

What is Electrodialysis Reversal and its New Innovations?

Key Takeaways

- Electrodialysis Reversal (EDR) technology and its specific application fit is explained.
- Innovations in EDR enables:
 - Treatment of highly scaling flows without expensive chemical treatment,
 - Selective extraction of ions, and
 - Treatment of highly contaminated organic flows.

EDR is not a competitor to reverse osmosis, but rather each have a specific fit. In some applications, such as FGD or produced water, EDR can provide a compelling cost advantage.

How does Electrodialysis Reversal Work?

Electrodialysis (ED) technology is the second most widely used membrane desalination technology and has been developed since the 1960s for a wide range of industrial applications. It involves applying a direct current (DC) electric field to flux positive ions across cation exchange membranes (CEM) in one direction, and negative ions through anion exchange membranes (AEM) in the opposite direction. The two types of membranes alternate within a stack (Figure 1).

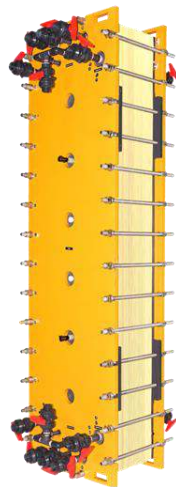


Figure 1. Electrodialysis Stack

As the process feedwater (or wastewater) enters the 'product' chamber, ions get pulled out of the product water as it travels up the length of the stack, parallel to the membranes. These ions get concentrated up in the concentrate chamber, also flowing parallel to the product chamber, see Figure 2 below. The Reversal term comes from recent innovation that allows the polarity of electrodes and hydraulic channels to 'reverse', which helps keep the membranes clean.

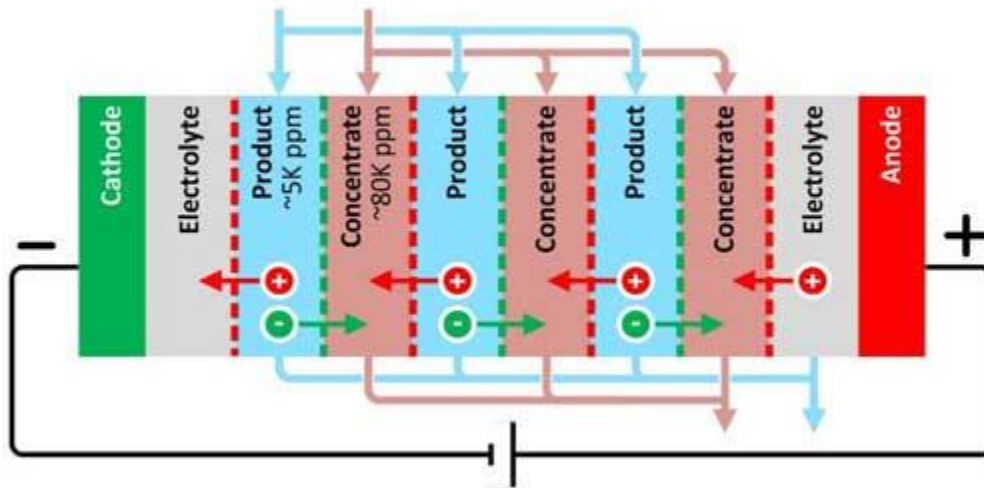


Figure 2. Diagram of How Electrodialysis Works

Typical electrodialysis systems are composed of stacks of these cation and anion exchange membranes. However, due to recent advancement in membrane manufacturing, it is now possible to selectively pull out monovalent ions using our IonFlux ion exchange membranes that have 98% divalent ion rejection. This monovalent electrodialysis reversal (mEDR) can be used for a number of treatment or reuse applications, including the following:

- Remove chlorides to reduce corrosion in water circulating loops that result in high blowdown. This is particularly useful for flue gas desulfurization wastewater, where 90% of the recovery can be recycled, while the final 10% residuals can be mixed with combustion ash or fly ash.
- Remove scale-causing gypsum from cooling tower blowdown to enable higher cooling tower cycling, provided the tower is designed to handle the higher salinity or the corrosion-causing chlorides are removed.
- Selectively remove sodium to reduce the sodium adsorption ratio (SAR) in agricultural or vertical farming wastewater to allow recycling of the nutrients or multivalent fertilizer by-products.

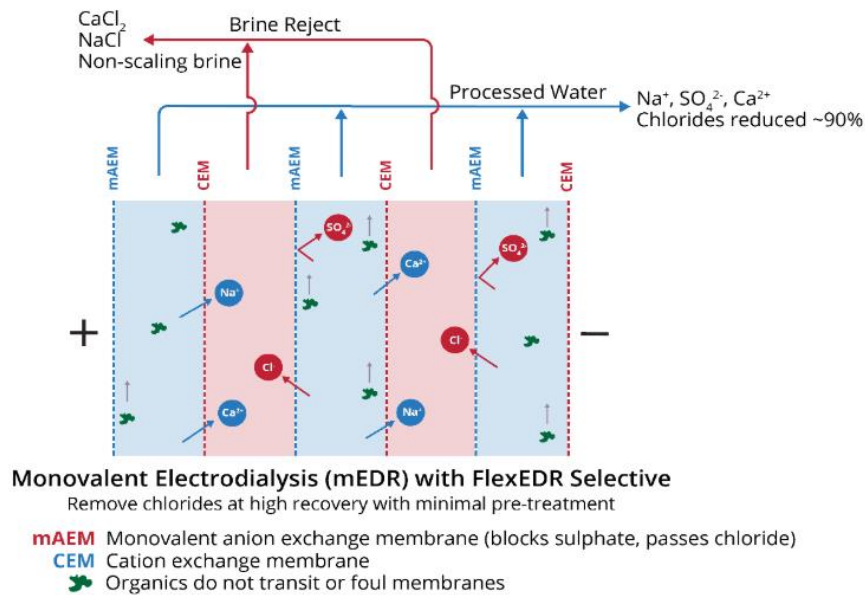


Figure 3. mEDR Process Flow Diagram

Comparing Electrodialysis Reversal and Reverse Osmosis: The Workhorses of Desalination

Reverse Osmosis and EDR are the top two membrane desalination technologies and have their own unique fit for a variety of applications. They should not be seen as competing processes. However, relative economics of either system will depend largely on factors related to water chemistry, process design and site requirements. Below is a quick comparison of EDR and RO technology.

Inorganic Scaling:

RO's main operating principle is the use of high pressure to force water through pico to nano-scale pores and rejecting salt ions. To mitigate scaling with RO systems, antiscalants are used. For higher scaling potential waters, chemical pre-treatment will be required to remove scaling compounds.

This is contrasted with EDR which uses a voltage difference to drive ions through the membranes instead of water; there is no pressurized impingement on the membrane surface. This means EDR is much more tolerant to inorganic scaling and organic fouling

and requires less pre-treatment. Additionally, the EDR process is configured to further mitigate scaling risk with easy clean-in-place design, and the ability to reverse polarity of electrodes and hydraulic channels to flux ions in the opposite direction. This reversal action causes the ions to flux in the opposite direction, and for the concentrate chamber to be cleaned with lower salinity product water, further mitigating scaling risk.

Organic Fouling:

Typically, membranes do not fare well in the presence of high organics wastewater. They are susceptible to damage due to the solvent-like properties of organics. To remove organics, oxidants (such as bleach or chlorine), which can also damage RO membranes, are required, but must be removed prior to the membrane stage. Both RO and EDR systems with conventional membranes are susceptible to membrane damage in the presence of organics. However, Saltworks' Flex EDR Organix system leverages cross-linked EDR membranes that are highly resistant to organics. Furthermore, the membranes can resist bleach or chlorine dioxide, which can be used to clean them after operating on highly fouling or organic wastewater.

Brine and Treated Water:

RO systems concentrate up all contaminants in the water into a single brine stream with no selectivity. This also means that the treated water produced by an RO system is typically very low in salinity and dissolved ions. The brine concentrations achievable are dependent on the amount of pressure that is being applied. Typical RO systems can concentrate to 80,000 mg/L (1200 psi) or 130,000 mg/L (1800 psi), assuming all scalants are removed. However, concentrating brine any further is challenging since RO membranes can withstand only certain amounts of pressure. This results in relatively larger brine volumes.

Since electrodialysis does not rely on pressure and is more tolerant to scale formation, it can concentrate the brine up to 180,000 mg/L TDS, resulting in almost half the brine volume compared to a typical RO system. Due to the flexibility in different ion exchange membrane arrangements, the brine from an EDR system can be tuned to selectively concentrate or extract certain ions. This also allows users to tune the salinity of their treated water outlets to any TDS concentration.

The Economics of Desalinating with EDR: The Importance of Δ TDS

The economics of electrodialysis reversal technology depend most strongly on the starting and final concentrations of the feed stream; this is the Δ TDS (change in total dissolved solids concentration). With increasing Δ TDS, or the more the EDR system has to desalt, the EDR system will require greater membrane area and more stacks (capital cost), as well as more power (operating cost).

EDR systems are sized based on current density and current efficiency. Current density is the amount of current that can be applied per unit area of membrane (typically 'A/m²'). Current efficiency is a measure of how effective the applied current is in moving ions across the membrane. The higher the current density and current efficiency, the more ions can be moved across the membrane with less membrane area and power. Figure 4 below illustrates the relationship between current density and how much desalination occurs in one pass of a full-scale stack (E200), assuming 80% current efficiency. Two different types of brine are shown: NaCl brine and CaCl₂ brine – typically, most wastewater will fall in between the two brine lines shown. Depending on the starting TDS of the wastewater feed, a typical EDR product water output of 1,500 mg/L TDS offers the best economics. Treating much lower TDS concentrations will increase the Δ TDS, and subsequently, the cost.

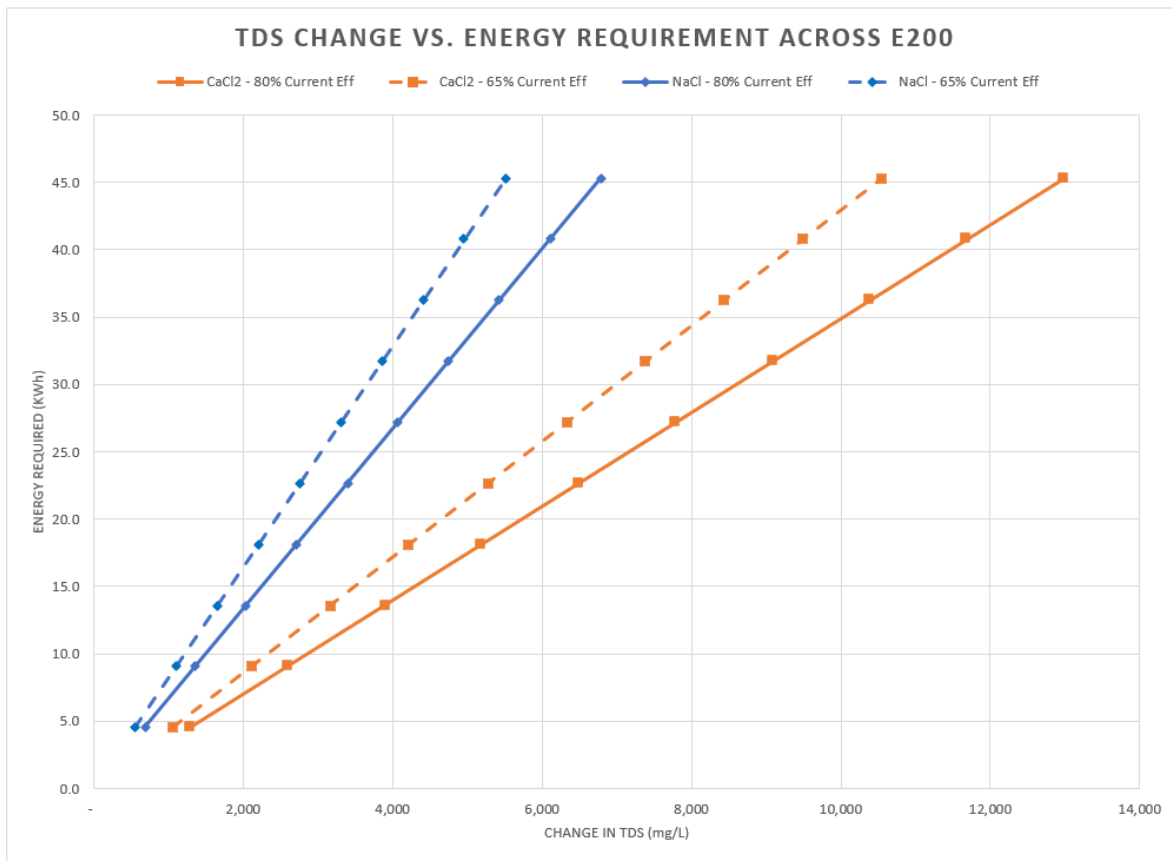


Figure 4. TDS Change Compared to Energy Requirements for a Flex EDR E200 Stack

Note that the maximum current density that can be applied is subject to the effects of current limiting density, also known as current limit. Driving EDR at currents higher than this limit will result in the splitting of water molecules at the boundary layers of membranes, which wastes energy to produce H₂ and O₂, and reducing current efficiency. Our Flex EDR systems can be driven at higher current limits than conventional systems due to our IonFlux membranes that offer low resistance, small boundary layers, and smooth membrane surface areas.

Current limit decreases with decreasing TDS, so the best economics may sometimes be obtained by arranging stacks in series operating at different currents. An example might be that a high TDS wastewater would require one stack operating at 200 A/m², which must then be sent for final polishing with a second stack at 60A/m² to avoid splitting water as the TDS decreases and pushes down the current limit with it.

Comparing the Costs of an RO vs. EDR System

Considering an RO system against Electrodialysis Reversal technology requires an in-depth examination of your project needs and water chemistry. In both cases, a simple bench test can show a great deal about the best approach to your water treatment problem.

An important factor to consider when evaluating the cost of RO or EDR systems is system efficiency. Due to the pressure applied to RO systems, they are much more likely to have their performance reduced by water chemistry that causes scale formation, fouling or organics that damage membranes. This reduction in performance will not only reduce the efficiency of your treatment system, but also drive up your operational and maintenance costs as labour and parts are required to provide fixes. EDR is much more resistant to these performance-decreasing factors, as mentioned earlier, reducing the operational overhead when operating on challenging wastewater compared to RO.

In both RO and EDR systems, the energy required to concentrate brine is dependent on the TDS. The more dissolved salts present in your water, the more expensive your water treatment operations become. However, this cost will scale much more rapidly in EDR systems, due to the impact Δ TDS has on capital and operating costs. For this reason, RO tends to be more cost-effective when significant reductions in TDS are required, and EDR may be more cost-effective when selective ion removal is required, or smaller TDS reductions are necessary.

The Future of EDR Technology

Homogeneous vs. Cross-linked Membranes

Modern membranes are manufactured from a continuous cast polymer, which, unlike RO and NF membranes, cannot delaminate. The next stage in membrane technology is having membranes with extreme chemical durability. Saltworks' IonFlux membranes are one example of such membranes: its highly cross-linked polymers enable its chemical durability as well as ductility and smoothness.

Modular Design

Having the option of scaling up wastewater treatment systems and changing system capacity according to desired needs is beneficial to companies that own treatment

systems. Systems such as Flex EDR arrive as complete packaged skids with the ability for modular implementation, meaning capacity expansions are easy.

At Saltworks, we offer three stack sizes to scale up during project testing – our benchtop E5 stack, our pilot E100 stack, and the E200 stack, which have 5, 100 m³/day and 200 m³/day capacities. Our standard skid combines six E200 stacks into a plant with a 1200 m³/day capacity, although stacks can be removed or added to adapt to different project needs.



Figure 5. Three Flex EDR Stacks, from left to right. E5 benchtop stack, E100 pilot stack, full-scale E200 stack.

Reduced Need for Pre-Treatment

EDR technology finds itself advantageous over other treatment technologies due to its reduced requirement for pre-treatment. Advances in EDR membrane technology, such as the IonFlux ion exchange membranes used in Flex EDR systems, further reduce the need for pre-treatment with its resilience to organics and rugged design, capable of treating demanding oilfield waters. Reducing the need for pre-treatment also provides significant monetary benefits to treatment system owners.

Learning More

Modern EDR may provide certain projects a real cost advantage. Readers do not need to learn how to size and quote an EDR system. Contact us today at info@saltworkstech.com to get started on your project.