Zero Discharge Desalination Technology – Achieving Maximum Water Recovery

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Abstract

The Zero Discharge Desalination (ZDD) process offers the potential to maximize the volume of product water from a brackish source while minimizing impacts to the environment caused by waste disposal. This emerging technology combines either reverse osmosis or nanofiltration with electrodialysis metathesis (EDM), a unique variant of electrodialysis, to remove divalent salts from water. In one recent application in the City of Alamogordo, New Mexico, ZDD was piloted on a brackish water source containing sparingly soluble calcium sulfate and a significant concentration of silica to achieve an overall system recovery of 98%.

Introduction

Population growth, decreasing volumes and quality of water supplies, and droughts are leading to increased competition between freshwater users for municipal, agricultural, power generation, and industrial manufacturing purposes. Consequently, it is becoming critical to maximize the yield of product water from brackish sources while minimizing adverse impacts to the environment caused by waste disposal. Additionally, as treatment challenges that are encountered can vary significantly for each specific water source, identifying and selecting the most appropriate treatment approach for a given water supply is becoming more important. Several factors must be considered in the selection of the optimal treatment technology for a specific application, including feed water characterization, regulatory drivers, available footprint, energy usage, and brine disposal options. By 2025, nearly one-third of the population of the developing world will face severe water scarcity, according to the International Water Management Institute (Keller et al., 2000). Therefore, increased recoveries are essential in order to address the water scarcity of inland communities and industrial operations where water supplies are fixed and demands are increasing.

In Zero Discharge Desalination (ZDD) reverse osmosis (RO) or nanofiltration (NF) is combined with electrodialysis metathesis (EDM), a unique variant of electrodialysis, to remove divalent salts from water. The concentrate from the RO or NF process is treated with EDM where the majority of the salts are removed from the water. The salt-depleted diluate stream from the EDM can either be blended with the RO feed or a portion can be directly blended with the RO permeate depending on project goals. Two concentrated streams from the EDM are mixed to precipitate insoluble salts such as calcium sulfate. The process prevents the salts from precipitating during the production of purified water and thus increases the water recovery rates.

In one recent application in the City of Alamogordo, New Mexico, ZDD, a combination of nanofiltration and EDM, was piloted on a brackish water source containing sparingly soluble calcium sulfate and a significant concentration of silica. This water chemistry limits the recovery to approximately 75% with a conventional brackish water RO system. The objective of the pilot was to demonstrate that a substantial increase in recovery could be achieved with ZDD at a comparable treatment cost. The pilot study demonstrated that a 98% water yield could be achieved with ZDD technology. As compared to other high recovery alternatives for this application, ZDD proved to be an economical solution when both the capital and operating expenses were evaluated to determine a total treatment cost.

City of Alamogordo, New Mexico

The City of Alamogordo lies in the Tularosa Basin in southern New Mexico. The population that depends on the water resources in the Tularosa Basin, which includes Alamogordo, is subject to water scarcity, and desalination yields of the existing water supply have been limited (Brady et al., 2005). The groundwater supply is almost 100% saturated in calcium sulfate. Even when scale inhibitors are utilized, conventional brackish water reverse osmosis can only recover approximately 75% of the source water, so the volume of concentrate requiring disposal remains a significant problem. An effective concentrate management system is vital for successful and sustainable implementation of inland brackish desalination systems.

Alamogordo has plans to install a 3-6 MGD desalination plant within the next few years. Water scarcity is a reality in the city, and the groundwater there has challenging characteristics. Historically, more than 70% of Alamogordo's water supply has been derived from surface water that is affected by drought, which creates a variable supply that is often not favorable for drinking water production and other uses. Alamogordo's 40-year Water Development Plan (2005 – 2045) states that the need for new water supplies is urgent (City of Alamogordo, 2002).

In addition to the high concentration of calcium sulfate, the brackish source water in Alamogordo, primarily originating from the Tularosa Underground Water Basin, contains high levels of TDS, calcium, sulfate, and silica. This challenging water quality significantly limits potential desalination yields. The resulting issues are twofold: first, nearly 25% of an already scarce water supply could be wasted if the water were desalted by conventional technology. Secondly, without an alternative technology that can provide higher yields, Alamogordo would need to identify and implement an acceptable brine disposal solution.

The lack of fresh water in southeastern New Mexico supports the need for a new, innovative technology that can significantly increase the desalination yield in Alamogordo. However, other factors create distinct challenges in developing a treatment system that is both technically and economically feasible. Although large evaporation ponds may not be desirable from an ecological standpoint, they are legitimate concentrate management solutions for Alamogordo to consider because land is relatively inexpensive and readily available in this remote location. In many other inland communities, land is much more expensive and may not be available. Furthermore, the evaporation rates in Alamogordo are relatively high (22.8 cm/month) as compared to many other areas in the west and southwest, which decreases the size requirement for evaporation ponds.

ZDD Process Description

ZDD technology addresses the demand for high water recovery by overcoming the treatment challenges previously identified. In ZDD, the concentrated salts rejected by a conventional RO system are fed to an electrodialysis metathesis (EDM) stack comprised of ion exchange membranes between thin solution compartments. A direct electric potential is applied to electrodes at the ends of the stack, resulting in a direct current that is carried by ions migrating through the membranes and solution compartments. The DC potential pushes ions through membranes from a lower concentration to a more concentrated solution. Water flows tangentially to the membrane, while the flow of ions is perpendicular to the membrane (Faust, 1998). An electrodialysis stack consists of anion membranes containing many fixed positive charges, usually quaternary amines, that are loosely associated with mobile negatively charged ions that permeate the membrane, and cation membranes with fixed negative charges, usually sulfonic acids, that allow positively charged ions to permeate (Meller, 1984).

In the ZDD technology, the salts that would cause scaling in a high recovery RO process are removed in an electrodialysis metathesis (EDM) process that is a variant of ordinary electrodialysis. The electrodialysis stack used for EDM has a repeating unit comprising four membranes, two depleting streams (an RO concentrate that is typically rich in calcium salts and a stream of NaCl) and two concentrating streams (one containing mixed sodium salts and the other containing mixed chloride salts). In essence, the major salts in the two depleting streams change partners to form concentrated solutions of highly soluble salts of the ions that are problematic in RO (see Figure 1). The two highly concentrated streams can then be mixed to precipitate a byproduct such as gypsum (calcium sulfate).

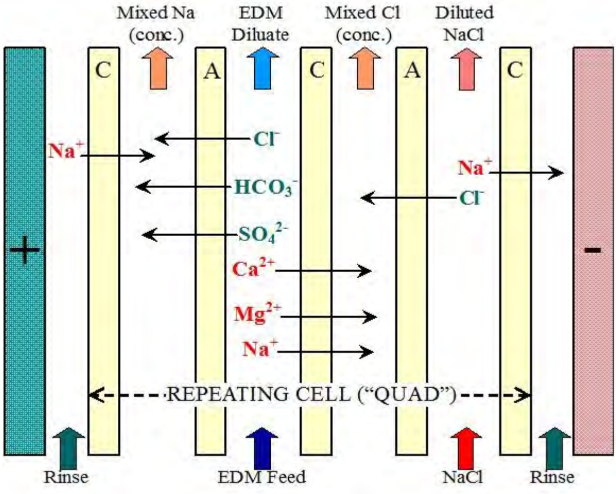

Figure 1 *Electrodialysis Metathesis (EDM)*

Alamogordo Design Basis

Presented in Table 1 below is the average expected feed water quality for Alamogordo's source water supply. This water supply originates from wells in a location referred to as the Snake Tanks. A 20-mile pipeline will be required to transfer the water from the Snake Tanks to the City's drinking water treatment facility. In order to provide drinking water of acceptable taste, permeate will be blended with untreated brackish water to create blended product water that meets acceptable drinking water standards. The city has defined a desired blended product water quality of 800 mg/l TDS (US Department of the Interior, 2010).

Table 1 *City of Alamogordo Source Water Design Basis*

Influent Quality		
Cations	mg/l	meq/l
Potassium	4.7	0.1
Sodium	180	7.9
Magnesium	88	7.2
Calcium	413	20.6
Anions	mg/l	meq/l
Bicarbonate	132	2.2
Chloride	133	3.8
Sulfate	1,433	29.8
Other		
Silica, mg/l	28	
Total Dissolved Solids, mg/l	2,412	
pH, standard units	7.6	

As indicated in Table 1, the predominant salt in the source water is calcium sulfate, which accounts for approximately 70% of the overall TDS concentration in terms of milliequivalents per liter (meq/l).

ZDD Demonstration Protocol and Results

Sponsored by the Bureau of Reclamation's Desalination and Water Purification Research (DWPR) program, the University of Texas at El Paso (UTEP) and Veolia Water Solutions & Technologies (Veolia) are collaborating on the demonstration of the ZDD process at the Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, NM.

The ZDD equipment used for the demonstration is capable of producing 20-25 gpm of permeate and is comprised of nanofiltration (NF) housed in a 40-ft container and an EDM system housed in a 20-ft container. Figure 2 shows the process flows for the equipment. (The calcium sulfate reactor was not used during this demonstration, but is shown for completeness of the process.) The NF itself is a 4 x 2 x 1 array of pressure vessels, each containing four Dow Filmtec NF270 4" x 40" membranes. The NF270 membranes were chosen for their low silica rejection. Hydrex™ 4101 antiscalant was dosed at 3 mg/l to the NF system. The EDM system includes the EDM "stack," pumps, chemical dosing systems, and DI tanks. NaCl is the only regular EDM chemical input.

Table 2 *Summary of NF and EDM Rejection (Field Samples)*

Field Measurement	NF	EDM
By Conductivity	64%	43%
By TDS	66%	
By Total Hardness	89%	
By Ca Hardness	99%	
By Mg Hardness	75%	
By Alkalinity	13%	
By Sulfate	99%	51%
By Silica	-2%	

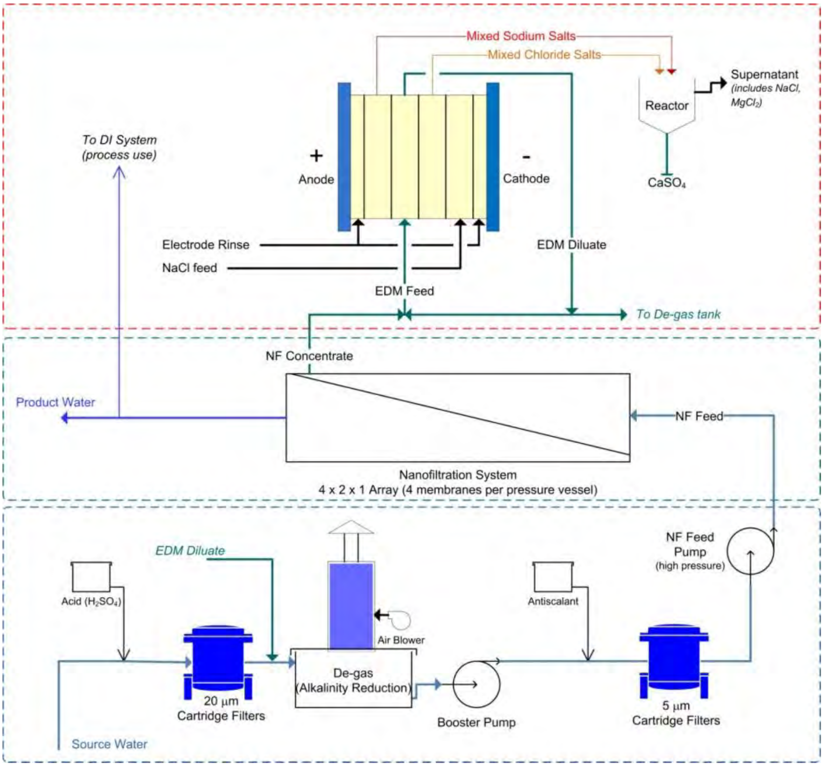

***Figure 2** ZDD Flow Diagram*

The ZDD system ran continuously (24 hours/day) for approximately 4 weeks in April 2011. At 20-25 gpm of permeate production, approximately 400 lb/day of NaCl was added. NF permeate production ranged from 14 gpm at the beginning of the experiment to 25 gpm during the last week of operation. The EDM feed-diluate stream circulation rate remained constant at 25 gpm. Overall recovery ranged from 97-99%. The NF system rejected calcium, magnesium, and sulfate very well. As predicted, most of the silica passed through to the permeate stream, which was desirable in order to prevent silica from concentrating in the EDM system. Silica did not appear to accumulate in the system. Table 2 summarizes the rejection effectiveness of the NF and EDM systems. Tables 3 and 4 summarize analyses performed by Hall Environmental Analytical Laboratories in Albuquerque, NM, for samples taken on April 5, 2011.

Table 3 *Summary of Hall Environmental Analytical Laboratory Analyses (mg/L) – NF System 4/5/11*

	Source	**NF Feed**	**Permeate**	**Concentrate**
F	1.7	1.4	0.86	2.5
Cl	290	210	260	160
Br	ND	ND	ND	ND
NO_3+NO_2 (as N)	1.6	1.1	1.4	ND
SO_4	1300	1300	9.5	3600
As	ND	NT	ND	NT
Ba	0.022	NT	ND	NT
Ca	250	220	19	NT
Fe	0.043	NT	ND	NT
Mg	94	94	7.5	NT
Mn	0.0099	NT	ND	NT
K	4.5	NT	1.6	NT
SiO_2	24	27	23	NT
Na	370	350	150	NT
Sr	4	NT	0.32	NT
TDS	2300	2180	471	4980

Conclusions

ZDD combines the best aspects of nanofiltration and EDM to achieve maximum possible recoveries for a membrane-based process. By separating the scaling constituents in the water and pairing them with different ion partners, the limiting factor in recovery becomes the solubility of very highly soluble salt streams. The resulting minimal volume mixed salt concentrate streams can be disposed of in a much easier fashion than high volume reverse osmosis or nanofiltration concentrate streams or processed in a small crystallizer to achieve complete zero liquid discharge. The results of piloting on a brackish groundwater have demonstrated that recoveries as high as 98% are achievable with ZDD.

Table 4 *Summary of Hall Environmental Analytical Laboratory Analysis (mg/L) – EDM System 4/5/11*

	Feed	Diluate	NaCl	Mixed Cl	Mixed Na	E-Rinse
F	1.8	0.82	2.1	ND	72	3.3
Cl	140	100	28000	89000	14000	760
Br	ND	ND	ND	ND	ND	ND
NO_3+NO_2 (as N)	ND	ND	ND	ND	22	ND
SO_4	2600	1300	980	1600	25000	5100
As	NT	NT	NT	NT	NT	NT
Ba	NT	NT	NT	NT	NT	NT
Ca	380	160	62	17000	690	7
Fe	NT	NT	NT	NT	NT	NT
Mg	190	86	31	7400	220	ND
Mn	NT	NT	NT	NT	NT	NT
K	NT	NT	NT	NT	NT	NT
SiO_2	33	33	4.3	5.7	37	12
Na	580	350	16000	21000	27000	4400
Sr	NT	NT	NT	NT	NT	NT
TDS	3840	1940	38000	133000	100000	10500

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