technical brief

Technologies for Improving Water Desalination

Energy Delivery & Utilization Division
Municipal Water and Wastewater Target

Summary

The Colorado River is the major water source for much of the Southwest. The high total dissolved solids (TDS) concentration of 600 to 800 milligrams per liter (mg/L) in Colorado River water (CWR) causes problems for agriculture, industry, and water reclamation. Recent technical progress in non-thermal desalting technologies such as ultra-low-pressure reverse osmosis (RO) membranes and capacitive deionization (CDI) with carbon aerogel may significantly lower treatment costs and make large-scale desalting feasible for water quality and supply projects in the Southwest and elsewhere.

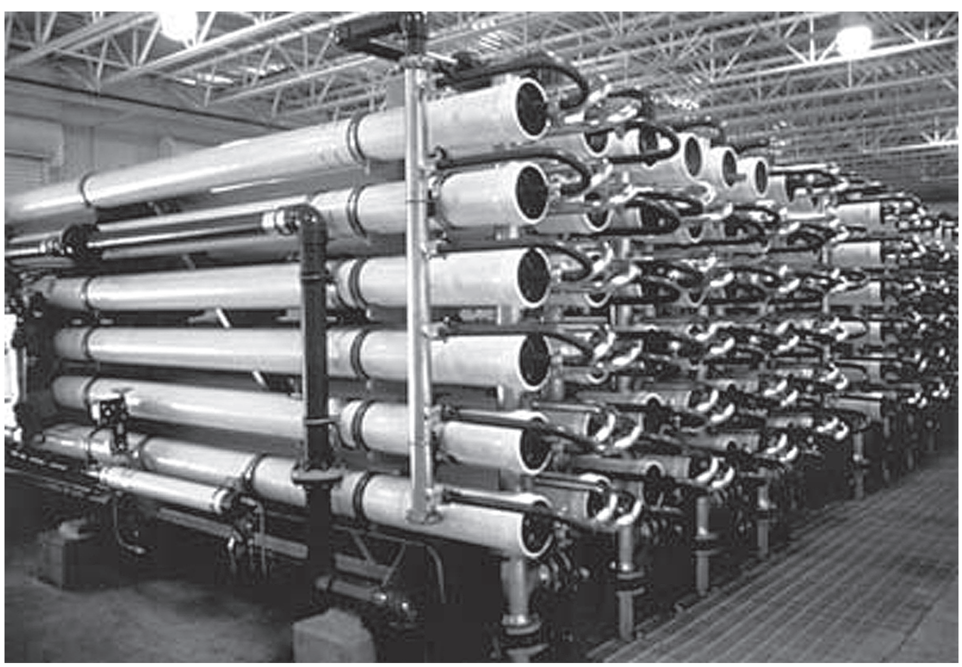
The objectives of this study were to compare CDI with carbon aerogel and RO for salinity reduction using conventional treatment (flocculation, sedimentation, and dual media filtration), conventional treatment with ozone and biologically active filters, and microfiltration (MF) as the pretreatment step. Results showed that both conventionally treated water with and without ozone and biologically active filters could be directly used for RO pretreatment. However, chemical additives to both the pretreatment and membrane processes adversely impacted long-term RO performance. Alternative process conditions will be studied to remedy these operational issues. The microfiltration pretreatment study is currently in progress. Current results for the state-of-the-art CDI technology, however, cannot be directly compared to RO, regardless of the type of pretreatment used.

The benefits of this project include the reduction of societal damages to the public and private sectors due to high salinity of Colorado River water through developing lower-energy desalting alternatives. Additionally, technologies evaluated during this project may be applicable to other source waters such as municipal wastewater, brackish groundwater, and agricultural drainage water.

Background

The Metropolitan Water District of Southern California (MWD) supplies water to a service area of over 16 million residents. The Colorado River, a major water source, contains elevated levels of salts. At 600 to 800 mg/L of TDS, the Colorado River exceeds the US Environmental Protection Agency's secondary (non-health based) standard of 500 mg/L TDS.

For every 100 mg/L over the 500 mg/L TDS standard, the TDS of CRW causes an estimated $95 million damage per year to Southern California's agricultural, industrial, commercial, utility, and residential sectors. However, reducing the TDS by current RO technology and split-flow treatment is expensive, approximately $0.88/1,000 gallons ($0.28/m^3), and is not economically viable at a large scale. Therefore, this project evaluated new and innovative technologies to reduce the cost of desalinating CRW.



Reverse osmosis membranes

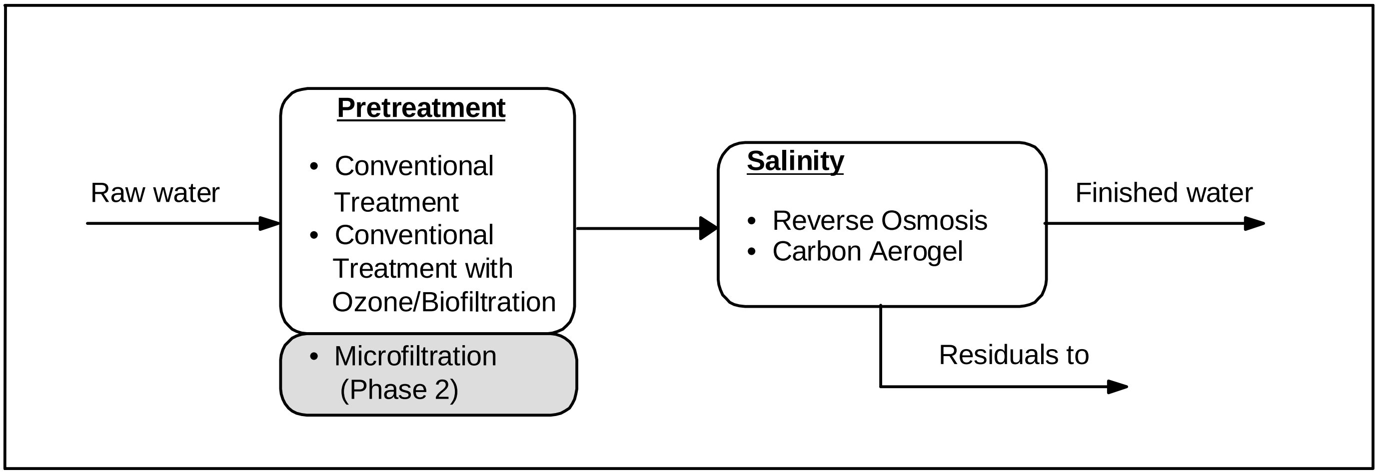


Figure 1. Research Testing Program

Technology Overview

All desalination technologies require pretreatment to remove particulates from the source water to protect downstream processes from damage or fouling. Little information is available on the use of conventional treatment plants prior to salinity reduction for surface waters. Low-pressure membrane processes such as MF—in addition to occupying a smaller footprint—produce cleaner water than conventional treatment. As a result of better pretreatment, RO membranes operate more efficiently. However, since conventional treatment facilities are already in place and require approximately one-third of the energy, significant savings could be realized by avoiding MF pretreatment. The use of conventional pretreatment for RO systems may be feasible, but the desalting process is highly sensitive to raw water quality. Thus, a major effort lies in determining whether MWD's current conventional treatment plants, either with or without ozone and biologically active filters, can provide adequate pretreatment for use with ultra-low-pressure RO.

RO is a mature technology used for many years to desalt brackish water and seawater. It is a pressure-driven membrane process that overcomes the natural osmotic pressure of the salts in water. Osmosis is a process that transports water through a semi-permeable membrane from a solution of low concentration to one of high concentration. RO occurs when pressure in excess of the osmotic pressure is exerted on the high concentration side of the membrane. Ultra-low-pressure RO membranes have been recently developed and operate at significantly lower pressures (75 to 150 pounds per square inch (psi) (517 to 1034 kPa)) than conventional low-pressure membranes (175 to 450 psi (1207 to 3103 kPa)). The reduced pressure results in significant energy savings.

Capacitive deionization with carbon aerogel electrodes is a new and developing technology for removing TDS and impurities from water supplies. Carbon aerogels consist of interconnected, uniform carbonaceous particles with small pores. This structure provides high specific surface area, low hydraulic resistance, and exceptional electrical conductivity. In capacitive deionization, water is passed between two carbon aerogel electrodes maintained at a potential difference of about one volt. Ions are removed from the process stream by the imposed electrostatic field and retained on the electrode surface until the unit is shorted-out. The CDI process may offer advantages when compared to other desalination methods because no high-pressure pumps or membranes are required. Limited performance data, however, are available for drinking water desalination.

The research approach is illustrated in Figure 1. Two pretreatment scenarios were evaluated:

- Conventional treatment
- Conventional treatment with ozone and biological filtration.

Two technologies were evaluated for salinity removal:

- Carbon aerogel CDI
- Ultra-low-pressure RO

The initial phase of study, discussed in this publication, does not include pretreatment using MF. Testing with MF pretreatment is scheduled for the Fall of 1999, and the results will be reported later.

Current Status of Research

For this project, a 60 gallons per minute (gpm) (13.6 m^3/h) conventional water treatment plant, complete with a dual-media filter, provided pretreatment. This plant was used for both pretreatment scenarios; when used for ozone/biofiltration, ozone was added prior to the flocculation zone and the filter was operated biologically active. Biofiltration was achieved by discontinuing chlorine addition at the plant influent and allowing a biofilm to establish on the filter media. RO was provided by spiral-wound, thin-film composite polyamide membrane elements. The RO unit was operated continuously at 85 percent product recovery with operating pressures ranging from 113 to 130 psi (779 to 896 kPa). The CDI unit was operated in either a batch-mode (3.3 gallons (12.5 L)) or single-pass (100 mL/min) configuration.

The performance results of the pretreatment and desalination testing using RO are summarized in Tables 1 and 2. The data indicate that the two pretreatment methods meet the effluent quality parameters of the RO membrane manufacturer. Carbon aerogel CDI test units exhibited low capacity (6 - 8 mg TDS per gram of carbon aerogel) and slow regeneration (>1 hr). Based on these results, the CDI unit underwent significant redesign and modification to improve performance.

Findings

Based on the results to date, the following findings are offered:

During preliminary research, repeated scaling of the RO membranes occurred when using conventional treatment as pretreatment. These episodes were attributed to aluminum silicate fouling caused by poor cross-flow conditions in the membranes. By changing the chemical coagulants to ferric chloride and cationic polymer and operating the RO unit with higher cross-flow velocities, fouling rates decreased. The choice of coagulants may have an effect upon silicate formation potential.

Despite producing effluent water quality within RO manufacturer's guidelines, both conventional treatments with and without ozone/biofiltration processes produced effluent water that fouled the RO membranes within two months.

Rapid fouling of the RO membranes was attributed to the interaction of iron and the acrylate-based antiscalant, which precipitated onto the RO membranes. A confounding factor may have been the recirculation of a portion of the concentrate to increase to RO system cross-flow velocities.

The RO fouling rate during the ozone/biofiltration study was comparable to that observed when using conventional treatment alone. However, analysis of the fouled membranes indicated that there was more biological foulant present during the ozone/biofiltration run, which was likely caused by bacteria and bacteriological material sloughing off from the biologically active filters (BAF). In addition, antiscalant interactions similar to those observed during conventional treatment may have been a contributing factor.

Redesigned CDI units exhibited better salt removal (up to 16 mg TDS per gram of carbon) and better regeneration (about 10 min). The scope of work for future CDI evaluations, therefore, was modified to gain a more fundamental understanding of carbon aerogel electrosorption capabilities.

Table 1. Effluent Water Quality Results From Pretreatment Test Program

Parameter	RO Membrane Manufacturer's Guidelines	Conventional Treatment	Conventional Treatment With Ozone/Biofiltration
Turbidity, NTU	<1	0.08	0.07
Silt Density Index	<5	3.1	3.0
Particles, #/mL	NA	33	233
pH, units	4-11	6.5-8.1	7.9-8.1

Table 2. Comparison of Alternative Pretreatment Methods With RO Desalination

Evaluation Criteria	Conventional Treatment	Conventional Treatment With Ozone and Biologically Active Filters
Permeate flux, gal/ft^2/day (L/m^2/day)	16.1 (656)	15.7 (640)
Average operating pressure, psi (kPa)	125 (862)	113 (779)
Energy usage, kWh/1,000 gal (kWh/m^3)	1.66 (0.44)	1.37 (0.36)
Process Recovery, %	85	85
Salinity rejection, %	98	99
Effluent water quality, mg/L TDS	14	27
Operational reliability	Good	Good

Ongoing Research Activities

The next phase of research continues the evaluation of desalination pretreatment technologies with special emphasis on microfiltration and modified conventional treatment with and without ozone and biologically active filters. Alternative desalination methods will also be tested using ultra-low-pressure RO membranes, nanofiltration, and fouling resistant membranes on treated water from MWD's Weymouth Filtration Plant. For surface water treatment, evaluations will include fouling rates, optimum operating parameters, and an economic assessment. The University of California at Riverside will conduct studies on solids removal using conventional and novel pretreatment technologies and innovative desalination technologies for agricultural drainage water.

Newly developed large-diameter (16 in. (406 mm)) RO membrane elements will be tested and compared to standard RO membranes in order to reduce costs and make large-scale RO more feasible. Each element of the new membranes is capable of filtering over four times more water than current 8 in. (203 mm) designs. A 200 gpm (45 m^3/h) pilot plant will be constructed and operated, focusing on characterizing the performance of the large-diameter elements. Pilot plant data will be used to develop design criteria for a 100 million gallons (0.4 million m^3) per day RO plant.

Research involving CDI is ongoing. Testing includes an assessment of operational variables on carbon aerogel performance, as well as the effects of individual ion properties on ion sorption.

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