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Technical Paper

Selection of EDR Desalting Technology Rather Than MF/RO for the City of San Diego Water Reclamation Project

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Introduction

The North City Water Reclamation Plant (NCWRP) is a high visibility project for the treatment and reuse of tertiary wastewater. The City of San Diego was ordered by the courts to focus on water reclamation as an environmentally sound approach to supplementing local water supply and minimizing discharge to the ocean.

An immediate reuse application for the water from NCWRP was identified as industrial process water and landscape irrigation. The City wished to use reclaimed water for landscaping irrigation along highways, in city parks and around public buildings, and to sell the water to other users including golf courses, schools, parks, nurseries and residential homeowner associations. Although the reclaimed water from the NCWRP meets guidelines for non-potable reuse, the water was found to be high in sodium concentration. Sodium poses a threat to several species of decorative flora by preventing the cells from growing properly. To use the reclaimed water for irrigation, a membrane desalting system was needed.

Feed Water Quality

Since NCWRP was not in operation during the bidding process, the feed water quality was projected from water quality sampling conducted in the plant service area. Table 1 shows projected quality of this tertiary treated reclaimed water from NCWRP. The City required the overall total dissolved solids (TDS) level to be reduced to less than 1,000 mg/l so that the sodium level would be acceptable for irrigation.

Table 1: Feed Water Quality

	Concentration			
Parameter	Mean Value	Low Value	High Value	Units
Temperature	24	20	29	°C
pH	7.4	7.0	7.6	units
TDS	1250	1110	1550	mg/l
Bromide	0.7	0.6	0.9	mg/l
Chloride	310	150	550	mg/l
Sulfate	340	180	385	mg/l
Barium	0.8	–	–	mg/l
Sodium	220	120	350	mg/l
Calcium	80	60	90	mg/l
Magnesium	50	0.2	50	mg/l
Potassium	15	12	18	mg/l
Iron	0.9	–	–	mg/l
Silica	15	14	17	mg/l
Boron	0.6	0.2	0.8	mg/l
Total Phosphorus	3.4	0.8	5.6	mg/l
Nitrate	5	1.6	15	mg/l as N
Nitrite	0.2	0.1	0.7	mg/l as N
Ammonia	0.8	0.1	3.2	mg/l as N
Bicarbonate	183 (est)			mg/l
Carbon Dioxide	12 (est)			mg/l
Total Organic Carbon	10	8	15	mg/l

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Evaluation of Alternative Membrane Processes

Since microfiltration/reverse osmosis (MF/RO) was being piloted by the City as part of the Aqua 2000 project, the City initially investigated MF/RO for this application. However, the City wanted to find the least expensive technology that could make water of the required quality, and so it evaluated EDR as an alternative. EDR has a proven record of operating on difficult-to-treat waters without extensive pretreatment[1].

Electrodialysis Reversal

Electrodialysis is an electrochemical separation process in which ions are transferred through ion exchange membranes by means of an electrical driving force. When a DC voltage is applied across a pair of electrodes, positively charged ions such as sodium move towards the cathode and negatively charged ions such as chloride move towards the anode.

Figure 1 shows a typical electrodialysis membrane stack. Membranes are placed between the electrodes to form several compartments. Flow spacers are placed between the membranes to support

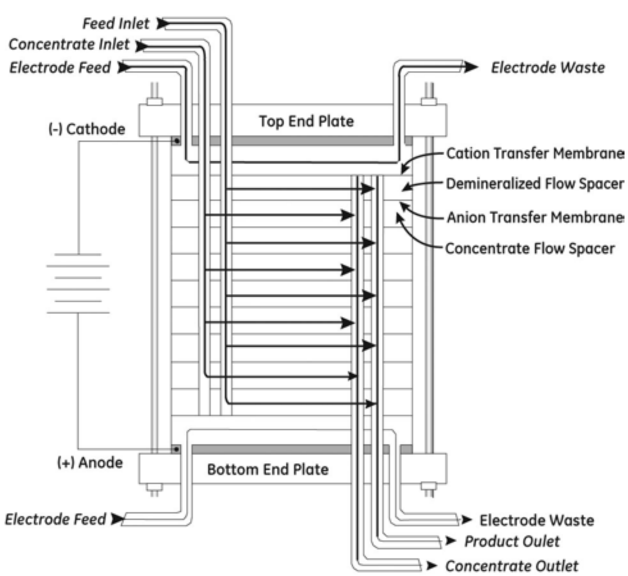

Figure 1: Electrodialysis Stack

the membranes and to create turbulent flowpaths. Water flows along the spacers' flowpaths across the surface of the membranes rather than through the membranes as in RO. EDR is an automatic self-cleaning version of electrodialysis in which the polarity of the DC voltage is reversed two to four times per hour2.

Comparison EDR—MF/RO

RO is a pressure driven process in which water is forced through a membrane while most suspended and dissolved solids are retained in a concentrate stream. RO membranes tend to be susceptible to biological fouling on the membrane surface, and so the feed water turbidity must be quite low. (A 15-minute SDI of less than three is preferred for RO feed water.) Since thin film composite RO membranes are destroyed by oxidizing agents, it can be very difficult to control biological growth on the surface of the membrane. Using MF as a pretreatment for RO improves the overall system performance by providing low turbidity, low microbial water to the RO system, but the additional cost of an MF system makes the MF/RO process an expensive option. The additional membrane barrier, which is an advantage for direct potable use of municipal effluent, is of no particular benefit for reuse of water for irrigation and most industrial applications.

EDR is an electrically driven process in which charged species such as ions are pushed through a membrane while the diluted water passes between the membranes. Non-charged particles are not removed by EDR, and so they do not concentrate on the membrane surface. Large, charged, organic particles may be absorbed on the membrane surface, but during reversal, the electrical driving force pushes the particles off the membrane surface into the waste stream. Thus, the EDR process is self-cleaning. EDR membranes are not as susceptible to degradation by chlorine, so dosing a small amount of chlorine to the feed water can control bio-growth in the system. These features mean that EDR can operate on surface and wastewaters with high levels of organic materials and microorganisms without significant fouling problems.

RO can achieve approximately 99% salt removal, whereas the amount of salt removed by EDR depends on the number of stacks in series, or stages, with each stage achieving about 50-60% salt removal. Since the expected average feed water quality to the membrane process at North City is 1,260 mg/l, and the required product quality is 1,000 mg/l, only 21% overall salt removal is required. With either membrane process, it is possible to design a plant to desalinate part of the water and by-pass some of the water to make blended water of the required quality. EDR has an additional advantage of being able to achieve higher water recovery than RO without chemical addition. Based on the projected feed water analysis, EDR was designed at 85% water recovery without chemical addition, whereas the RO would have required acid dosing and a scale inhibitor to achieve the same recovery.

The specification required a price for an MF/RO system capable of producing 3 mgd (million gallons per day) of blended water of 900 mg/l TDS. EDR was allowed as an acceptable alternate bid.

The results of the bid process are presented in Table 2. The lowest bid for an MF/RO system was US$4,775,975 whereas the lowest bid for an EDR system was US$3,569,000. This represents a capital cost savings of US$1,206,975, which is a 25% saving over the lowest bid MF/RO system. The City of San Diego awarded the contract to Earth Tech for an EDR system.

Table 2: Results of Bids for MF/RO and EDR Systems

Bidder	Microfiltration / Reverse Osmosis	Electrodialysis Reversal
Earth Tech	$ 6,236,000	$ 3,569,000
CDM	$ 6,076,100	$ 6,076,100
Metcalf & Eddy	$ 4,775,975	$ 4,047,792
Black & Veatch	$ 5,654,104	$ 4,276,573
CH2M Hill	No Bid	No Bid

Note: amounts shown in USD

EDR at North City

The EDR system at North City was commissioned in spring 1998. The system consists of two separate trains of 5 parallel lines of stacks. Each train produces 1.1 mgd. The EDR product is blended with up to 800,000 gpd (gallons per day) of tertiary reclaimed water to achieve the required TDS quality. The total quantity of blended product water was designed to be 3 mgd.

Each line of stacks consists of a single stage stack of 600 cell pairs. The lines are designed to be expandable to two stages should it be required to make more water by blending, and the system is built to be expandable to a third train of 1.1 mgd for a total of 3.3 mgd of desalted water.

The system was built by GE Water & Process Technologies with the new EDR 2020 design, using variable frequency drives to minimize pumping power and 4-way valves to maximize recovery by minimizing the amount of mixing of product and concentrate during reversal[3].

The system includes three feed pumps operating in parallel. Two of the pumps operate at one time to supply both EDR units, and the third pump is on standby. Three cartridge filter housings containing 10-micron filters are installed in parallel, so any two can be used to feed the EDR units. The third housing makes it possible to change the filters without shutting down the EDR system. The EDR product is sent to a product tank, after which it is blended with water supplied from the tertiary bypass pumps. Each EDR unit is controlled with a PLC (Programmable Logic Controller) using a touch screen operator interface. The overall system has a PLC and a SCADA (Supervisory Control and Data Acquisition) system to connect the EDR plant to the main NCWRP control room.

Performance of EDR

Expected Performance

Previous experience of operating membrane systems (both EDR and RO) on wastewaters has shown that desalting the tertiary treated reclaimed water might have some problems. Since the NCWRP was not in operation until a few months before start up of the EDR plant, there were several unanswered questions.

1. The TDS of the feed was likely to vary significantly depending on the season and rainfall. As the TDS varies, the allowable current density that can be applied to a membrane stack varies. An appropriate method of operating the EDR system needed to be selected, so that the operators did not have to spend significant time adjusting the operating conditions while ensuring that the system ran within design limits.
2. Concentrations of individual ions might also vary depending on the performance of the NCWRP. For example, the total phosphorus concentration was projected to vary between 0.8 and 5.6 mg/l. There is virtually no data available relating to the precipitation of calcium phosphate in membrane systems. We have, however, experienced calcium phosphate pre-

cipitation in RO membranes on a wastewater reclamation project. EDR can typically operate at much higher levels of supersaturation than RO, but at the designed 85% water recovery, there was potentially a risk of calcium phosphate scaling if the phosphorus level did reach the maximum values. Since the saturation point of calcium phosphate is highly pH dependent, plans were made to monitor the calcium phosphate level and then to add acid to adjust the pH if this problem occurred.

3. Obviously, the turbidity of the water from NCWRP will vary. The advantage of EDR with a variable feed is that EDR systems can recover from high turbidity upsets in the wastewater treatment plant. Customers handle upsets in pretreatment to the EDR differently, so that EDR performance is affected in different ways. Another EDR plant in the US that desalts reclaimed water is at Moody Gardens in Galveston, Texas. Moody Gardens uses EDR to reduce the sodium and chloride concentration of tertiary treated reclaimed water at a therapeutic, educational and recreational complex, for applications, such as watering the landscaped grounds, greenhouses, and a rain-forest pyramid. The complex includes many exotic species of plants and fish. The customer prefers to clean the EDR manually every few months rather than use chemicals in the feed water that might put the expensive tropical fish at risk. In some places, adding chemicals to the feed water is very expensive, and customers sometimes prefer to allow poor quality water with high turbidity (4 NTU average, 15 NTU maximum) to run through the EDR system. This affects the performance of the EDR by increasing the DC power consumption and requiring more CIPs (clean in place) of the membrane stacks.

At North City, the maximum design feed turbidity is 2 NTU. Our experience of well-designed and operated wastewater treatment facilities is that the turbidity of the tertiary treated water is better than this as it later proved to be at North City. Since the plant was new, however, we expected that there might be some turbidity variations while experience was gained on this particular application. We didn't plan, however, for one of the worst El Niños for many years.

Feed Quality

In order to select operating conditions, a number of grab samples were taken (between 11/17/97 and 12/11/97) before the start up of the EDR plant. The range of feed analyses is shown in Table 3. There was some daily variation in the feed. For instance, in the three samples taken on 12/10/97, the TDS was 1135, 1189, and 1268 mg/l. The phosphate level was generally good at less than 3.5 mg/l, although the sample taken on 11/17/97 at 6.56 mg/l was higher than the maximum design value and was a cause for concern.

Table 3: Actual Feed Quality

	Concentration		
Parameter	Low Value	High Value	Units
pH	7.17	7.6	units
TDS	1119	1268	mg/l
Chloride	274	325	mg/l
Sulfate	296	342	mg/l
Barium	0.08	0.09	mg/l
Sodium	206	238	mg/l
Calcium	87	99	mg/l
Magnesium	43	46	mg/l
Potassium	15	17	mg/l
Iron	0.05	0.05	mg/l
Phosphate	1.9	3.5	mg/l
Nitrate	15	25	mg/l as N
Bicarbonate	89	125	mg/l
Total Organic Carbon	6.7	7.7	mg/l

Plant Operation

The important operating parameters from the performance specification are summarized in Table 4.

Salt Removal

The EDR plant was started up on 2/4/98. Figure 2 shows the feed and product conductivity, and the % salt removal of Unit #2 during the initial 1,600 hours of operation. The operation of Unit #1 was very similar. The DC voltage applied to the stacks was adjusted for approximately 55% salt removal.

Table 4: Operating Parameters

Salt Removal	55%
EDR Production Rate	2.2 mgd
Water Recovery	85%
Pumping Power Consumption	2 kWh/kgal
DC Power Consumption	< 1.05 x GE supplied

The salt removal was maintained between 52 and 55% from the time of plant start up, with an exception at about 700 hours when there was a drop off in performance that will be discussed later. The EDR plant performance was recovered after acid CIPs. In the 1,600 hours of operation, the feed TDS varied between 1,270 and 854 mg/l. The EDR system consistently produced 2.2 mgd at a TDS of between 664 and 355 mg/l. The system was designed to produce a total of 3 mgd of blended product of 900 mg/l. Since the feed TDS was quite low due to the high rainfall caused by El Niño, it was possible to blend more water than the design 0.8 mgd. Table 5 gives a typical water analysis for the blended product. The EDR plant was operated at the high salt removal level to demonstrate plant performance. An alternative way of operating the plant is to reduce the voltage and produce a higher TDS product with less blending and less DC power consumption.

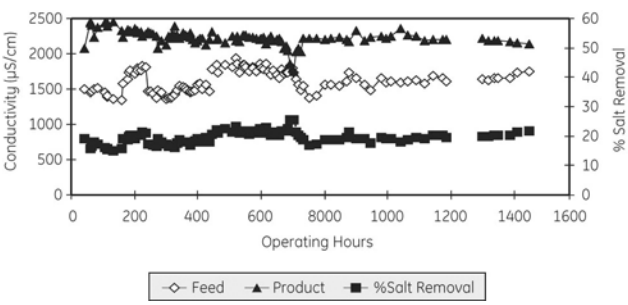

Figure 2: Conductivity and Salt Removal versus Time

Water Recovery and Power Consumption

The performance specification required a minimum water recovery of 85%. Throughout the test period, the EDR system operated at above 85% water recovery without chemical dosing, as expected. Calcium phosphate was monitored in the concentrate, and although the concentrate was super saturated with calcium phosphate to about 370% saturation, no precipitation was observed.

Power consumption was divided into two parts: pumping power and DC power. Pumping power is the power required to pump the feed and recycled concentrate through the system. The specification

Table 5: Typical Blended Product Quality

Parameter	Concentration	
pH	7.5	units
TDS	704	mg/l
Chloride	145	mg/l
Sulfate	194	mg/l
Sodium	134	mg/l
Calcium	52	mg/l
Magnesium	24	mg/l
Potassium	6.6	mg/l
Iron	0.09	mg/l
Phosphate	2.9	mg/l
Nitrate	27	mg/l
Bicarbonate	119	mg/l
Total Organic Carbon	11.7	mg/l

called for pumping power not to exceed 2 kWh/kgal. The actual pumping power varied between 0.9 kWh/kgal and 1.05 kWh/kgal. The system uses variable frequency drives to minimize power consumption; as the 10-micron cartridge filters in front of the EDR system plugged and the stack pressure drop increased, pumping power consumption also increased. The measured pumping power was approximately half the design power.

DC power is the power used to desalt the reclaimed water. The specification was based on a set of performance curves that predicted DC power consumption at different feed TDS and temperatures. The DC power was allowed to be up to 1.05 times the value on the curves shown in Figure 3. For example, at 1250 mg/l TDS, the predicted DC power consumption at 55% salt removal was 1.3 kWh/kgal. The specification allowed the DC power to be 1.37 kWh/kgal. At 1000 mg/l, the predicted DC power consumption was 1 kWh/kgal, and the specification allowed 1.05 kWh/kgal. At a higher TDS, more salt is transferred across the membranes to achieve 55% salt removal, and so the current, voltage, and power increase with TDS. DC power consumption varied between 0.78 and 1.15 kWh/kgal and was just at or below the design specification as shown in Figure 3. The high power consumption at low salt removal corresponds to the drop off in performance at 700 hours, a relationship that is discussed below.

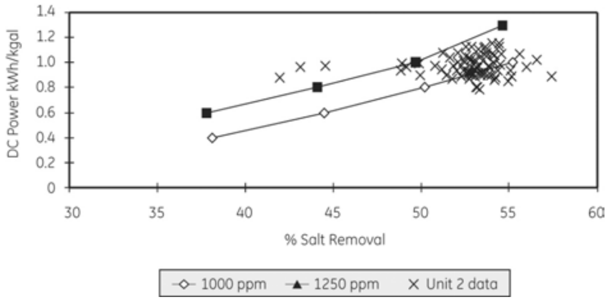

Figure 3: DC Power Consumption versus % Salt Removal

Performance Problems

There were several issues relating to the plant performance that were a concern to the City, and everyone working on the project has worked hard to resolve this situation. Although the pumping and DC power consumption combined were much lower than design, the DC power consumption was only just within performance limits. Initially, the system was acid CIPed more than anticipated to keep it running to design. Two reasons requiring this were identified after membrane samples were taken. One reason was membrane fouling due to the high organics in the feed. This form of fouling was anticipated, and the system design provided for salt CIPs to remove the fouling.

A second cause of membrane fouling that was not anticipated was precipitation of alum on the membrane surface. Whenever the turbidity of the feed prior to the filters reached 4 NTU, alum was dosed to the filters to bring down the turbidity. The filters remove about 50% of the turbidity, so alum dosing was required to maintain a reclaimed water of below 2 NTU. Alum flocs can be weak in physical structure and break up under shear forces in filter media as the pressure drop in the filters increases. At times the alum got through the anthracite filters and cartridge filters and precipitated in the EDR stacks. Alum was identified as causing short cartridge filter life, and although alum precipitate can be easily removed with acid, a CIP represents additional expense and downtime. So the City was concerned about extra costs caused either by having to replace filters or perform more frequent CIPs.

These problems were attacked in several ways. In the original design, chlorine is added to the blended product after the EDR. But, unlike RO, EDR membranes are not destroyed by small amounts of chlorine. So, a chlorine injection system was set up to add 0.5 mg/l of chlorine to the EDR system feed water. This approach minimized bio-fouling of both the ion-exchange membranes and the cartridge filters.

Ferric has been tested as an alternative to alum as a coagulant, but this also increased the cartridge filter plugging rate and frequency of EDR system CIPs. At this point, while the problem has been identified, the long-term solution is not clear. Alum flocs can be strengthened using a filter aid. Aids can be high molecular weight anionic, non-ionic or cationic polymers. Jar tests have shown that these polymers increase the strength of the alum floc to reduce breakthrough from the filters and reduce the feed turbidity. However, the City has elected not to add polymer. Instead, on the rare occasions when there is a turbidity upset, the City shuts down the EDR plant to extend cartridge filter life and reduce the frequency of CIPs of the EDR system. The most recent CIPs were performed for Unit 1 after 930 hours of operation and for Unit 2 after 1,050 hours of operation. The longest operational lifetime for a set of cartridge filters was over 1,100 hours.

Summary

EDR was selected for desalting reclaimed water at North City for irrigation applications since it was 25% lower cost than MF/RO. The EDR system has been in operation since start up in February, running at 85% water recovery with low power consumption.

Initially, short cartridge filter life and periods between acid CIPs have been extended by chlorine dosing to the EDR feed and the bypassing of the EDR system during periods of high turbidity.

The City of San Diego is presently evaluating an expansion of the EDR plant to 3.3 mgd.

References

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