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Voltea's Technical Bulletin

Technology comparison

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This bulletin explains Voltea's patented Membrane Capacitive Deionization technology (CapDI©) and describes other ion-removal technologies such as Reverse Osmosis, Electrodialysis, Electrodeionization and the Ion Exchange softening process. It explains the principle, fields of application and limitations of each technology.

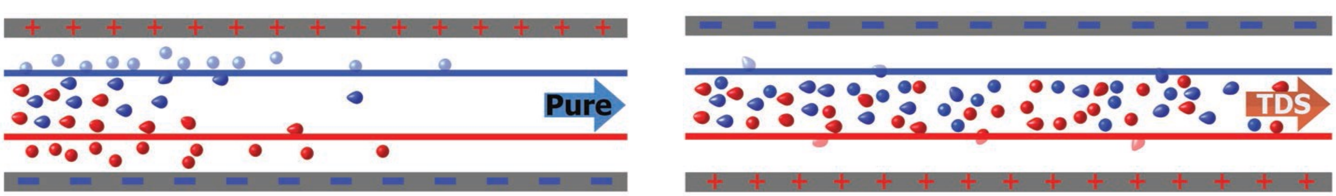
Membrane Capacitive Deionization (CapDI©)

In Voltea's patented Membrane Capacitive Deionization technology CapDI©, ions are removed from the feed water by applying an electrical potential difference between two electrodes covered with selective ion exchange membranes. Electrodes are separated from each other by a mesh spacer, whereby water flows and the ions are removed from the feed water (purification step). These removed ions are temporarily stored in the electrical double layers formed at the electrode surface. When the electrodes become saturated with ions, they are regenerated by reversing the applied voltage and/or short circuiting (regeneration step). After the ions have been released from the electrodes, a concentrate stream is produced and captured ions are flushed from the module. It is important to note that ions are removed through membranes and water molecules stay behind.

Figure 1: Schematic of CapDI© operation.

Purification step
Saline water passes between oppositely charged electrodes that electrostatically remove dissolved ions, leaving pure water flowing out of the cell.

Regeneration step
Feed water flushes through the cell at a lower flow rate, while electrode polarity is reversed. Ions are rejected from the electrode surface, concentrated in the flow channel and flushed from the cell.



Applications

Voltea's CapDI© technology is a chemical-free, low-cost, and environmentally friendly alternative to conventional water softening and brackish water desalination systems. CapDI© offers the benefit of electronically adjusting the product TDS level. CapDI© is used to deionize water with moderate levels of salt concentration (TDS <4000ppm).

- **Industrial and Commercial applications**

  Voltea's CapDI© can soften feed water to boilers and cooling towers, polish tertiary wastewater effluent for reuse and desalinate brackish surface or ground water to make it suitable for industrial reuse. Voltea's Industrial Systems (see Figure 2) employ a simple modular design providing flexibility to treat a few liters per minute (LPM) up to hundreds of LPM in a compact footprint. The IS series features real-time, remote monitoring and control capability. Modular designs allow flexibility to meet performance targets in a limited space.

- **Commercial Laundry**

  CapDI© removes TDS from laundry wastewater at laundering temperatures up to 60^{0}C/140^{0}F and recovers up to 90% of the treated water. Addition of CapDI© to the treatment system allows recycling without ever reaching the standard operational TDS limit of 1,000 ppm. Voltea reuse solutions work across all laundry intakes, industrial, food and beverage, healthcare and hospitality applications.

- **Consumer Appliance**

  Voltea's CapDI© technology offers the freedom and flexibility to customize module size, shape and geometry. It allows consumers the benefits of no-salt softening combined with low TDS for higher water quality. Typical TDS removal is in the range of 50-90% at up to 90% water recovery.

Figure 2: Voltea's Industrial System (IS12) producing 30GPM* (110LPM) of purified water.
* Capacity may vary depending on system design

Reverse Osmosis

Reverse osmosis (RO) is a water purification technique that involves the movement of water through a semi-permeable membrane. The driving force of this process is an applied pressure greater than osmotic pressure. Water is pressed through the semi-permeable membrane that has small pores and in principle only allows water molecules to pass through, whereas the ions and larger species get concentrated in a separate brine channel.

Osmosis
Water flows from compartment with lower salt concentration to the compartment with higher salt concentration and creates osmotic pressure.

Reverse osmosis
If an applied pressure is higher than the osmotic pressure then the flow of water is reversed; water flows from higher salinity solution to lower salinity solution.

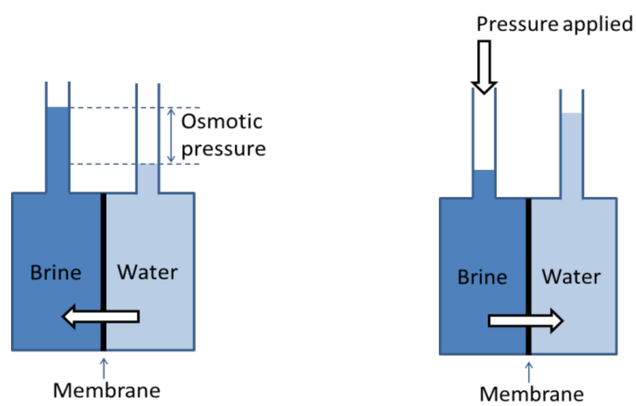


Figure 3: Principle of reverse osmosis

Applications

RO is widely used for the desalination of water; it removes up to about 95-99% of most ionic species and the maturity of the technology allows for competitive pricing.

- **Large scale sea and brackish water desalination**

  Large RO plants are used in the Middle East; the energy requirements of the plants are high, but electricity can be produced relatively cheaply with the abundant oil reserves in the region. Sea Water Reverse Osmosis (SWRO) is a RO desalination membrane process that has been commercially used since the early 1970s.

- **Drinking water production**

  Sea or groundwater can be purified in order to supply drinking water. However, RO represents only one step and the process often requires many more steps such as sediment filtration (pre-treatment), active carbon filtration, UV disinfection and remineralization (post-treatment).

- **Water and wastewater treatment**

  Industrial wastewater can be purified by using RO. However, chemicals, extreme pH values, oxidants and heavy metals can potentially damage the RO membranes; multistage treatment is often required.

- **Food & Beverage Industry**

  RO is often economically more favorable for concentrating food liquids (such as fruit juices) than conventional heat-treatment processes. Its advantages include lower operating cost and the ability to avoid heat-treatment processes, which makes it suitable for heat-sensitive substances like proteins and enzymes found in most food products.

Limitations

- **Water pretreatment**

  Extensive pre-filtration is essential when operating RO membranes, because the membranes are susceptible for fouling e.g. high concentrations of sulfates, barium, calcium alumina, and where Silt Density Index (SDI) average is >3. RO membranes are very sensitive to disinfectant and cannot be exposed to the disinfectant chlorine >0.1ppm. It is not a chemical-free technology because it requires acid cleaning as a sequestering agent resulting in highly acidic waste that cannot be discharged without neutralization. Most brackish RO systems require an antiscalant dosing system to prevent membrane scaling.

- **High energy consumption**

  High pressure pumps are required to force the water through the membrane. Therefore, RO is relatively less cost effective when feed water salt concentrations are TDS <4000ppm. At higher salt concentrations (e.g. seawater), RO systems usually incorporate an energy recovery device (centrifugal or isobaric type) in the process to lower the net power consumption.

- **Low water recovery rate**

  RO water recovery is normally below 75%, and at small scale as low as 20 – 30%. The non-desalinated water stream is discharged as wastewater, which can be costly, restricted or require post-treatment for final disinfection.

Electrodialysis

Electrodialysis (ED) is an electrochemical technique to remove ions from water. In ED water flows through a flow channel between a pair of ion exchange membranes; one side of the flow channel is formed by a cation exchange membrane (CEM) selective for positive ions, and the other side by an anion exchange membrane (AEM) selective for negative ions. Under the influence of an electric field, positive ions will travel towards the negative electrode, and negative ions towards the positive electrode. Half of the flow channels in an ED stack are therefore used to transport water with an increased ion concentration and the other half to transport water with a decreased ion concentration. In this process ions are transported through membranes and water molecules stay behind.

Electrodialysis reversal (EDR) is based on a similar principle as ED, with the difference that the polarity of the electrodes is reversed at regular intervals. This leads to a certain degree of self-cleaning of the membranes, because dirt that has built up on the membrane is forced off into the solution. Frequent polarity shifts lead to lower the water recovery.

Electrodialysis

The diluate stream is produced under the influence of an electric field where cations migrate through a cation exchange membrane (CEM) and anions migrate through an anion exchange membrane (AEM) producing water with a decreased ion concentration.

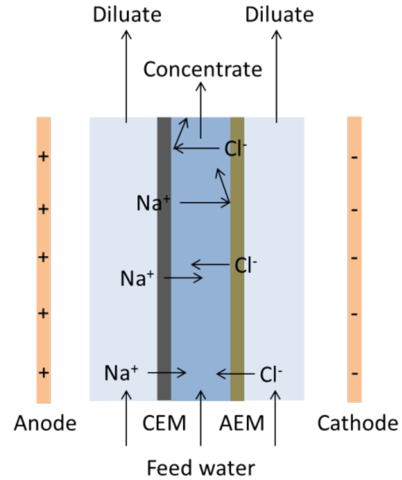


Figure 4: Schematic of electrodialysis process

Applications

ED and EDR are used to desalinate water with a medium level of salt concentration (TDS <3000ppm):

- **Brackish water desalination**

  The major application of ED has historically been the desalination of brackish water as an alternative to RO.

- **Large scale water production**

  ED is a suitable method to produce desalinated water at large scale, supplying towns and large factories.

- **Industrial wastewater treatment**

  ED is applied in wastewater treatment systems in processing rinse waters where it is a suitable method to reduce not only TDS, but particularly inorganic elements like nitrates, sulfates, radon and bromides.

- **Wine stabilization**

  ED offers an efficient solution for wine stabilization solving the problem of crystalline deposits that can form in bottled wine. The components that form the crystals (tartaric acid, potassium, calcium, and others) migrate through the membranes and out of the wine, greatly minimizing the chance that tartrate crystals can form in the bottle.

Limitations

- **Water pretreatment**

ED systems are sensitive to fouling and scaling. ED therefore requires extensive feed water pretreatment to remove species that coat, precipitate onto, or otherwise "foul" the surface of the ion exchange membranes. This fouling decreases the efficiency of the electrodialysis process. In the concentrate flow channel hardness ions can potentially precipitate and anti-scaling chemicals are therefore needed to manage scale formation. In addition, biocides are used to prevent biofouling. ED(R) is not a chemical free technology and requires careful monitoring and control to prevent biofouling and scaling.

- **Highly purified water required**

  ED and EDR become less economical and less efficient when very low salt concentrations are required in the product water. Current density becomes limiting and current utilization efficiency typically decreases as the feed salt concentration becomes lower.

- **High costs**

  EDR requires high investment cost especially for membranes and electrodes and is often not economically viable at small scale.

Electrodeionization

Electrodeionization (EDI) or Continuous Electrodeionization (CEDI) can be seen as an improved electrodialysis method targeting the ultrapure water segment. (C)EDI requires pre-treatment of the feed water so that it only contains a few ppm of ions before the water is fed into the (C)EDI. The conductivity of the water at these salt levels is very low and therefore ED will not work effectively. In (C)EDI the flow channels are filled with ion exchange resins which increase the ion flux through the membranes and improve the electrical conductivity. (C)EDI is a polishing step and is often used in combination with a RO system; this method can provide very pure water. Ions are transported through the membrane and water molecules stay behind. Process is enhanced with use of ion exchange resins.

Electrodeionization

The diluate stream with significantly decreased ion concentration is produced under the influence of an electric field where cations migrate through ion exchange resin particles and a cation exchange membrane (CEM), and anions migrate through ion exchange resin particles and an anion exchange membrane (AEM).

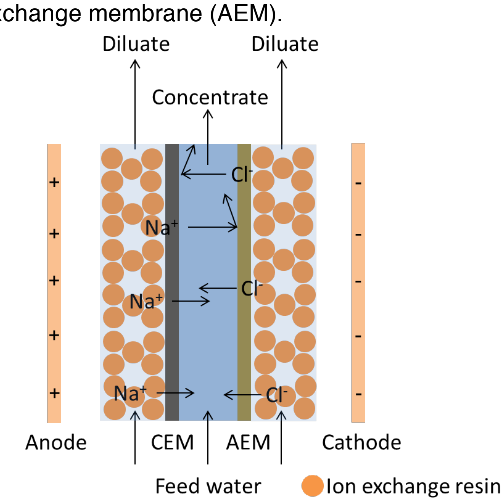


Figure 5: Schematic of electrodeionization process

Applications

The principal use of EDI/CEDI systems has been in the production of pure or ultrapure water for industrial processes.

- **High purity water**

  Feed water for laboratories, pharmaceutical, biotechnology and hospitals. (C)EDI can produce water with very low salt concentrations from 0.01 to 0.1ppm.

- **Boiler and steam generation feed water**

  Increasing water temperatures increase the risk of corrosion and scaling, therefore boiler feed water needs to be extremely pure. Purifying water in front of the boiler with (C)EDI is a way to reduce those risks and improve the boiler's performance, lifetime and reliability.

- **High quality rinsing water**

(C)EDI systems are producing high quality water for electronics, surface finishing and optical glass applications.

Limitations

- **High salt concentration**

  (C)EDI is not relevant for treating water with feed salt concentrations above 30ppm. It requires low TDS feed (e.g. feed purified by RO).

- **Fouling and scaling sensitive**

  (C)EDI is highly sensitive for fouling and scaling, therefore water pretreatment is required. Feed water hardness typically needs to be below <1ppm (as $CaCO_3$), total chlorine <0.05ppm, TOC<0.5ppm, SDI<1 and Fe, Mn, H_2S <0.01ppm.

- **High costs and high maintenance**

  In order to provide high purity water, (C)EDI needs to be used in combination with other purification techniques (typically with RO). Ion exchange resin needs to be occasionally regenerated with chemicals. Higher power consumption due to utilization of electrical current to continuously regenerate resin.

Ion exchange water softening

Ion exchange water softeners (IEX) are based on ion exchange resins which are capable of exchanging hardness ions present in the feed water to another ion type. As the water passes through, an ion exchange resin takes up calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions and releases sodium (Na^{+}) ions. This resin type is prepared from synthetic polymers such as sulfonated styrene-dicinylbenzene copolymers capable of exchanging cations. The ion exchange process is rapid and reversible by periodic regeneration. It means that if the resin reaches its exchange capacity (i.e. all the available sodium ions have been exchanged to magnesium or calcium) it must be re-charged by passing a solution containing a high concentration of sodium salts such as brine (sodium chloride) through the ion exchange resin in a process known as regeneration. Figure 6 illustrates the process of softening using cation-exchange resin.

Ion exchange water softening

Hard water with calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions flows through a column containing a strongly acidic cation exchange resin in the sodium (Na^{+}) form. The calcium and magnesium ions are exchanged for an equivalent number of sodium ions.

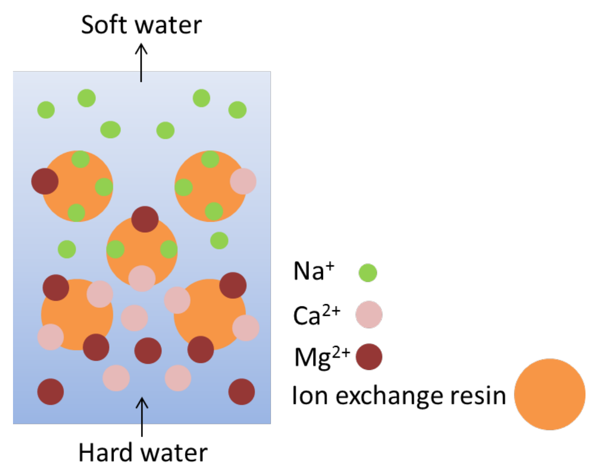


Figure 6: Schematic of an ion exchange softening process

Applications

Scale and deposit buildup in boilers and the formation of insoluble soap curds in washing operations have created a large demand for softened water. Therefore the main use of ion exchange water softeners has been in the production of softened water for laundries, domestic water boilers, low pressure industrial boilers, textile industry and chemical proceses, among others.

- **Point-of-Entry softeners**

Calcium and magnesium ions in water decrease the effectiveness of most cleaning processes and cause film and scale buildup in and on plumbing and fixtures. Water softening is an effective method for reducing hardness and improving the efficiency of these processes.

- **Laundry**

  Hard water causes soap precipitation, which forms an undesirable gray curd and increases the amount of wasted soap. IEX improves not only process efficiency, but also improves quality of the laundry.

- **Boiler water**

  Increasing water temperatures increase the risk of corrosion and scaling, therefore boiler feed water needs to be extremely pure. Purifying water in front of the boiler with IEX is a way to reduce those risks and improve the boiler's performance, lifetime and reliability.

Limitations

- **High maintenance**

  It is critical to perform regular maintenance of the unit to in order to keep effectiveness of the unit. Exhausted ion exchange resin needs to be regenerated on regular basis with a highly concentrated sodium chloride solution.

- **Fouling sensitive**

  Iron fouling is the most common cause of softener failure. Iron in Fe^{2+} form is oxidized via aeration to Fe^{3+} and in consequence precipitates as ferric hydroxide, which clogs resin beads and prevents ion exchange.

  Untreated water from lakes and rivers contain dissolved organic material, which can become irreversibly adsorbed at the resin surface. This accumulated organic matter is a nutrient source for bacteria and micro-organisms growth. Chlorine damages resins therefore it cannot be used as disinfectant agent.

- **Discharge brine is not permitted**

  These devices have a serious impact on the environment, which has prompted some communities to ban residential and commercial softeners. During regeneration IEX softeners discharge salt brine, which is harmful to soil, lakes, rivers and ecosystem. Connecticut, Massachusetts and numerous cities in California (e.g. Los Angeles, San Diego, Santa Clarita Valley, etc.) recently passed measures banning these devices.

- **High level of sodium**

  People with high blood pressure may have problems with the higher concentration of sodium ions present in tap water after the exchange process.

SUMMARY

Each presented desalination technology has specific benefits in certain applications and respective limitations. Table 1 below presents a technical comparison among them.

Table 1: Technology comparison

	CapDI©	RO	ED/EDR	(C)EDI	IEX Softener
Pre treatment	Low	High	Medium	High	Low
High temp system*	Yes	No	No	No	Yes
Scaling and fouling	Low	High	Medium	High	Low
Dynamic TDS adjustment	Yes	No	No	No	No
Problematic ions in feed	No	Yes	No	Yes	Yes
Chlorine tolerance	Yes	No	Yes	No	No
Chemicals	No**	Yes	Yes	Low	Salt
Consumables	Low	High	High	High	Salt
Maintenance	Low	High	High	High	Low
Energy use	Low	High	Medium	High	Low
Operational pressure	Low	High	Low	Low	Low
Water recovery	75-90%	20-75%	70-90%	90-95%	90-95%
Operation costs	$	$$$	$$	$$$	$$
Price	$$	$$	$$$	$$$	$

* Above 45°C/110°F.

** Acid injection may be required in some applications

For more information, contact Voltea by telephone: +31(0)252200100, e-mail: info@voltea.com, or visit www.voltea.com.