Design, Construction and Operation of a 6,730 gpm RO/CEDI System for Con Edison's East River Repowering Project

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Abstract: Con Edison's East River Repowering Project (ERRP) included the installation of a 6,730 gpm RO/CEDI system for production of makeup water. This is believed to be the largest RO/CEDI system ever constructed for a combined cycle make-up system. This report describes design and construction of the plant as well operating experience from the first year of commercial operation.

INTRODUCTION

Con Edison's steam system, which serves more than 1,800 customers in New York City, is the largest district heating steam system in the world. The East River Repowering Project (ERRP) expanded the steam generating capacity of the East River complex from 2.7 to 5.7 million pounds/hour, and the electric generating capacity from 300 to 660 megawatts. This was accomplished by the installation of two dual-fuel combustion turbines, two heat-recovery steam generators, a 6,730 gpm demineralization facility, and 80,000 feet of process piping – all without increasing the footprint of the station. Full commercial operation was achieved in April 2005.

Con Edison elected to use reverse osmosis (RO) and continuous electrodeionization (CEDI) to provide the demineralized water required as makeup to the steam generators. In addition to being some of the latest technology available, this system also avoids the regular use of hazardous regeneration chemicals required by conventional ion exchange systems.

This paper will describe the design and construction of the entire makeup water system, including the challenges associated with placing the equipment in an operating powerhouse. Operating data from the first year of service will also be presented.

SYSTEM DESIGN

Con Edison undertook this Repowering Project in 2001 to ensure that the Con Edison steam system would continue to provide the environmental benefits of steam service year-round and to provide a new source of efficient electric generation to New York City. The East River Station facility was selected for the project because it had the needed space and allowed for the maximum use of Con Edison's existing energy infrastructure. The new

East River equipment replaces Con Edison's Waterside Station, which is being dismantled by the new property owner. The new state-of-the-art equipment at East River uses natural gas as its primary fuel and has the most up-to-date emissions control technology. Overall air quality in New York City will benefit, as the project's overall annual emissions will be significantly less than those of the Waterside Station it is replacing.

Washington Group International of Princeton, NJ, provided a feasibility study, licensing support, conceptual design, and engineering and procurement services for the water treatment project with the input of several major water treatment equipment companies including US Filter and GE Water Technologies.

Two water sources are available to East River Station through the New York City potable water system via the Catskill/Delaware watershed and the Croton watershed. Although Catskill water is lower in TDS, the most likely available source for the plant was the Croton watershed. Therefore, the initial system design was based on the water analysis of the Croton watershed (shown in Table 1) as this was felt to be the "worst case." However, due to construction activities on the supply aqueduct, water from the Croton watershed has not been supplied and the system has to date been fed exclusively from the Catskill/Delaware watershed (see Table 2).

Table 1. Croton Watershed - Design Analysis

Specific conductivity	389 µS/cm
Calcium	62.0 ppm as $CaCO_3$
Magnesium	36.1 ppm as $CaCO_3$
Sodium	65.4 ppm as $CaCO_3$
Potassium	3.3 ppm as $CaCO_3$
Aluminum	0.11 ppm as $CaCO_3$
TOTAL CATIONS	166.9
Bicarbonate	57.2 ppm as $CaCO_3$
Chloride	80.7 ppm as $CaCO_3$
Nitrate	0.5 ppm as $CaCO_3$
Sulfate	15.8 ppm as $CaCO_3$
Fluoride	3.1 ppm as $CaCO_3$
Silica	4.7 ppm as $CaCO_3$
TOTAL ANIONS	162.0
TOC	3.6 ppm as C
Turbidity	2.2 NTU
PH	6.8-7.6
Free CO_2 @ pH 6.8	16.8 ppm as $CaCO_3$

One of the main system design constraints was to minimize the storage of on-site bulk chemicals, as well as transportation of these chemicals by truck through New York City. This motivation for the requirements of the system is in line with Con Edison's commitment to environmental excellence. Other system design constraints included limits on the water discharged to the East River (Table 3) and the product water quality specifications (Table 4).

Designed to produce 6,730 gpm of de-ionized water, the makeup water system is much larger than typical for a combined heat and power (CHP) plant. The reason is that the New York City district heating system dates back to the late 1800's, and the steam distribution system was not designed for return of the steam condensate. Therefore, the units providing the steam supply to this system are 100% makeup.

Table 2. Catskill/Delaware Watershed - Design Analysis

Specific conductivity	179 µS/cm
Calcium	29.0 ppm as $CaCO_3$
Magnesium	10.3 ppm as $CaCO_3$
Sodium	27.7 ppm as $CaCO_3$
Potassium	8.6 ppm as $CaCO_3$
Aluminum	0.22 ppm as $CaCO_3$
TOTAL CATIONS	75.8
Bicarbonate	26.1 ppm as $CaCO_3$
Chloride	22.4 ppm as $CaCO_3$
Nitrate	0.32 ppm as $CaCO_3$
Sulfate	11.0 ppm as $CaCO_3$
Fluoride	3.4 ppm as $CaCO_3$
Silica	4.4 ppm as $CaCO_3$
TOTAL ANIONS	67.6
TOC	2.4 ppm as C
Turbidity	4.1 NTU
PH	6.6-8.8
Free CO_2 @ pH 6.6	11.3 ppm as $CaCO_3$

The water treatment system for the Repowering Project was designed to consist of two parallel trains, with each train consisting of five parallel banks, or skids. Each train is comprised of pre-filtration, chemical addition, reverse osmosis, and electro-deionization. A schematic diagram of the system is shown in Figures 1 and 2. The water treatment equipment was supplied by US Filter (now Siemens Water Technologies) and installed by Slattery Skanska.

Table 3. Limits on Discharge to East River

pH	6-9
TSS, instantaneous	100 ppm
TSS, monthly average	30 ppm
Oil & grease	15 ppm

Table 4. Product Water Specifications

Conductivity	< 1.0 µS/cm
Sodium	<28 ppb as ion
Silica	< 150 ppb as SiO_2

PROCESS DESCRIPTION

The raw water feed to the water treatment system is supplied by the raw water pumps that take suction from an 80,000 gallon raw water storage tank. Before it reaches the multi-media filters, the raw water passes through heat exchangers to provide a heat-sink for the units' closed cooling loops. This results in seasonally varying supply temperatures to the water treatment system.

The pre-treatment section is composed of chemical treatment, as well as multi-media, and cartridge filtration. A chemical feed system was provided to allow injection of polymer coagulant prior to the inlet of the multi-media filters. The treated raw water is passed through the multi-media filters to remove small particulate matter to a nominal size of 10 µm. The filtered water is then injected with an antiscalant before it reaches the cartridge filters. The cartridge filters were designed to remove additional small particulate. Filtered water from the cartridge filters is treated with sodium bisulfite to keep the free chlorine in the water source from oxidizing the thin film composite polyamide membranes.

The water is then forwarded via the RO feed pumps to the inlets of the RO banks. RO permeate flows to the inlet of the CEDI banks while the RO reject and RO flush flow to the East River. RO permeate dump water from pre- and post-service flushing flows back to the raw water storage tank.

The CEDI system uses all-filled type modules and therefore does not require concentrate brine injection or concentrate recirculation. The CEDI product flows to the five demineralized water storage tanks while the CEDI reject flows to the inlet of the decarbonators. The decarbonated CEDI reject is recycled back to the raw water storage tank.

Backwash and rinse flows from the multi-media filter cleaning sequence are directed to an Auto Pulse Filter (APF) system for treatment for discharge to the East River. These filters operate via a diatomaceous earth (DE) filtration aid. The Auto Pulse Filters discharge particulate matter to a sludge tank for trucking off-site.

Control of the water treatment system consists of two redundant Allen Bradley PLC 5/80B Controllers with Ethernet side cards. The operator interface consists of two 21" LCD graphic displays driven by two project computers (Dell Desktop PCs). The computers run RSView32 SCADA packages, displayed on the LCDs, which communicates to the PLC via DH+. The PLC communicates with the plant DCS via Ethernet. Smart transmitters and controllers communicate with the plant Asset Management System, using the HART protocol.

The system makeup to the demineralized water silos is based on tank level. All five water silos are typically operated as one unit so the level is uniform across them. Control logic is "unitized" in that the skids each operate at nearly constant flow, but turn on or off based on the need for water. Units are rotated based on a "first in/first out" arrangement. Generally both Train A and Train B will be in operation, but the number of skids operating per train varies with the demand.

Additional details on the each of the major unit operations are provided below:

Pre-treatment Filtration

(3) Polymer dosing pumps; (1) per train, (1) spare
Maximum flow per pump 1.7 gph
Output (stroke) controlled by train flow

(2) Trains of (5) multi-media pressure filters
Design flow 880 gpm each
144" DIA x 60" STR, plasite lined
120 ft^3 anthracite, 113 ft^3 sand, 56 ft^3 garnet

(2) Auto Pulse Filters with (1) DE feeder,
(precoat/bodyfeed) system and (1) sludge tank
(6,500 gal). These are for MMF backwash water.

(3) Antiscalant dosing pumps; (1) per train, (1) spare
Maximum flow per pump 1.7 gph
Output (stroke) controlled by train flow

(2) Trains of (5) cartridge filters
Design flow 880 gpm each, 24" OD vessel
(52) 40" x 2.5" elements, 5 µm nominal rating

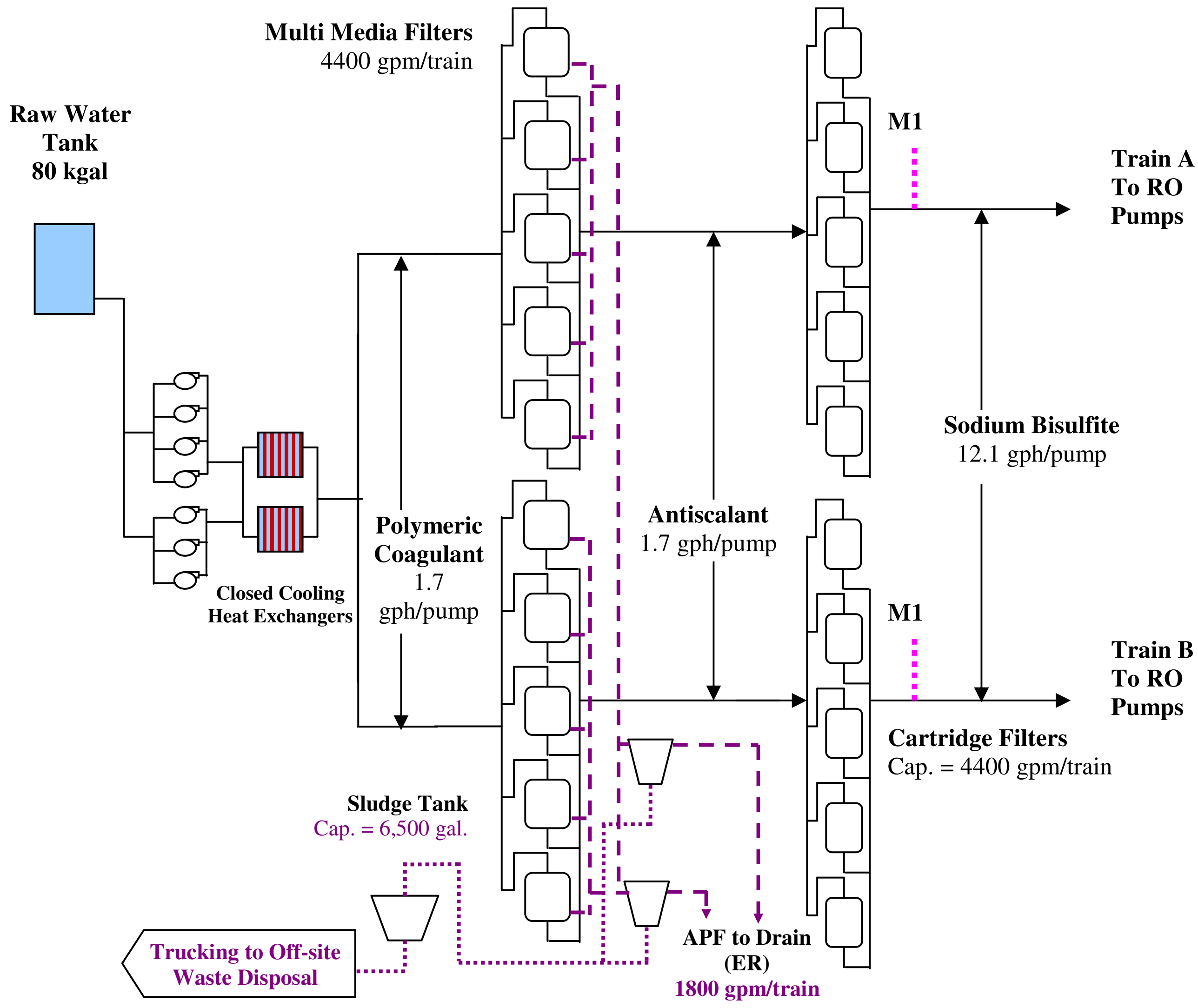
(3) Sodium bisulfite dosing pumps; (1) per train, (1) spare
Maximum flow per pump 12.1 gph
Output (stroke) controlled by flow
On-line ORP for reference only

Demineralization

(2) Trains of (5) RO skids, one pump/skid
Design product flow 748 gpm per skid
Design reject flow 132 gpm per skid
Single product pass, 2 reject stages
20 : 10 array, 7 elements/vessel (210 elements/skid)
Hydranautics 8", 400 sq. ft. CPA-3 elements

(2) Trains of (5) CEDI skids complete with (5) rectifiers
Design product flow 673 gpm
Design reject flow 74 gpm

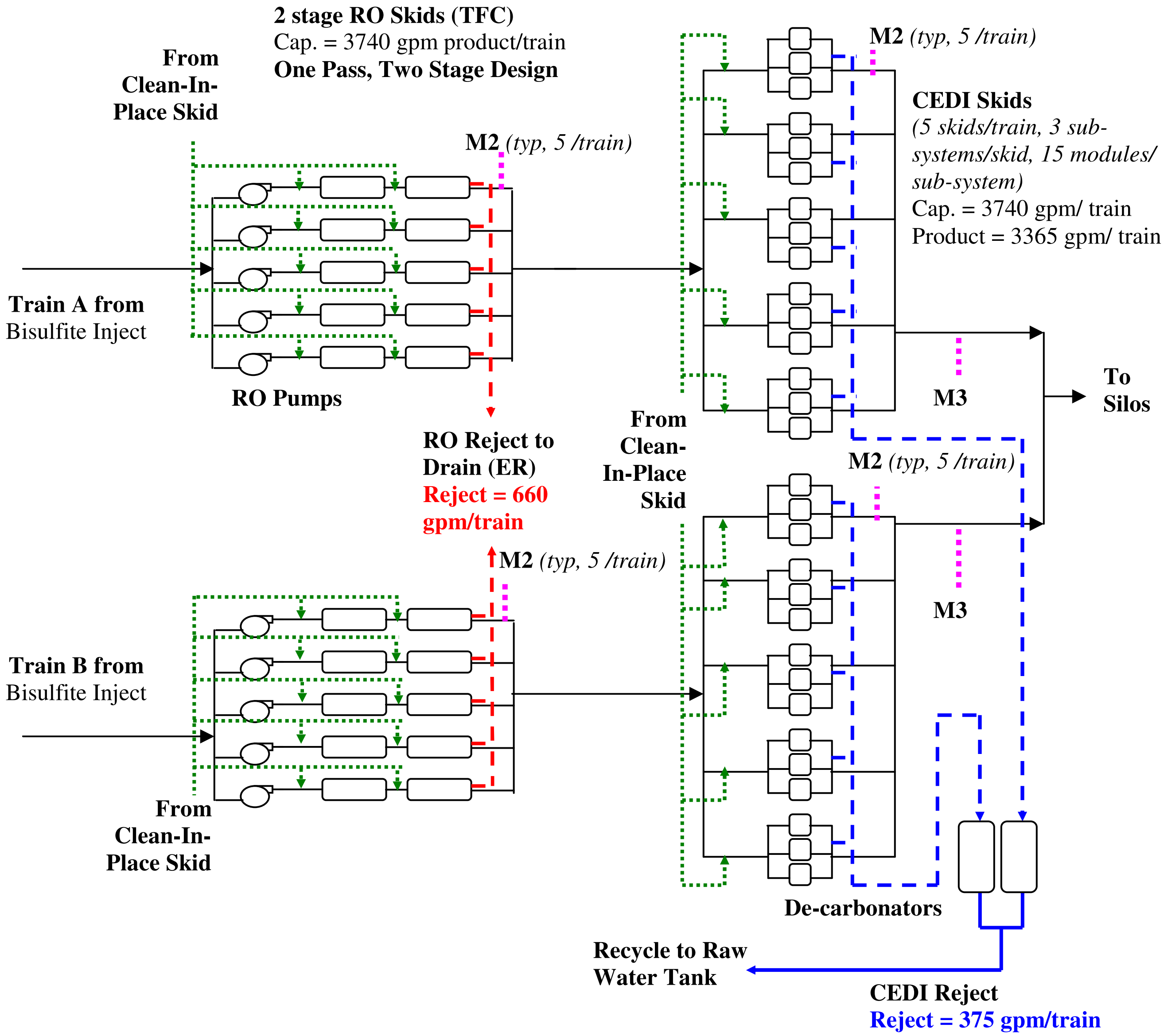
Pretreatment Section Flow Schematic



Chemical Monitoring Legend

M1 – ORP (Oxidation Reduction Potential, ppm Cl), pH, Conductivity

Demineralization Section Flow Schematic



Chemical Monitoring Legend

M2 – Conductivity

M3 – Conductivity, Silica, Sodium

45 modules/skid, Ionpure IP-LXM30X-3
Rectifier design 400 VDC, 450 amps each
These modules have been described previously [1,2]

(2) Decarbonator Systems with Two (2) Fans
Maximum flow 375 gpm each
48" DIA x 120" SS, 100 ft3 packing
(2) fans/tower, 1125 SCFM, 1.5 HP

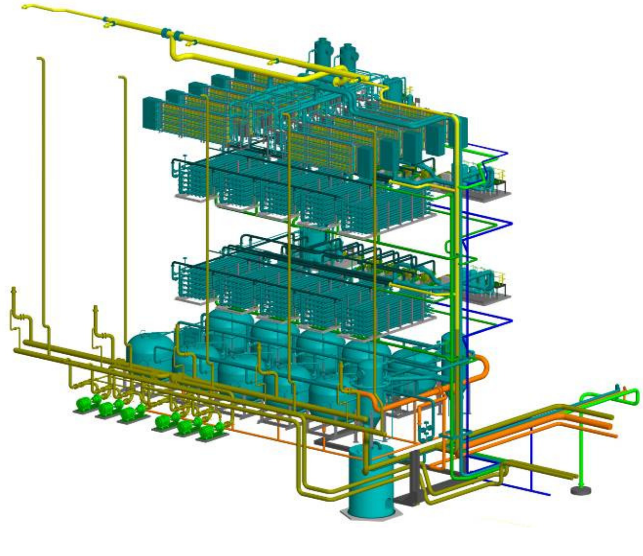
(2) RO Clean in Place (CIP) systems and (1) CEDI CIP system were included as part of the equipment package.

CONSTRUCTION

One of the most unique aspects of the Repowering Project was the challenge of fitting two combined cycle units and their associated auxiliary systems into an existing structure. In terms of the water treatment system, there were two major aspects of equipment siting that are particularly interesting; those are the location and construction of the main process equipment and storage space for the demineralized water.

The location chosen for the water treatment system was the former footprint of a high pressure boiler in the station. The boiler had been retired and removed, and structures were built in its place to support the load of the water treatment equipment. There is one floor of multi-media filtration, two floors of reverse osmosis skids, and one floor for the CEDI modules. The water treatment flow path is from the ground floor elevation up to the 119' 11" elevation where the CEDI modules are housed.

RO/CEDI Plant Isometric



The foot print of the retired boiler extends from the ground floor elevation of 10' 6" up to 218' 6". This portion of the building structure was originally built circa 1950. Portions of this area still support sections of the building that are in use and therefore modifications had to account for the need of the structure to support the appropriate existing loads.

One of the existing floors within the boiler space was removed completely, one floor was added at a different elevation, and three existing floors were modified for the new equipment at the lower elevations. The total equipment weight added to the building in that area was less than 1/3rd of the weight of what was removed, and therefore reduced the stresses in the columns supporting the new water treatment plant. The design of the new and modified floors was such that it maintained the originally devised integrity of the structure.

In addition to the structural work required to prepare the area for the equipment, this portion of the Repowering Project had the most live equipment that required relocation based on its proximity to the existing operating plant. In combination with the fact that the structures had to be modified at the same time that equipment needed to be landed, this made the construction process challenging. Before the floor structures were completed and closed, openings had to be left so that equipment could be rigged into place. To complete enough of the structural work and still be able to move the equipment into the appropriate areas, the openings could not be tremendously large. Some of the equipment had to be rigged and lifted into the building sideways.

To provide storage capacity for demineralized water and ensure that a significant unit run time is available upon a failure of the water treatment plant, large storage vessels were required. Taking into consideration the space constraints, the solution to this problem was to utilize five retired coal silos that had formerly housed fuel for the plant equipment.

The diameter of each tank is 23' 10". Each demineralized water storage tank is designed for a usable water storage capacity of 150,000 gallons. The total water storage for the five tanks is 750,000 gallons. This capacity enables approximately two hours of continuous full load operation of the Heat Recovery Steam Generators, with no additional demineralized water supply to the tanks.

To repurpose the silos for use as water tanks as opposed to coal silos, modifications had to be performed. Concrete repairs were made to any area identified during inspections. Each silo was constructed of original and repaired reinforced concrete, with an internal PVC liner and external reinforcing steel tendons around the circumference of the tank. The reinforcing tendons were required because of the difference in density between the liquid water and the pulverized coal. This ensured that the silo would be able to withstand the stresses created by the volume of water to be stored.

OPERATING RESULTS

Commissioning of the water treatment system began in early 2005 and commercial operation began in April. The system was designed to be run by one operator position with 24 hour coverage; however the equivalent of a second operator is often required during cleaning periods.

Figures 1 through 12 are plots of the RO/CEDI system performance for the period of June 2005 through June 2006. Figure 1 shows the variation in temperature of the RO permeate (and thus the RO feed water). The variation in feed water temperature is important because it is seen to impact several operating parameters, most notably the RO permeate conductivity (Figure 2 and 6) and CEDI electrical resistance (Figure 11). Monitoring of the system thus requires separating the temperature effect from other potentially more harmful effects such as fouling or scaling.

Figure 2 illustrates the stepwise nature of DI water flow as skids are taken in and out of service, in increments of about 650 gpm.

Figure 3 reveals what to-date has been the major issue with system operation – the increase in the RO system feed-to-reject pressure drop, resulting in the need for periodic cleaning. The original estimated cleaning frequency supplied by the US Filter was 4 - 6 times per year. While initially cleaning of the RO was required about every two months, recently it has been much more frequent. In early 2006 the cleaning frequency increased to 1 – 2 times per month. Fouling of the RO appears, via multiple element autopsy, to be the result of a combination of biofilm growth and passage of fine (<2 µm) particulate material through the pre-treatment filtration section of the system. It is suspected that some of the RO biofouling may have resulted from periods of RO inactivity during the first few months of system operation. This may be addressed by incorporating chemical disinfectants into the cleaning regimen or adding an on-line biocide injection system. In addition, the chemical control provided for the sodium bi-sulfite feed is flow based only. Since there is no ability to trim the feed there is frequently a bisulfite excess of 2 – 8 ppm at the original design dosage. Better chemical control is being investigated and will be implemented by the station.

To date the plant has operated without the addition of any coagulant or polymeric filter aid upstream of the multi media filters in accordance with the recommendations of the equipment supplier, which were based on pilot testing performed before system startup. The silt density index of the RO feed water (SDI_{15}), however, is approaching the maximum possible value for a 5 minute test, and Con Edison is therefore considering implementation of polymer injection before the media filters. This will increase the rate of filter backwashing at the same time so a balance must be struck between solids removal and backwash frequency.

The operation of the CEDI system has been stable, and has not yet required any chemical cleaning. After an initial stabilization period during which instruments were being calibrated and outputs scaled to provide the correct input to the data acquisition system, product water quality has been consistently less than 0.1 µS/cm, less than 15 ppb silica, and less than 3 ppb sodium (Figures 7, 9 and 10). CEDI pressure drops and electrical resistance have been stable, once the effect of temperature is accounted for (Figures 11 and 12).

CONCLUSIONS

Construction of such a large demineralization system in an operating power plant in downtown Manhattan posed numerous challenges from locating and sizing of equipment to rigging to scheduling. The RO/CEDI system for the East River Repowering Project has now operated for a year and a half, and has produced over 750 million gallons of deionized water. The system has provided stable final product water quality, easily meeting the outlet water quality specifications. However a significant amount of additional work needs to be done to improve the RO pretreatment, reduce the frequency of RO membrane cleaning and reverse the increase in resources and maintenance required to ensure that the system is able to maintain its consistent outlet water quality.

REFERENCES

(1) Gifford, J. and Atnoor, D. An Innovative Approach to Continuous Electrodeionization Module and System Design for Power Applications, International Water Conference, Paper IWC-00-52, October 2000.

(2) Wood, J., Westberg, E. and Blackbourn, D., Field Experience with a New CEDI Module Design, International Water Conference, Paper IWC-03-37, October 2003.

Figure 1: RO Permeate Temperature

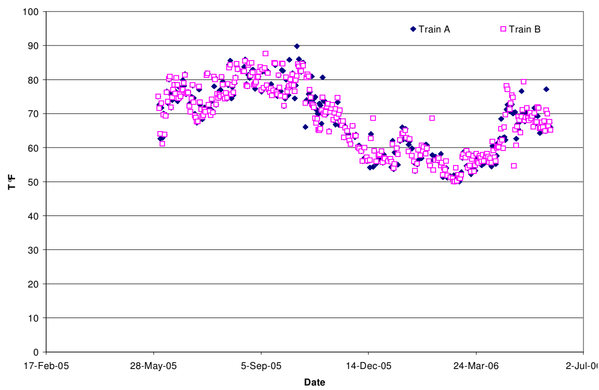


Figure 2: RO Permeate Conductivity

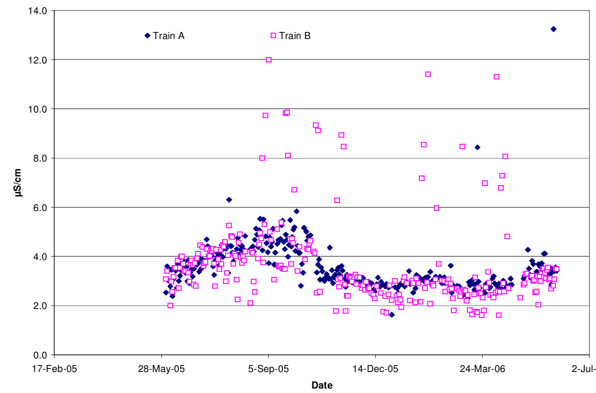


Figure 3: Normalized DP, RO Skid 1401

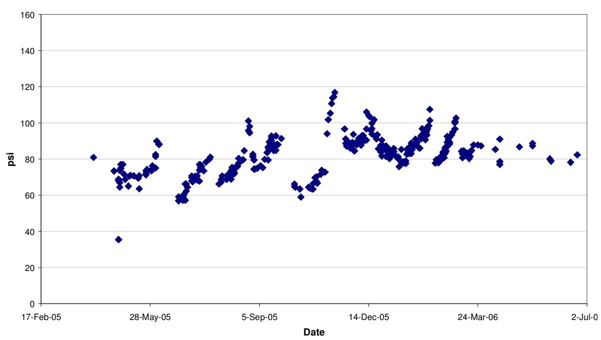


Figure 4: Normalized Permeate Flow, RO Skid 1401

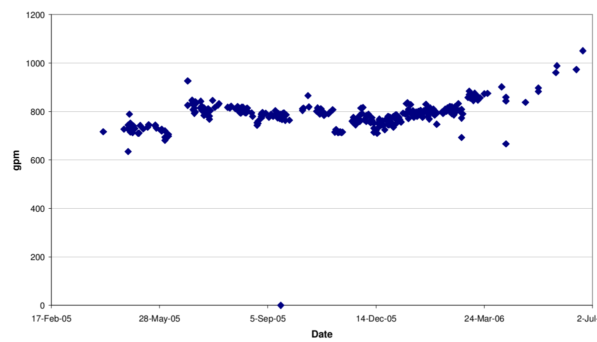


Figure 5: Normalized Salt Passage, RO Skid 1401

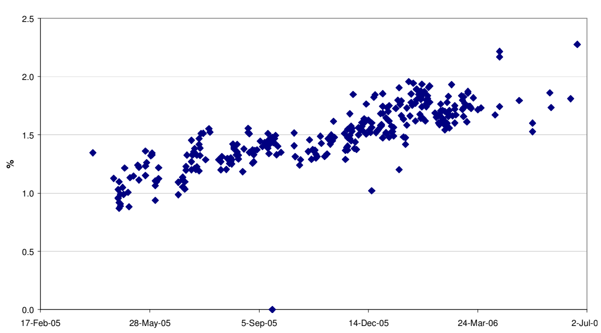


Figure 6: Permeate Conductivity, RO Skid 1401

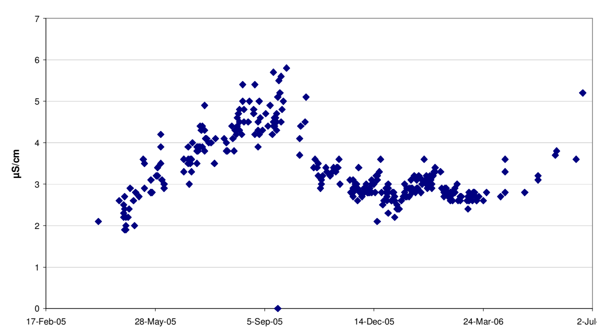


Figure 7: CEDI Conductivity

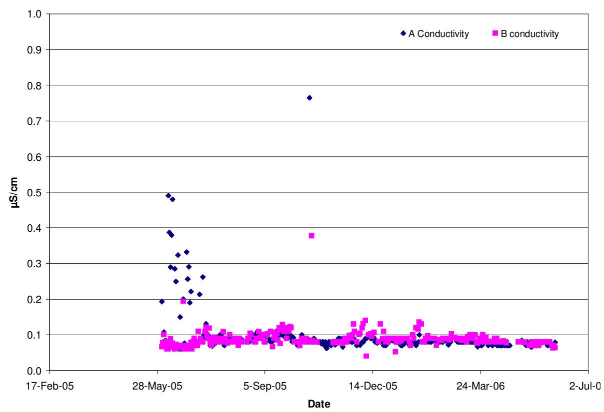


Figure 8: CEDI Flow

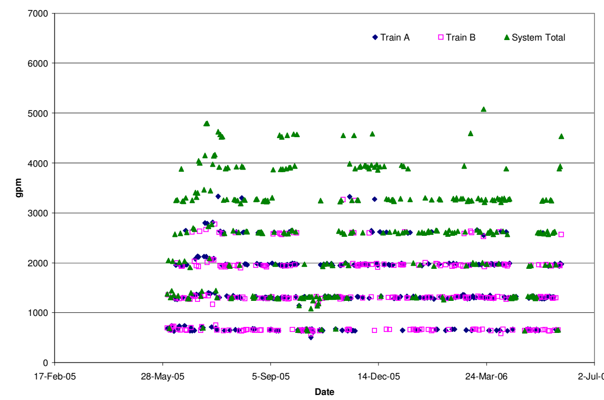


Figure 9: CEDI Silica

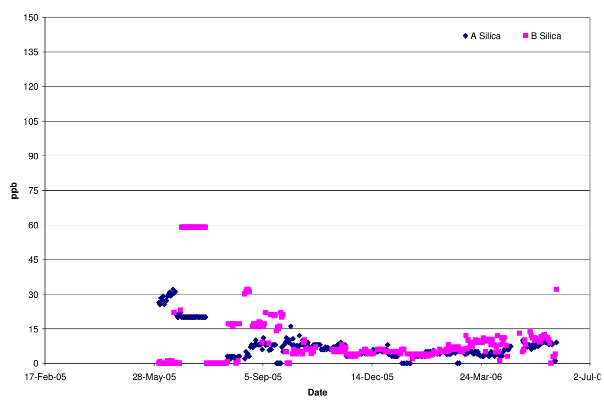


Figure 10: CEDI Sodium

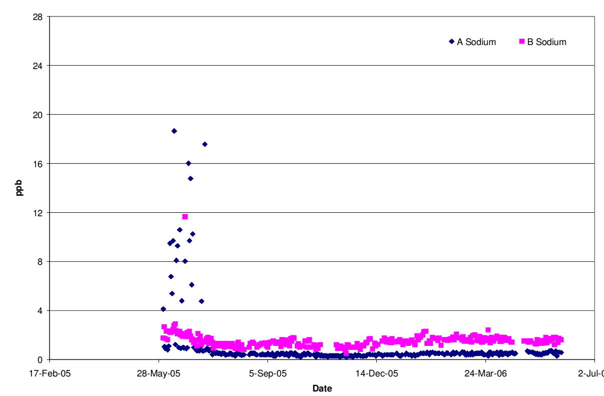


Figure 11: Average CEDI Electrical Resistance

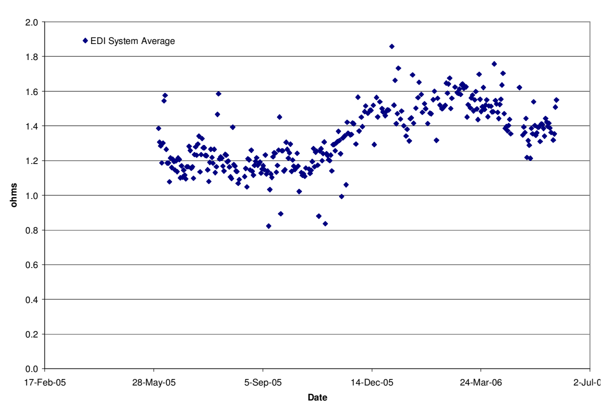


Figure 12: Product & Reject DP, CEDI Skid 1401