COLORADO
Colorado Water Conservation Board
Department of Natural Resources

1313 Sherman Street, Room 721
Denver, CO 80203

Memorandum

To: Colorado Water Conservation Board Members
From: Rebecca Mitchell, Section Chief
Water Supply Planning Section
Date: May 8, 2014
Subject: Agenda Item 17, May 21-22, 2014 Board Meeting
Zero Liquid Discharge Grant Presentation
Water Supply Planning Section

Staff Recommendation: This is an informational item only. No Board action is required.

Background:
Utilities in Colorado and throughout the western United States have been reluctant to build reverse osmosis (RO) membrane plants due to the uncertainty surrounding the disposal of concentrate (brine). Concentrate minimization and zero liquid discharge (ZLD) technologies show promise to provide cost effective means for brine disposal. The purpose of this project was to pilot test concentrate minimization and zero liquid discharge technologies suitable for use in Colorado.

A new technology, Zero Discharge Desalination (ZDD), was pilot tested at two drinking water RO plants in Colorado. The ZDD technology is an integrated system combining electrodialysis metathesis (EDM) with nanofiltration. The first pilot test reached 96% recovery when treating brackish groundwater to levels suitable for human consumption. The second pilot test demonstrated increasing the recovery an existing membrane system to 98% by treating its concentrate stream.

The ZDD technology did not obtain zero discharge as its name implies, but it demonstrated the ability to produce excellent water quality and obtain high recovery. The ZDD technology shows good potential to reduce the volume of concentrate produced by membrane plants. But further development of the technology is needed with the goal of reducing cost, increasing reliability and simplifying its operation before the process is suitable for full-scale use in Colorado.

CWCB funded this study through the Water Supply Reserve Account ($100,000 Arkansas, Metro, S. Platte Basin Accounts and $700,000 from the Statewide Account). CWCB staff and the consultant will present the study's findings.

EXECUTIVE SUMMARY

Project Background

Increasing demand for potable water in Colorado and throughout the western United States has forced drinking water utilities to consider lower quality source waters. These sources require the use of advanced treatment technologies such as reverse osmosis (RO) or nanofiltration (NF) membranes to treat the waters to levels that meet Safe Drinking Water Act (SDWA) standards. At present, drinking water utilities within Colorado have been reluctant to undertake RO or NF projects due to the uncertainty surrounding the availability of feasible disposal options for the concentrate. Concentrate (brine) minimization and zero liquid discharge (ZLD) are disposal options that may present a long-term solution for concentrate disposal for utilities that need membrane treatment to produce high quality drinking water. A pilot test demonstrating concentrate minimization and ZLD will help address the technical and financial uncertainties which currently hinder the implementation of membrane technology.

The purpose of this project was to investigate the feasibility of concentrate minimization and ZLD and pilot test a concentrate minimization/ZLD technology suitable for use in Colorado.

Project Summary

A multi-step screening approach was used to select concentrate minimization and ZLD technologies for testing. Using the 2007 Report of the Colorado Water Quality Forum's Membrane Treatment Working Group (MTWG) as the point of departure, a comprehensive literature review was compiled and published. This review identified 27 different technologies for brine minimization and disposal. Seven of these technologies were carried forward for additional screening to determine their suitability for pilot testing. The technologies were ranked using eight criteria:

1. Technology is sufficiently mature to be pilot tested and full-scale application of the technology is feasible.
2. Technology is suitable for use in Colorado given Colorado's water quality, regulatory and climatic conditions.
3. Effective evaluation of the technology requires pilot testing. Satisfactory evaluation of the technology cannot be obtained by bench testing or modeling.
4. Provides new data or supplements missing data with respect to the technology's use in Colorado.
5. Equipment is available for pilot testing.
6. Participating utilities are willing to host the pilot testing of the technology.
7. Adequate data to evaluate performance of the technology can be collected within a 90-day test period.

8. Technology does not require extensive permitting to allow piloting to proceed.

As a result of the ranking process a new process, electrodialysis metathesis (EDM) was selected for pilot testing. This process is part of a technology called Zero Discharge Desalination (ZDD) developed by Dr. Tom Davis of the Center of Inland Desalination Systems at the University of Texas El Paso. The ZDD technology is being commercialized by the major water treatment equipment provider, Veolia Water.

The ZDD technology was pilot tested at the La Junta, CO, Water Treatment Plant (WTP) during the summer of 2012 simulating a 'greenfield' application. The La Junta pilot test evaluated the ZDD technology's ability to treat La Junta source water to Safe Drinking Water Act (SDWA) standards while obtaining 98% recovery of the water treated. A second pilot test was performed at the Brighton, CO, WTP during the summer of 2013. This pilot test investigated the feasibility of increasing the overall recovery of the existing RO plant to 98% by recovering 90% of the existing concentrate stream using the ZDD technology.

A life cycle cost estimate for the ZDD technology for the greenfield configuration was prepared using the results of the La Junta pilot test. These costs were compared to an alternative brine minimization technology, Dual RO with intermediate chemical softening (Dual RO), which had previously been tested in Colorado. To perform this cost comparison, the design and anticipated performance of the Dual RO process for a greenfield configuration at La Junta was developed through a combination of computer modeling and bench level testing. The results of the Brighton pilot test were used to investigate the ramifications of disposing residual solids from a fully mature ZDD technology, potentially capable of obtaining 100% recovery - zero liquid discharge.

Pilot Test Configurations at Brighton and La Junta

Figure ES-1and Figure ES-2 are schematics of the configurations the ZDD technology tested at La Junta and Brighton respectively. The ZDD technology is an integrated process combining EDM and nanofiltration (NF). Functionally, the technology uses the EDM to preferentially remove multivalent ions that cause membrane scaling from the water being treated, thereby improving the recovery of the system. Hydraulically, this is accomplished by using the EDM to treat concentrate from the NF and then blending the EDM treated water with the feed for the NF. The treated or finished water produced by the ZDD technology is the permeate stream produced by the NF system. The waste or concentrate water produced by the ZDD technology are two streams, termed the Mixed Sodium (Na) and Mixed Chloride streams, flowing out of the EDM. Although not illustrated in the figures, a stream of dissolved sodium chloride flows into the EDM, supplying ions to facilitate the metathesis separation process performed by the EDM.

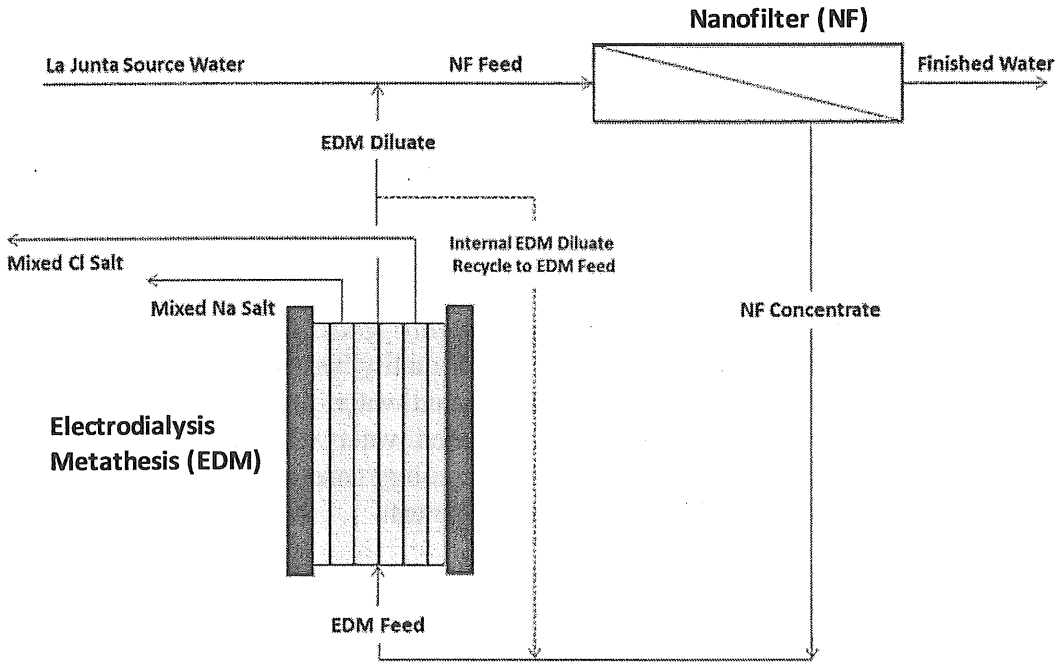

Figure ES – 1 La Junta Pilot Test Schematic.

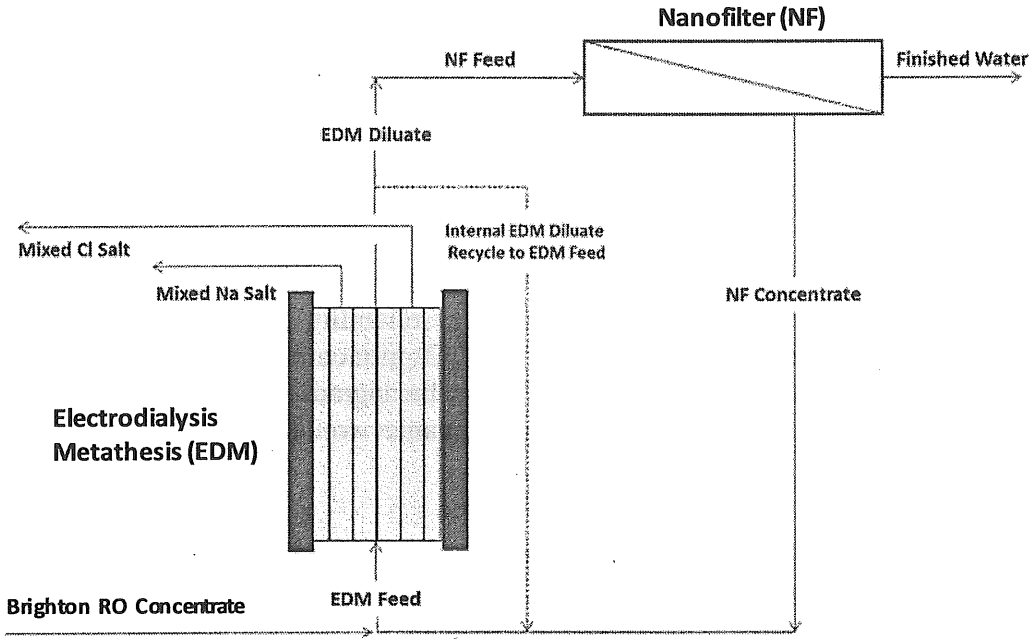

Figure ES – 2 Brighton Pilot Test Schematic.

Assessment of the ZDD Technology

Based on the results of the pilot tests, an assessment of the performance and estimated cost of the ZDD technology was completed.

Technical Assessment of the Performance of the ZDD Technology

- *Electrodialysis metathesis was found to be an effective separation process for removing multivalent ions responsible for forming membrane scalants.* For the ZDD technology to be effective, the EDM process must separate ions responsible for scaling from the water being treated and selectively concentrate the ions in the appropriate waste streams. Water quality data gathered during both the La Junta and Brighton tests demonstrated that EDM is highly effective in separating ions responsible for scaling. The basic feature of the ZDD process, using EDM to separate ions responsible for scaling, is fundamentally sound.

- *The ZDD technology met the project's water quality goals.* The ZDD technology is inherently capable of producing excellent water quality because of its use of NF to produce treated water. The ZDD technology met the treated water quality goals set for both pilot tests. At La Junta, the ZDD technology produced treated water with TDS less than the 100 mg/L goal set for the test. At Brighton, the ZDD technology consistently produced treated water with TDS less than the 650 mg/L goal set for the test.

- *The ZDD technology demonstrated the capability to obtain high recovery. At La Junta, recovery exceeded that estimated for a Dual RO treatment process.* The ZDD technology demonstrated the ability to obtain high recovery during both pilot tests. During the La Junta pilot test, the ZDD technology fell short of the goal of 98% recovery set for treating La Junta source water, demonstrating an average recovery of 96%. But this exceeded the estimated recovery of 92% for a conceptual full-scale Dual RO plant at La Junta. For the Brighton test, the ZDD technology treated the existing Brighton RO concentrate stream. In this case the goal was for the ZDD technology to obtain 90% recovery when treating the concentrate stream. During the Brighton test, the ZDD technology obtained between 87% and 90% recovery treating the Brighton concentrate.

- *The ZDD technology did not demonstrate the ability to maintain performance over extended periods of time.* During the La Junta and Brighton pilot tests there was evidence of decreasing effectiveness of ionic separation by the EDM over time. This was indicated by steadily increasing electrical resistance across the EDM and decreasing conductivity removal by the EDM. Due to a combination of equipment reliability issues, staffing limitations and water availability, the longest period that the ZDD pilot continuously operated was 228 hours. This was not long enough to characterize the degradation in performance of the EDM with time or to investigate what periodic maintenance would be required to restore EDM performance.

Operational Assessment of the Performance of the ZDD Technology

- *In its current state of development, the ZDD technology was found to be a complex technology that was difficult to control and operate.* Several months were required at each pilot site to start-up and optimize the operation of the pilot units. Mechanical, electrical, process, instrumentation and control deficiencies were uncovered during both pilot tests to a degree beyond that typically experienced when piloting mature water treatment technologies. The Project Team believes these problems are indicative of the inherent complexity of the ZDD technology. Because of difficulties in starting-up and optimizing the pilot unit at Brighton, the Project Team was not able to assume responsibility for operating the pilot unit as planned. Instead, a representative from the technology's inventor was needed to successfully operate the ZDD pilot. The skill level required to operate the ZDD technology in

its current state of development is highly specialized and probably beyond the capabilities of most utilities.

Cost Assessment of the ZDD Technology at La Junta, CO

A life cycle cost for analysis for a greenfield full-scale ZDD plant treating La Junta source water to Safe Drinking Water Act requirements at 96% recovery was developed. The estimate was based on the results of the La Junta pilot test and equipment cost estimates provided by the ZDD vendor. The estimated life cycle cost for the ZDD technology ranges from $2.98 to $4.60 per 1000 gallons (Table ES-1). The lower end of the cost estimate is based on performance predictions made by the vendor assuming less membrane area per volume of water treated, greater ionic fluxes and greater recovery than were verified during the pilot test. The upper end of the cost estimate is based on the configuration evaluated by the La Junta test. The Project Team's recommends that the upper end 20-year life cycle cost of $4.60 per 1000 gallons should be used to estimate the cost of the ZDD technology at La Junta. Future development of the technology may lower its cost.

ES - 1 Comparison of Conceptual Full-scale ZDD and Dual RO Plant Costs – La Junta.

Item	ZDD Costs ($M)		Dual RO Costs ($M)	
	Low Range	High Range	Low Range	High Range
Capital Construction	$46.2	$55.4	$26.4	$32.1
Annual O&M	$1.7	$2.6	$1.5	$2.5
20-year Value of O&M*	$52.2	$78.1	$44.5	$72.8
20-year Life Cycle Cost	$98.4	$133.5	$70.9	$104.9
20-year Cost per 1,000 gallons	$2.98	$4.60	$2.13	$3.43

* i = 3%

The estimated life cycle cost for a full-scale plant using the Dual RO technology operating at 92% recovery treating La Junta source water is between $2.13 to $3.43 per 1000 gallons. For La Junta, the ZDD technology's estimated 20-year life cycle cost is greater than the cost of the Dual RO technology. Because of its greater recovery, the ZDD technology requires approximately 135 ac-ft/year less water than the Dual RO technology to meet La Junta's potable water demands. But the cost of the water saved by the ZDD technology would not offset the differences in cost between the two alternatives at La Junta.

Conclusions

The ZDD technology did not obtain zero discharge as its name implies, but it demonstrated the ability to produce excellent water quality and obtain high recovery. The ZDD technology shows good potential to reduce the volume of concentrate produced by membrane plants. But further development of the technology is needed with the goal of reducing cost, increasing reliability and simplifying its operation before the process is suitable for full-scale use in Colorado.