has a history of employing new technology, for both water treatment and in the fuel combustion/power production process. For example, Unit 2 is the site of the first coal re-burn project in the world. The project's goal was to improve air quality by reducing nitrogen-oxide emissions by as much as 50 percent. The process employs two additional combustion zones to re-burn flue gases before they are discharged from the plant stack. In cooperation with the U.S. Department of Energy's Industry Clean Coal Technology Demonstration Program, Babcock and Wilcox, and other electric utilities, the Wisconsin Power and Light (WP&L) project serves as a prototype for similar units around the world.

Nelson Dewey also is a forerunner in the utility industry's burning of low-sulfur Western coals. Barges deliver nearly 600,000 tons of coal to the plant every year, the only WP&L power plant that depends on water as its primary link to fuel supplies. The plant consumes about 2,000 tons of coal per day to generate over 10% of WP&L's total generation. Coal not used in daily generation is stockpiled for winter use. A large accumulation of coal is needed to fuel the plant once the river ices over, cutting off the coal supply.

PLANT DI WATER SYSTEM

The original boiler makeup water system for the plant consisted of weak acid cation resin, a forced-draft decarbonator, strong acid cation resin, weak base anion resin and strong-base anion resin (all with cocurrent regeneration). Demineralized water was fed to a 150,000 gallon DI water storage tank, from which it was fed to the boilers. Raw feed water for the DI water system is taken from a private well, and has the typical quality shown in Table 1.

Table 1. Raw Water Analysis, 05 Feb 2001

Specific conductivity	597 µS/cm
Calcium	185 ppm as $CaCO_3$
Magnesium	154 ppm as $CaCO_3$
Sodium	15 ppm as $CaCO_3$
Potassium	1.5 ppm as $CaCO_3$
Bicarbonate	294 ppm as $CaCO_3$
Chloride	23 ppm as $CaCO_3$
Nitrate	9 ppm as $CaCO_3$
Sulfate	21 ppm as $CaCO_3$
Silica	19 ppm as SiO_2
TOC	2 ppm as C
Turbidity	< 0.1 NTU
PH	7.46
Free CO_2	23 ppm as $CaCO_3$

In the 1970's, Nelson Dewey became one of the earliest power plants to employ reverse osmosis (RO) as pretreatment to a demineralizer in order to reduce chemical consumption, well before this became widespread practice in the industry. A cellulose acetate RO system was retrofit upstream of the deionization system. Pretreatment for the RO system consisted of preheating, pH adjustment, and antiscalant injection. The RO system fed directly into the top of the primary cation unit, which then fed the decarbonator.

In 1995, with parts of the original DI water system then 36 years old, a complete renovation of the system was performed. The old cellulose acetate RO was replaced with a new system employing polyamide, thin-film-composite RO membranes. At the same time, the original cation/forced-draft-degasification/anion system was replaced with a short-cycle, countercurrent regeneration, cation/anion/cation system. The RO pretreatment was also upgraded to include ultraviolet disinfection, multi-media filtration, sodium cycle ion exchange softening, caustic addition (for removal of carbon dioxide) and cartridge filtration. Since the raw water was from a private well, there was no need for dechlorination. Two 2500 gallon break tanks were added at this time, one after the RO system and one after the two-bed deionizer. Table 2 gives an analysis of the RO permeate several months prior to the installation of the CEDI system.

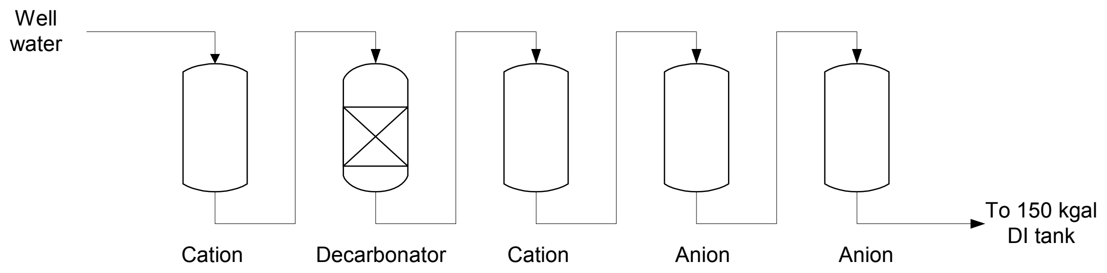
Table 2. RO Permeate Analysis, 05 Feb 2001

Specific conductivity	1.5 µS/cm
Calcium	< 0.01 ppm as $CaCO_3$
Magnesium	< 0.01 ppm as $CaCO_3$
Sodium	1.5 ppm as $CaCO_3$
Bicarbonate	1.0 ppm as $CaCO_3$
Chloride	0.12 ppm as $CaCO_3$
Nitrate	0.3 ppm as $CaCO_3$
Sulfate	0.01 ppm as $CaCO_3$
Silica	0.050 ppm as SiO_2
TOC	0.21 ppm as C
Turbidity	< 0.1 NTU
PH	7.47
Free CO_2	0.1 ppm as $CaCO_3$

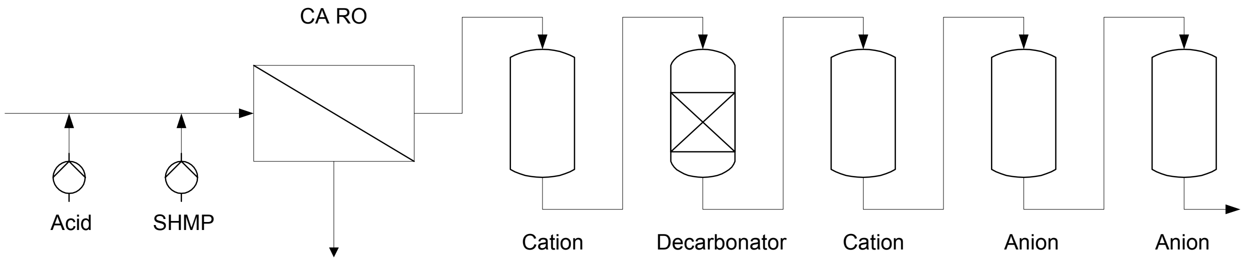
While the countercurrent demineralizer system met the plant's requirements for deionized water quality and quantity, there were some maintenance issues, such as difficulty getting replacement parts for the European-built packaged system, and the inability to change the ion exchange resin on-site. Therefore, in 2001 the plant decided to replace the three-bed deionizer with a continuous electrodeionization (CEDI) system. This provided the additional benefit of eliminating the regenerant chemicals and the need for neutralization of waste regenerant. Figure 1 shows the evolution of the boiler makeup DI water system at the Nelson Dewey generating station.

Figure 1 Evolution of the boiler makeup water deionization system at the Nelson Dewey Generating Station

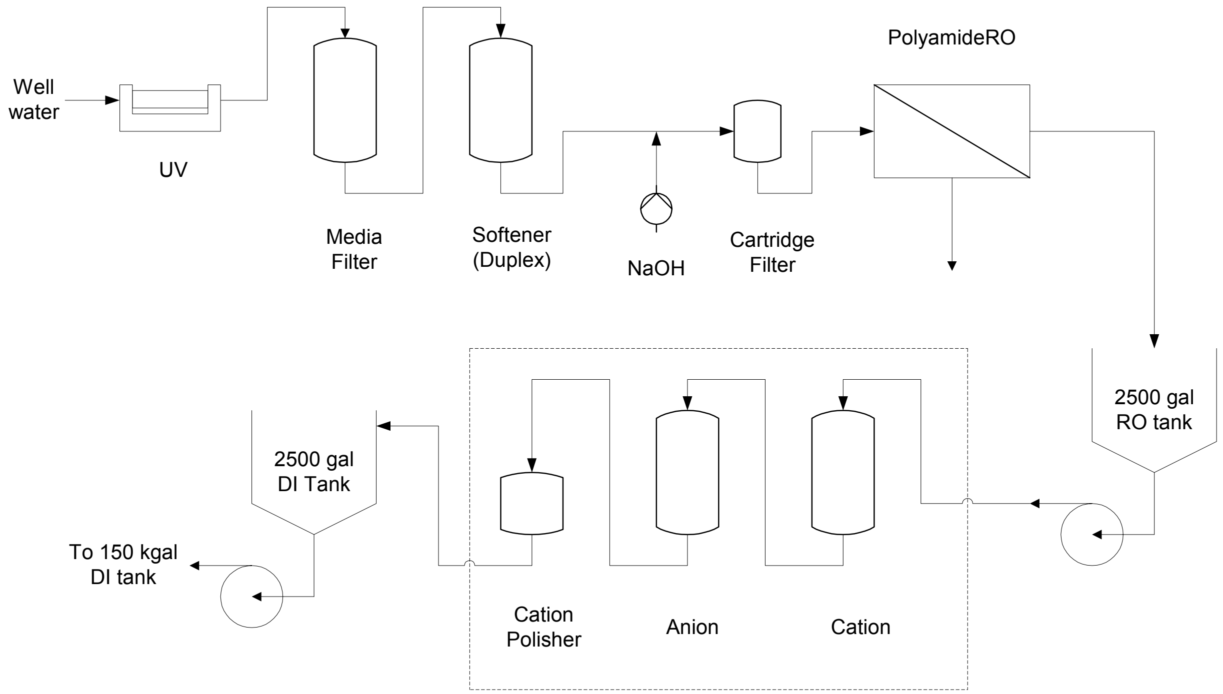
1959 - Original system design



1970's - System upgrade



1995 - System Renovation



2001 Upgrade - Countercurrent deionizer replaced by CEDI (not shown)

CEDI MODULE DESIGN

The electrodeionization system installed at Nelson Dewey consists of four 24-cell CEDI modules, each rated for a nominal product flow rate of 12.5 gpm. The system was designed to produce an average of 50 gpm of product water meeting the EPRI makeup water guidelines shown in Table 3. This power plant has achieved over 40-year life on the cyclone boilers, which is attributed to the careful attention paid to makeup water and steam quality. The plant alarm point for the concentration of silica in the boiler makeup water is normally set at 20 ppb.

Table 3. Product Water Specifications

Specific conductivity	< 0.1 µS/cm
Sodium	< 3 ppb as ion
Chloride	< 3 ppb as ion
Sulfate	< 3 ppb as ion
Silica	< 10 ppb as SiO_2
TOC	< 300 ppb as C

The process of continuous electrodeionization was first commercialized in 1987 (1) by the Process Water Division of Millipore Corporation (now part of USFilter). This process has been described at length 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 has been described as "thin cell" product water compartments (about 2.5 mm between ion exchange membranes) with a mixed-bed ion exchange resin filler. In recent years a variety of new designs has 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). The CEDI device used in the Nelson Dewey system was first described in a paper by Gifford at the IWC in 2000. (3) This is a thick cell, layered bed, plate and frame device that is unique in that it employs resin filler in not only the product compartment, but the concentrate and electrode compartments.

Figure 2 is an exploded view of the CEDI module, which shows the repeating unit of a product compartment and a reject compartment. This is pictured without the ion exchange resin, which is filled into what is shown as an open area in the center of the resin compartments (spacers.) The RO permeate feeds into both the product and reject compartments in a cocurrent, downflow configuration.

The thick dilute spacer affords the ability to incorporate grooves for O-ring seals. There is an O-ring around the perimeter of the resin bed as well as an O-ring around every flow port. This yields a double seal between the different flow ports and the resin beds, thus isolating purified product from concentrated reject water. There is a second perimeter O-ring to provide the same double seal to the outside of the module, eliminating external leakage. This also prevents evaporation of water from the outer edge of the ion exchange membranes, thus eliminating the formation of salt deposits on the outside of the module. Figure 3 gives a closer view of the product compartment.

The smaller holes around the perimeter of the spacer are where the tie bars pass through to compress the module and hold it together. For protection against electrical short circuiting, the tie bars are encased in plastic sleeves, with an elastomeric seal between the outside of the sleeve and the electrode block (not shown).

Figure 2 CEDI module, exploded view

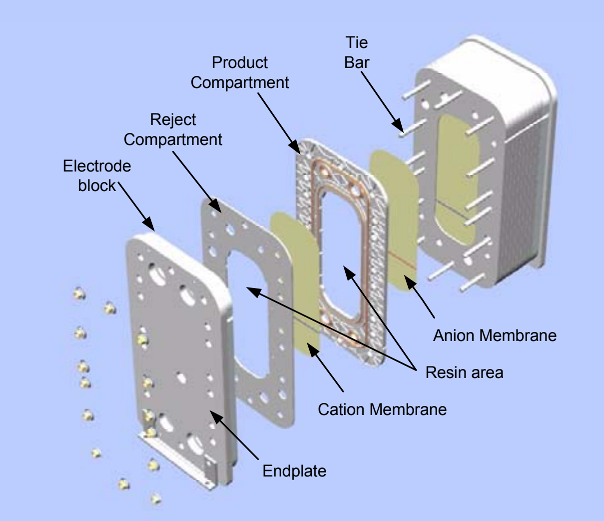
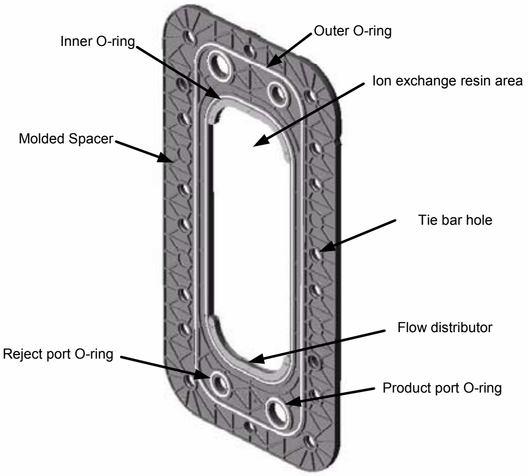


Figure 3 Product water compartment (without resin)



The spacer was designed using finite element analysis (FEA) modeling, which showed that the large radius on each corner of the resin bed is critical to the strength of the spacer. It is well known that ion exchange resins swell as they are converted from the salt form to the regenerated form, and some anion resins can expand 20% or more. Testing has shown that in an electrodeionization device this resin swelling can impart an internal pressure equivalent to about 100 PSI of hydrostatic pressure. Therefore these spacers were designed to handle a total internal pressure of 200 PSI, with a safety factor of over 2X. In an assembled module the safety factor is actually higher due to the additional strength contributed by the tie bars and endplates.

When employing ion exchange resin filler in the concentrate and electrode compartments of a CEDI module, the overall electrical resistance of the module is essentially independent of the concentrate water conductivity. Such devices will draw sufficient DC current at normal operating voltages (less than 600 VDC) without the use of concentrate recirculation or concentrate salt injection. Single-pass operation with high water recovery can be achieved by putting the O-ring grooves on only the product compartments, allowing the concentrate compartments to be thinner and thus require less flow.

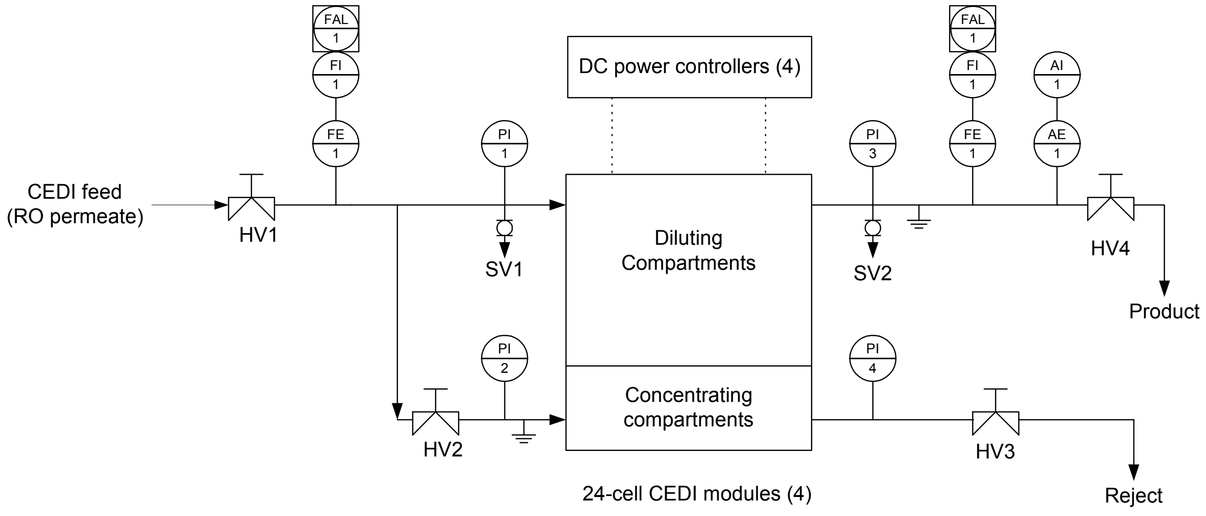
CEDI SYSTEM DESIGN

The module construction described above avoids the need for salt injection or concentrate recirculation pumps, reducing the system complexity and maintenance requirements. This also lowers the operating cost, since in some cases the concentrate recirculation pump can use nearly as much electricity as the CEDI modules.

Figure 4 is the process flow diagram for the CEDI system installed at the Nelson Dewey plant. For the most part the system design approach is similar to an RO system, with the CEDI module analogous to an RO element. Control and instrumentation are provided at the system level, not the module level. This has become commonplace for systems which use multiple smaller stacks in parallel to attain high product flow rates.

One exception to this design approach was taken in providing a separate rectifier for each CEDI module. If one rectifier fails, that particular rectifier and module can be taken out of service until a new one can be installed, while the rest of the system remains in operation. Having individual rectifiers also offers some degree of flexibility in monitoring, control and optimization of the DC power applied to each module. The power supply is operated in "constant current" mode, where the DC voltage will be automatically adjusted as necessary (in response to changes that effect CEDI module resistance, such as feed water temperature) in order to keep the DC amperage stable.

Figure 4 CEDI system process flow diagram



OPERATING RESULTS

The CEDI system at Nelson Dewey was first put into service in October 2001. At this time the RO permeate was found to be about 14 µS/cm with nearly 200 ppb silica, both significantly higher than the Feb 5, 2001 permeate analysis used for sizing the CDI system. The problem was found to be due to a hairline crack in one of the RO end adapters. After replacing the adapter the RO performance improved to about 4 µS/cm and 40-60 ppb silica. There were also some startup issues with the DC power supply, requiring replacement of a rectifier circuit board and a display board.

Table 4 shows the typical performance of the CEDI system after about 16 months of operation. The system has now produced over 10 million gallons of deionized water in about 20 months of operation.

Table 4. CEDI Performance 25 Feb 2003

Feed CO_2	2.5 ppm as CO_2
Feed conductivity	4.4 µS/cm
Product conductivity	0.058 µS/cm
Feed silica	50 ppb as SiO_2
Product silica	1.6 ppb as SiO_2
Water recovery	90%

Figures 5 through 8 are plots of the CEDI system performance after complete data collection for the CEDI system was begun in August 2002. These show stable performance of the CEDI system up until a recent upset in RO system performance. In the late spring of 2003 there was an incident in which the softener failed to regenerate, leading to scaling of the RO membranes. This is seen as a spike in RO and CDI product water conductivity in Figure 5. Acid cleaning of the RO system restored the effluent conductivity of both the RO and CEDI systems.

The CEDI system has now operated almost two years with essentially no maintenance. The CEDI system was not cleaned after the RO scaling occurrence, and CEDI product conductivity remains at 0.06 µS/cm. However, Figure 8 indicates that there has been an increase in CEDI module electrical resistance, especially around the time of the RO scaling. This may indicate that some hardness passed through the RO into the CEDI module, and formed some scale on the ion exchange membranes (most CEDI modules are limited to a maximum of 1-2 ppm of hardness in the feed water). Since there has been little impact on the module product conductivity or concentrate pressure drop, it is likely that acid cleaning will remove the precipitate and reduce the module resistance to the previous level.

The fact that the flow and pressure drop have been stable in both the product and concentrate compartments also indicates that there has been no damage to the ion exchange resin, and no accumulation of particulate or biological material.

Figure 5 - CEDI Water Quality

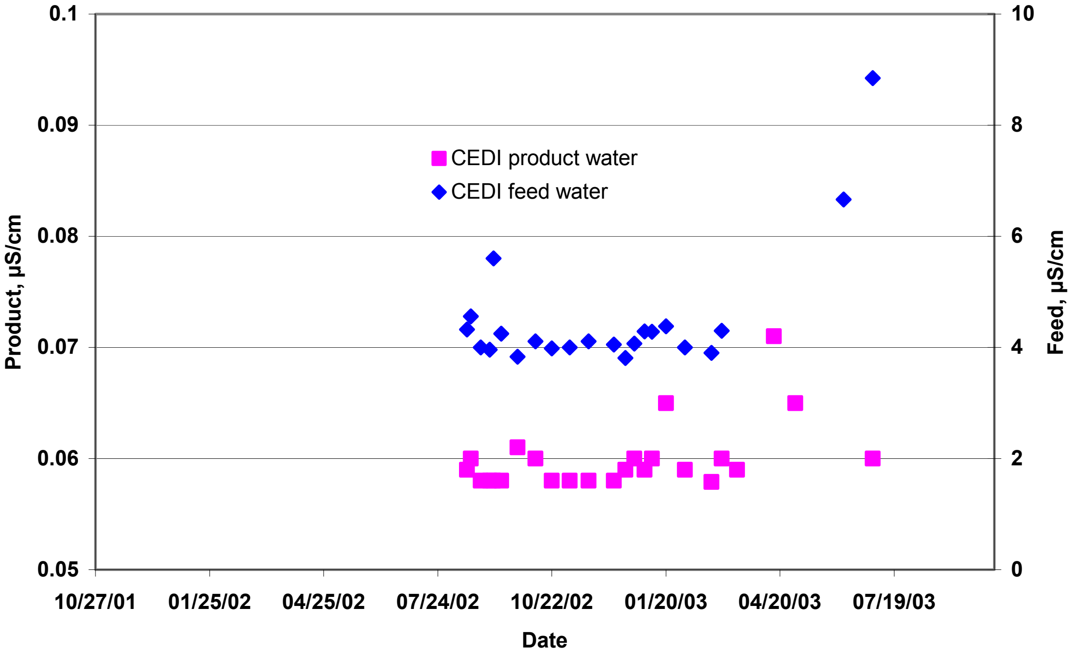


Figure 6 - CEDI Product Pressure Drop

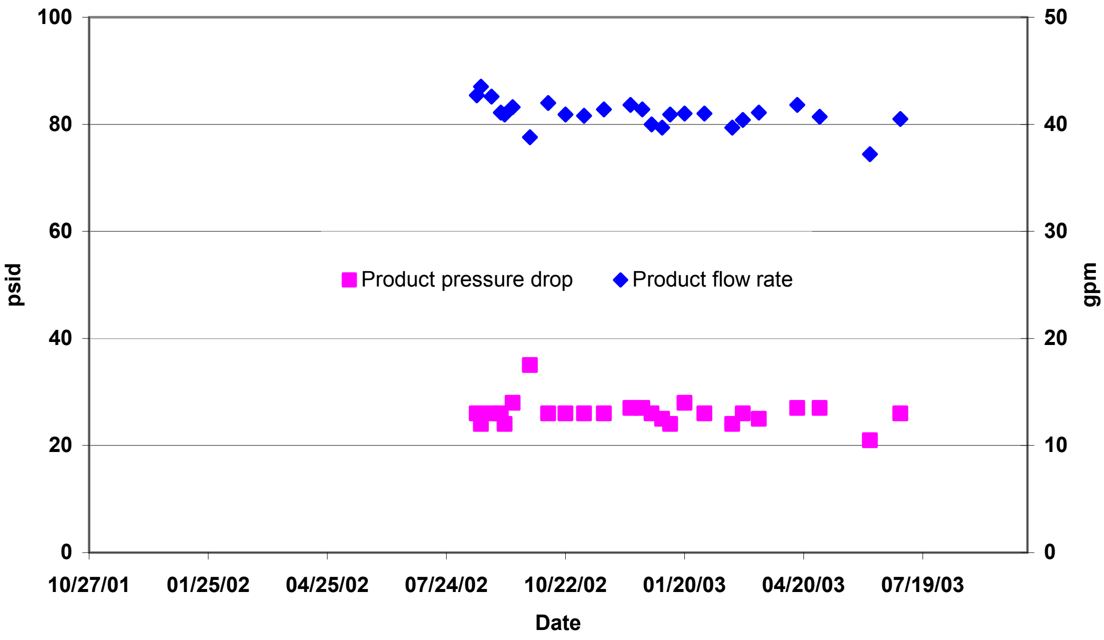


Figure 7 - CEDI Concentrate Pressure Drop

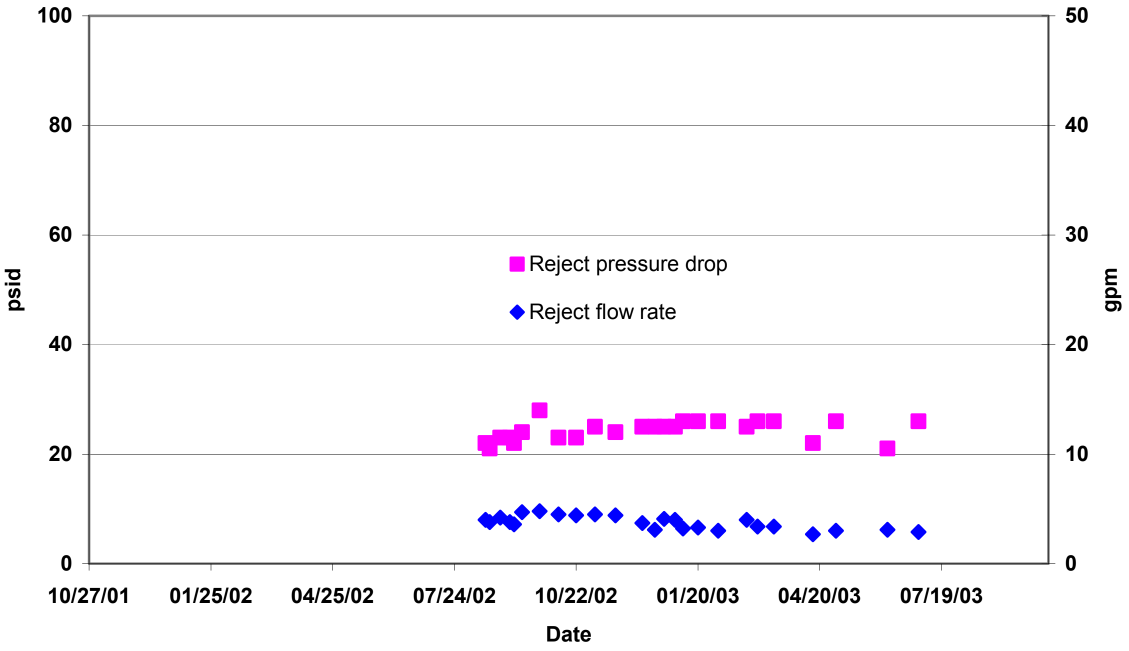
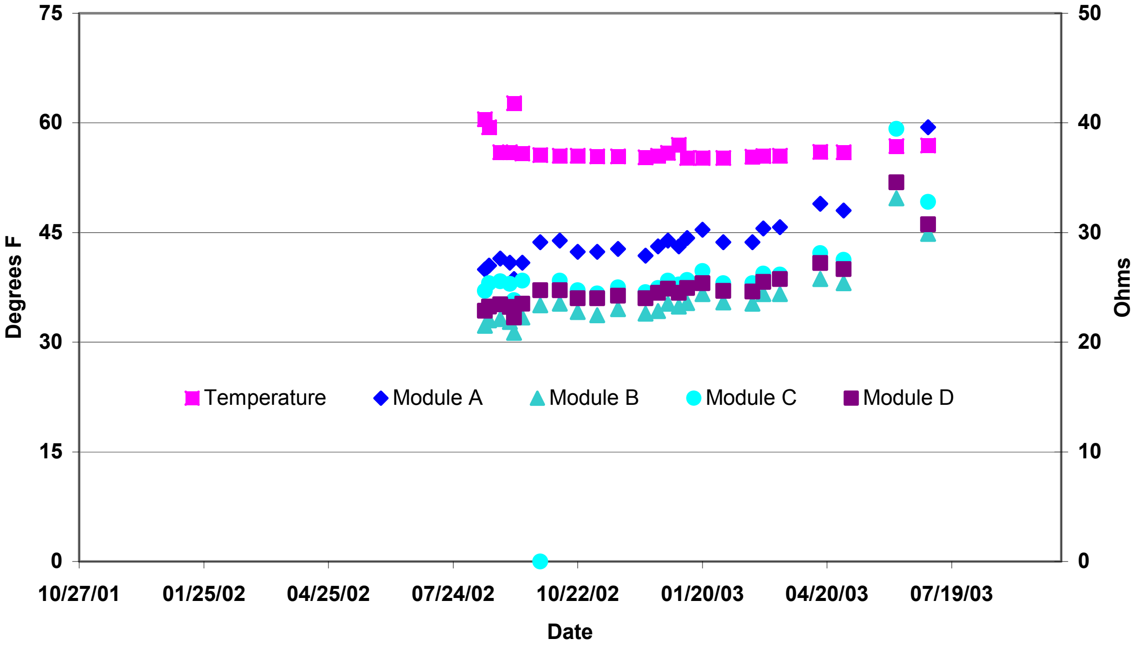


Figure 8 - CEDI Electrical Resistance



CONCLUSIONS

The CEDI system at the Nelson Dewey Generating Station has operated trouble-free for almost two years with minimal maintenance. The use of "all-resin-filled" CEDI module construction has allowed operation without concentrate recirculation or concentrate salt injection. The module design with O-ring seals and encapsulated tie bars has avoided any module leaking or arcing.

Some other factors that have contributed to system performance and reliability are the use of softening ahead of the RO system; the low TOC of the raw feed (well) water, and the use of caustic addition pre-RO to reduce the CO_2 load on the CEDI system.

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