Half A Century of Desalination With Electrodialysis

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A Short Tour Through Fifty Years

On February 21, 1952 the New York Times ran an interesting cover story. It described how a young company called Ionics (which was purchased by GE Water & Process Technologies in 2005) invented a new technology that could change the world. The invention was Electrodialysis, or ED, and with its use of salt transfer membranes ED, offered for the first time, a truly practical and less expensive way to desalt brackish water. Distillation had been the only way. That was a cumbersome process, best suited to treat sea water and it required large amounts of energy to operate. The US Congress saw the promise of ED, and passed The Saline Water Bill in 1953 to fund additional research into desalination. In December 1953, ED became commercially viable when Ionics supplied an oil field campsite in Saudi Arabia with their first ED system. Many more ED units followed that one. ED used electricity to generate a DC field across a stack of flat sheet ion exchange membranes arranged in a cation – anion configuration. The DC field pulled unwanted salts across the membranes, creating both a product and a recirculating brine water flow.

For practical purposes, reverse osmosis (RO) was commercialized in 1969. By January 1970, 208 electrodialysis units (with 6.2 mgd or 24,000 m^3/day total capacity) had been installed, including Coalinga, CA (1958), Buckeye, AZ (1962), Port Mansfield, TX (1965), White Sands Missile Range, NM (1969) and many others. In 1973, the Foss Reservoir Conservancy decided to build a 3 mgd (11,000 m^3/day) desalination plant. After 15 years of having a potentially useful, but high salinity surface water supply sitting dormant behind a dam, Ionics ED was selected to be the basis of a regional water treatment plant. The ED site, located 80 miles west of Oklahoma City went on line in 1974. At the time, it was the largest membrane desalination plant in the world.

ED became Electrodialysis Reversal, (EDR) in 1974, when the membrane stack DC electric field was alternatingly reversed to drive salt scale off the membranes before those materials become permanently attached. DC field reversal eliminated the need to feed either acid or anti-scalant chemicals into the desalination process. Not having to feed chemicals at remote water treatment sites in the Middle East was a major advantage of EDR over RO. That advantage remains the same today.

Through the 1970s, the applications of membrane desalting technology increased rapidly. EDR and RO competed on many projects. EDR offered advantages over RO on some applications, while ROs ability to remove silica often favored that process. EDR and RO membrane systems were used for drinking, industrial and wastewater projects. From the late 70s through the mid–80s, EDR and RO membrane plant installations up to and beyond 5 mgd were not uncommon.

In the mid 80s RO made a dramatic process improvement through the development of new thin-film-composite (TFC) membranes. Acid was no longer needed in RO feedwater, RO operating pressures were significantly reduced, and membranes had more consistent salt rejections over a longer period of time. New families of anti-scalant chemicals made it possible to increase RO water recovery. As RO made technical advances, EDR become a niche technology.

With self-cleaning membranes, and the ability to easily disassemble membrane stacks for hand cleaning under worst case catastrophic upsets, EDR was applied to desalting very difficult to treat waters. EDR was even applied to reclaim 8,000 ppm TDS RO concentrate – yielding combined RO-EDR water recoveries of 96% to 98% in several applications. The ability to operate at significantly higher water recovery than RO saw EDR installed when ground water was in short supply. In the late 80s, EDR itself was running up to 94% water recovery, and on ground waters containing up to 5,000+ ppm TDS. These plants remain in operation today. Some will be undergoing major expansions in 2004 and 2005.

In 1995, the largest EDR plant in the United States was installed in Sarasota County, Florida. Today it produces 12 mgd (45,000 m^3/day) of drinking water from a 1,300 ppm high calcium sulfate groundwater. Sarasota went to EDR because RO could not match its 85% water recovery. On through the 1990s, RO and EDR processes continued to compete on many desalination projects.

In 1997, Ionics reinvented EDR

The new second generation EDR technology with improved membrane spacers, improved system design, and improved operating efficiency saw EDR applied to many projects that normally would have used RO. EDR was sold to reclaim tertiary treated wastewater for irrigation reuse. It proved to be 25% less costly than MF-RO. At one wastewater site, EDR flow was expanded from 2.2 mgd (1998) up what will be 12 mgd (45,000 m^3/day) (blended) EDR + bypass water by the fall of 2004. Beyond this, EDR was applied to larger flow applications (9 mgd or 34,000 m^3/day) to remove radium and hardness from groundwater. With a greater ability to remove salts, EDR was applied to preferentially remove selected ionic species from public water supplies, such as nitrates, which EDR does very reliability over the long haul.

Since silica does not affect EDR performance, numerous EDR plants are now producing drinking water from sources with 100 ppm + silica in the feed...and doing it at very high water recovery to conserve available aquifer supplies.

Now at 50 years, second generation EDR is replacing earlier ED installations. After 30 years of operation, the Foss Reservoir plant has just been replaced with a new 4.5 mgd EDR system. When the old ED units were shut down, many of the cation membranes at Foss were from the original 1974 startup. Systems such as Foss, and others with over 20 years of operating life, have proven that EDR membranes have an average life of 12 to 15 years when operated properly.

Why EDR Is Still Favored On Many Applications

EDR has several distinct and unique operating characteristics that make it a successful process. One reason is EDR's ability to perform at very high water recovery. This is possible because EDR polarity reversal allows the system to operate with concentrated salt scale factors well beyond saturation. And this is without any chemical feed. Combining EDR with anti-scalant addition increases the allowable concentration of these scale forming entities even further. As calculated in RO membrane projections, for comparison purposes, these EDR limits are: EDR offers two main advantages over RO on selected applications where (1) brine disposal costs are high, and/or (2) aquifers are very deep (1,000+ ft or 305+ m), or where they have limited supplies of raw water to be desalted. EDR is a more cost effective process, as illustrated on "typical" 1200 ppm raw water, with high hardness and relatively high silica.

Table 1: EDR Limits

Scale Forming Constituent EDR	EDR (with no Chemical Feed)	EDR *** (with Chemical Feed)	RO (with Chemical Feed)
Langelier Index	+1.9 to + 2.2	+3.0 and beyond	+2.4
C_aSO_4	175% to 200%	300% to 325%	225% to 250%
B_aSO_4	10,000%	16,000 %	8,000 %
CaF	12,000 %	5,000,000 %+	To be determined
$Ca(PO_4)$	150%	400%+	400%

*** *testing with newer anti-scalants such as Ondeo-Nalco Permatreat 191 or equivalent may raise limits further*

As an electrically driven process, product water quality from EDR can be varied by controlling the voltage input into the membrane stack, and by controlling how many stacks in series (or stages) are used. Salt removal rates can be altered to specifically meet optimum conditions on any project.

Figure 1 is typical of a 2-stage EDR system. Sometimes using EDR only, without blending, is more cost effective. Both options can be investigated on any water.

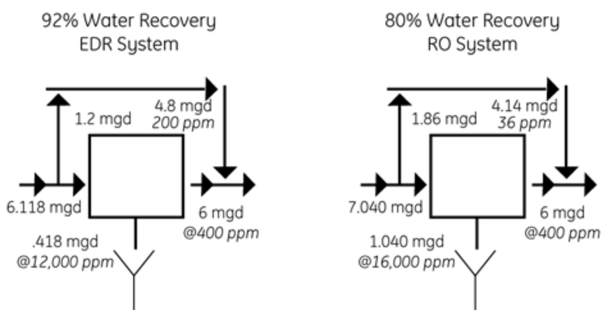


Figure 1: 2-Stage EDR System

Beyond EDRs ability to operate at high salt concentration levels in the brine, is what happens on the inlet end of the system. Unlike RO, which is an absolute barrier process, EDR works by flowing feed water over the surface of an ion exchange membrane, while the DC field pulls unwanted salts across the membrane. EDR is not affected by as many feed water constituents as RO, which limit that processes performance. This is illustrated in Table 2 below.

Table 2: EDR and RO Limits

Influent Feed	EDR Limits	RO Limits
Well or Surface Supply	flow through system is unaffected by source	Reduced flux on surface water of wastewater
Silt Density Index	15 (5 min SDI)	5 or less (15 min SDI)
TOC	up to 15 ** (1)	Up to 2 – 5 ppm **(1)
Silica	unlimited to saturation **(2)	Depends on water recovery
Oil & Grease	up to 1 ppm ** (3)	ZERO
Turbidity	up to 2 NTU	0.1 NTU to 1 NTU
Iron (Fe +2)	0.3 ppm ** (4)	0.3 ppm ** (4)
Mn (+2)	0.1 ppm ** (4)	0.1 ppm ** (4)
H 2 S	up to 1 ppm ** (4)	No limit if not mixed with 0 2
Normal Temp Range	40F to 110F	40F to 110F
Free Chlorine	0.5 ppm continuous with spikes to 15 – 20 ppm +	None, Cl 2 will destroy TFC membranes
Feed pH	2.0 to 11.0	2.0 to 12

** (1) *EDR lowers TOC by 20% - 40% + of TOC by removing lower molecular weight, ionized organics.Consult Ionics for details on TOC limits and applications with EDR*
(2) *EDR drinking water plants are in operation with up to 140 ppm silica in the feed*
(3) *EDR reclaim plants are in operation with up to 1 ppm of oil....specific data is required before approving EDR for operation on water containing oil residue*
(4) *Iron, manganese and H 2 S levels in excess of 0.3 ppm may be allowed if feedwater is kept free of entrained air*

Many of the world's desalination sites (or potential sites) are remote, hard to get to, and a challenge to staff with highly skilled operators and maintenance staff. This is true for remote deserts, and on islands isolated by thousands of miles of ocean. From the outset, this was the environment EDR thrived in. Without the need for chemicals, EDR can operate without what can be very difficult to provide chemicals (acid and anti-scalants) in some places.

At these challenging sites, on more than one occasion, EDR plants had no operators and had raw water conditions that dramatically changed. One advantage of EDR that is still with us today is the ability to take EDR membrane stacks apart and clean them by hand. This is done on site, and while not approved by the factory, operators have been known to use sand paper to clean off the membranes.

Four Ideal Applications for EDR Treatment

Figures 2, 3, 4, 5 and Table 3 show how EDR is selectively used to desalinate drinking water and reclaim wastewater supplies.

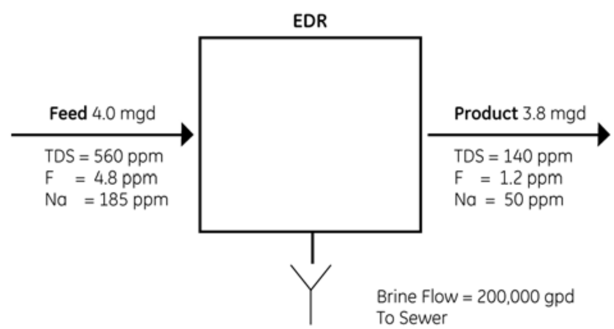


Figure 2: 94% Water Recovery For Optimum Use of Available Supplies (Suffolk, VA 1990)

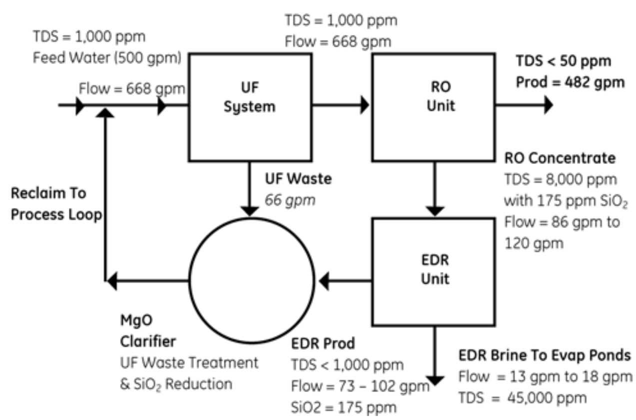


Figure 3: EDR Reclaims RO Concentrate For 97% Water Recovery (Tucson, AZ 1985)

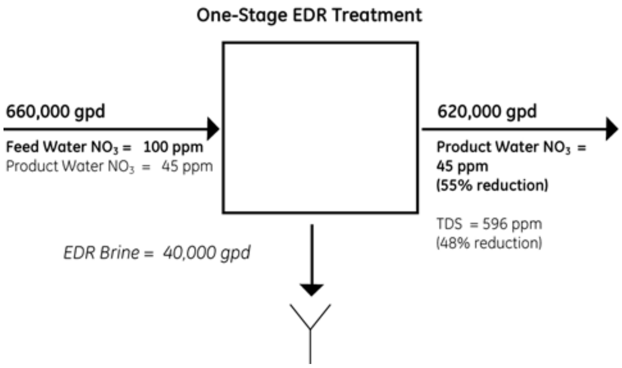


Figure 4: 94% Water Recovery With Reduction In Public Water Supply Nitrate Level (Israel, 2000)

Table 3: High Nitrate EDR Installations

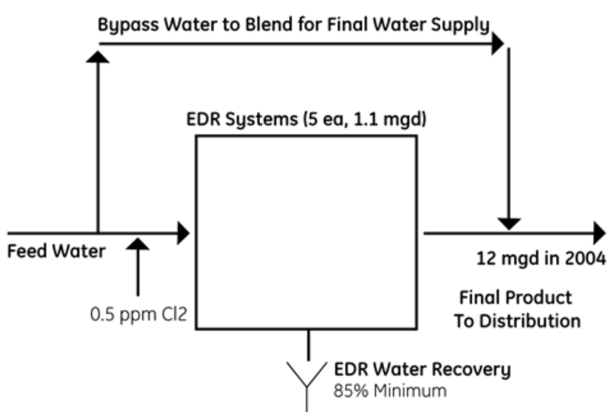
Capital and O&M Costs For EDR

Project costs are usually measured in terms of combined capital and long term O&M costs. On 800 ppm to 2,000 ppm waters the combination of capital (equipment, installation and building required) along with long term O&M can favor EDR. This is especially true on applications requiring higher water recovery. EDR systems operate with up to a 60% TDS reduction per stage, depending on the specific constituents in the water. EDR is usually most competitive when a one or two stage system is used to desalt raw water sources. However, three stage and four stage EDR systems have also been shown to be more cost effective than RO when certain combinations of feed water constituents are present with the need for high water recovery.

Other Example High Nitrate EDR Installations (data in mg/l) ***

	# Stages	Water Recovery	Feed NO_3	Product NO_3	Feed TDS	Prod TDS	Year On-Line
Delaware (USA) (92.6% NO_3 reduction) (88%TDS reduction)	3	90%	61	4.5**	114	11	1985
Bermuda (86.7% NO_3 reduction) (81% TDS reduction)	3	90%	66	8**	1614	278	1986
Italy (70% NO_3 reduction) (53% TDS reduction)	2	90%	120	37**	1012	474	1990

*** EDR NO_3 reduction is stable over full life of membrane system. NO_3 reduction does not drop off over time.



	1998	1999	2004
Feed Water Quality	1,100 – 1,500 ppm	1,100 – 1,500 ppm	1,100 – 1,500 ppm
Feed Water Volume	typical 4.3 to 5.4 mgd	typical 8.1 to 8.8 mgd	typical 12.9 to 13.9 mgd
EDR Product Water Quality	typical 500 ppm	typical 300 ppmt	typical 300 ppm
EDR Product Water Volume	2.2 mgd	3.3 mgd	5.5 mgd
Final Blending Quality	900 ppm	900 ppm	900 ppm
Bypass Water Volume	typical 1.8 to 2.8 mgd	typical 4.2 to 4.9 mgd	typical 6.5 to 7.5 mgd
Total Blended Water Flow	typical 4 to 5 mgd	typical 7.5 to 8.2 mgd	typical 12 to 13 mgd

Figure 5: EDR on Desalting Tertiary Treated Municipal

EDR is capital competitive or slightly higher in cost compared with RO, unless RO requires additional treatment, which EDR does not (the need to add acid to RO feed + post RO decarbonation to strip out CO2). Normally, on larger systems (1.5+ mgd or 6,000+ m^3/day) the EDR building required will be larger than that for RO.

Offsetting this is EDR's lower O&M cost with reduced (or no chemical feed), with reduced pretreatment/post treatment costs, and with reduced long-term membrane replacement costs. On lower TDS waters (less than 1500 ppm), the EDR electrical power consumption can be less than RO. When "ancillary costs" such as raw water pumping, and waste brine disposal are added in, the O&M cost consideration often times outweighs the higher capital costs for EDR. End users then choose EDR to meet their long-term goals.

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GE Water & Process Technologies purchased Ionics in 2005 and continues to drive innovation in the water treatment industry.