

CTO

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FROM THE CHIEF TECHNOLOGY OFFICER

Desal was initially driven by DC current and private equity

Tom Pankratz tells the story of how desalination was driven by electro dialysis before its thunder was stolen by reverse osmosis.



In 1946, the American Research and Development Corporation (ARD) was created to encourage private sector investment and managerial support in new businesses that were run by entrepreneurs and returning war veterans. The Boston-based company was the first publicly funded venture capital firm, and one of the first modern venture firms started after the war.

ARD's founders included its president, George Doriot, a French émigré and US Army brigadier general, who was the dean of Harvard Business School and became known as "the father of venture capitalism", MIT president Karl Compton and the head of MIT's chemical engineering department, Ed Gilliland.

Within two years, Ionics, a local water purification company—founded by a group of scientists and engineers from the Massachusetts Institute of Technology (MIT) and Harvard—became one of the first companies funded by ARD, with Doriot serving as its chairman and Gilliland as its president.

On February 20th, 1952, The New York Times ran a front page story about Ionics' new permselective ion exchange membrane and its method of electro dialyzing aqueous solutions, calling it a "revolutionary process for desalting sea water, promising to open vast new reservoirs of fresh water for use in agriculture, industry and the home wherever water is now scarce."

Meanwhile, in Coalinga, California, sixty miles southwest of Fresno, city officials had seen the Times' story and thought that the new electro dialysis (ED)

process might be a solution for treating their brackish water. They contacted Ionics, who dispatched Bill Katz to the site to conduct pilot tests.

Katz, an army veteran, joined Ionics in 1949 after finishing graduate school at MIT, and was part of the "collegial team" that developed ED technology. He also served on the board with Doriot and Gilliland. Last week, the 94-year-old Katz told your correspondent, "Coalinga's brackish groundwater was in the right salinity range and ideally suited for ED technology. After a couple of months of testing, they bought the first commercial ED unit and installed it in 1958." Coincidentally, Coalinga, California, was also the site of the first RO system, a 9 m³/d brackish water system that was commissioned by RO membrane co-inventor Sid Loeb in 1965.

Ionics was not the only company interested in ED back then; Japan's Asahi began looking at ED for brine concentration in the production of salt in the early 1950s. And, in 1960, when the US Office of Saline Water (OSW) funded the construction of a 950 m³/d ED demonstration plant in Webster, South Dakota, the project was awarded to Asahi. The decision was reportedly made because Ionics refused to release all of the proprietary information required by the government.

What makes ED unique among desalination processes is that it removes dissolved ions from a feedstream rather than removing water from the feedstream. It is an electrochemical process that separates a solution's ionic components by drawing the charged species through ion selective

“The development of EDR reinvigorated the ED technology.

membranes towards a cathode or anode operating in a DC electric field. ED is generally most cost effective when used on brackish waters with a total dissolved solids (TDS) concentration of less than 4,000 mg/L.

Through the 1960s, ED enjoyed a growing lead over RO, and by the end of the decade, there were over 200 ED installations around the world. In 1974, Ionics developed a variation on ED known as electro dialysis reversal (EDR), where the electrode polarity is periodically reversed so that a diluting compartment becomes a concentrating compartment and vice versa, resulting in an automatic self-cleaning.

The development of EDR reinvigorated the technology. Since then, other incremental advances and process variations such as Evoqua's NEXED technology have kept the technology relevant to the point that it is still widely used in many applications. However, Ionics itself no longer exists. It was acquired by GE Water in 2005, which in turn was sold to Suez in 2017.

This month, CTO takes a closer look at the alphabet soup of electrochemical desalination and deionisation processes, beginning with ED through an evolutionary process that also considers EDR, EDI, EDM, CEDI, CDI and RED, using IEMs and/or IX, to produce DI or UPW. ■

MARKET MAP

Fulfilling electric dreams for desalination

New technology developments are helping electrochemical processes increase their market share of the desalination space. Complementing reverse osmosis systems is clearly the largest opportunity, but can they compete directly?

Electrochemical processes for desalination are emerging from the shadow of reverse osmosis due to improving process economics and a slew of new solutions based on the principles of electro-separation. After having played second fiddle to reverse osmosis (RO) for many years in desalination applications, generally remaining confined to niche applications, electrochemical technologies, particularly those based on electrodialysis (ED) (see diagram, below) and electrodialysis reversal (EDR) are finding favour in applications such as brackish water desalination, industrial wastewater reuse and RO reject concentration.

Though the technology emerged after ED, RO took over as the dominant technology for desalination from the 1980s onwards, leaving ED in its wake. Today, ED and EDR do not always ‘compete’ with RO, but rather often complement it, acting as an additional upstream or downstream process steps. Thus the proliferation of ED/EDR technology is linked to the uptake of RO technology in certain applications. Demand for electrodeionisation (EDI)—a related, electrochemical process that combines ED and ion exchange resin—meanwhile continues to go from strength to strength, with suppliers capitalising on the general move away from mixed bed ion exchange systems, which require frequent regeneration.

Two significant advantages of electrochemical technologies over brackish water RO systems are generally higher recovery rates and a greater tolerance to fouling. New solutions are aimed at driving recovery rates even higher, without compromising energy consumption. Whatever their roles in desalination or deionisation, electrochemical technologies look set to play a larger role.

The rise of EDR

EDR, a variation of the ED process whereby membrane surfaces are cleaned automatically using electrode polarity reversal, has gained more interest in the water sector in recent years than the original technology, where greater pull comes from applications such as liquid processing in food production. Aside from one huge 200,000

m³/d system commissioned for desalting river water for the residents of Barcelona, Spain, and a 57,000 m³/d system treating wastewater for irrigation near the same city (both commissioned towards the end of the 2000s), EDR has not had especially sizeable references compared to RO (see chart, facing page). This does not mean it has not been extensively deployed however: just over 2.5 million m³/d of ED or EDR capacity for water treatment has been commissioned over time, according to GWI Desal-Data. These are however, usually small systems that desalt brackish water for small communities.

The leading supplier of ED and EDR systems is Suez Water Technologies & Solutions (with technology acquired from the legacy Ionics business via its acquisition of GE Water), which has recently seen a strong growth in the market.

“We’re doing more EDR than we ever have in the past and every year it grows. It’s primarily because we’re making good progress on making it a cost competitive technology,” said global product management director Erik Hanson, adding that economic considerations will likely continue to hold back the technology in the near-term.

Suez continues to see strong uptake in the brackish water space, as well as for applications that only need to remove some salinity, providing an alternative to RO. For example, relatively low concentrations of silica may cause scaling of RO membranes, but since silica is a non-ionic species, it passes through an ED/EDR system and does not limit recovery.

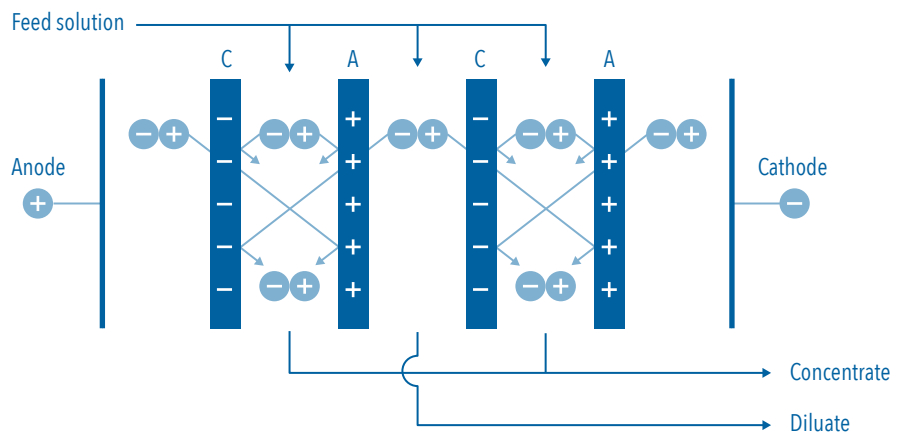
“The other application that we’re really seeing growth in, especially in the last three to five years, is industrial wastewater reuse,” said Hanson. “One of EDR’s advantages is that it has pretty high tolerance to organics and process upsets.”

One of Suez’s main competitors in the ED space is Czech firm Mega, which has been supplying ED technologies for over 20 years and in 2015 moved into the EDI space. Senior sales manager at Mega Tomas Dornik told GWI that currently the main interest for Mega was using ED to concentrate RO reject as part of a zero liquid discharge (ZLD) application.

“We can concentrate [RO reject] up to 200 or 220 grams per litre in industrial wastewater applications, meaning we can avoid evaporation and go straight to a crystalliser,” Dornik noted. ▶

NO LONGER SO CURRENT

The electrodialysis process dates back to the 1950s and is still widely used to remove salts from water, but numerous processes based on ED principles have evolved according to market needs.



*C = cation exchange membrane; A = anion exchange membrane

Source: Wiesler

EDR continues to be explored for concentrating RO reject in municipal applications. Suez Water Technologies (in its former life as GE Water) in 2015 deployed a 10 gallon per minute (gpm) pilot of its combined EDR and calcium sulphate precipitation technology on a brackish water RO (BWRO) system operated by the Eastern Municipal Water District (EMWD) in California. After the pilot was deemed successful, designs for a much larger 100 gpm demonstration project were drawn up. Construction bids for this project were received in September, pricing the total cost of the project at about \$5.4 million. However, the project has been shelved by EMWD in favour of a demonstration project of a competing technology, Desalitech's closed circuit RO (CCRO) process. This demonstration will take place throughout 2018, with findings expected at the year's end. EMWD commissioned a full-scale capital cost comparison, which, worryingly for the EDR/precipitator process, came out nearly twice as much as Desalitech's technology for treating only a little more than half the amount of brine.

Canadian company Saltworks meanwhile has numerous commercial demonstrations of its EDR with industrial clients. The main application it is focusing on is electrodialysis metathesis (EDM) with its Salt Splitter process. It is typically used on solutions saturated with inorganics such as scaling calcium sulphate (gypsum), and "splitting" the calcium sulphate into non-scaling calcium chloride and sodium sulphate. CEO Ben Sparrow sees EDR supplementing RO, enabling higher recoveries to be obtained from the latter, and competing with RO pretreatment rather than the process itself.

"Once you change the chemistry, you can now use RO," he told GWI. "Using RO as the core engine and the electrochemical salt splitter as the turbocharger moves us away from expensive chemical softening approaches."

Demonstration projects on mining wastewater and power flue gas desulphurisation (FGD) wastewater have enabled Saltworks to demonstrate its system's ability to change the chemistry and concentrate RO reject simultaneously.

Fujifilm has developed new monovalent membranes for EDM, which were tested in the EU-funded ZELDA project, concluded in summer 2017. By separating the brine (from both brackish water and seawater desalination) into two waste streams of highly soluble salts (e.g. sodium with anions and chloride with cations) through EDM, the members of the project found

TEN OF THE BIGGEST

The table demonstrates the variety of feedwaters that some of the largest ED or EDR plants are treating. Seawater is notably absent, where ED or EDR cannot yet directly compete with RO.

Location	Country	Feedwater type	End-user	Commissioning year	Capacity (m ³ /d)
Barcelona	Spain	River (brackish)	Municipal	2008	200,000
Barcelona	Spain	Wastewater	Irrigation	2010	57,000
Sarasota, FL	USA	Brackish	Municipal	1995	45,420
-	Taiwan	Brackish	Industry	1995	40,000
Vicksburg, MS	USA	River	Industry	2011	34,000
-	Mexico	Brackish	Municipal	2001	29,330
California	USA	Brackish	Municipal	2016	28,390
St Louis, MO	USA	River	Industry	2010	28,350
Nogales, AZ	USA	Brackish	Industry	2011	27,720
Barranco Seco	Spain	Wastewater	Irrigation	2002	18,000

Source: GWI DesalData

“We’re doing more EDR than we ever have in the past and every year it grows. It’s primarily because we’re making good progress on making it a cost competitive technology.”

Erik Hanson, Suez Water Technologies

that valuable compounds such as sodium sulphate and magnesium hydroxide could be recovered much more easily from the waste streams.

Unlocking the EDR market

One problem that ED and EDR face is the small pool of technology suppliers. Clients are often wary of being tied to a very select amount of suppliers that provide a whole system with all the components.

"When you need ED or EDR, you are linked to Czech firm Mega, GE Ionics [now Suez] or Japanese suppliers," explained Wolfgang Neubrand, manager at WBG Kulmbach. "They will give you everything from the inlet flange to outlet flange. There is no OEM culture and this is hindering the penetration of the market."

The resurgence of interest in EDR is partly down to new suppliers in the market, including Evoqua (a leader in EDI modules) and Fujifilm, which does not supply entire ED systems (Saltworks meanwhile can supply either modules or systems).

"[The new market entrants] are making quite a big promotion for ED and now a lot of people can see the advantages of Mega's technology more than they could do before," Dornik told GWI. "There were three main larger companies doing ED but

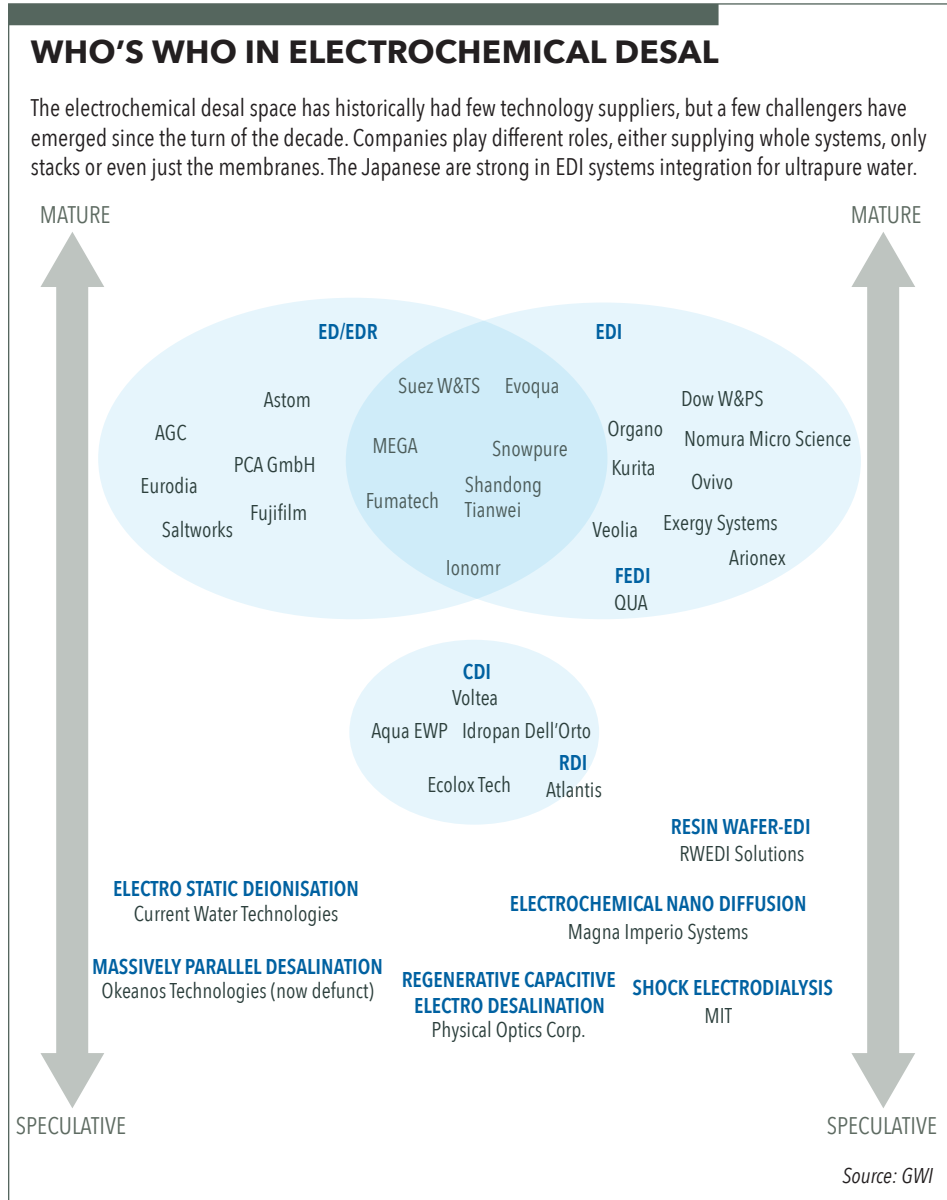
they are not capable of promoting the technology everywhere."

Evoqua's activities have piqued the desalination community's interest. A significant amount of attention has been drawn towards Evoqua's NEXED system, described by the company as a next generation configuration of EDR. The technology, under development since Evoqua's past life as part of Siemens, marked the company's foray into the ED and EDR market, in addition to its strong position in the EDI module market. In Singapore, Evoqua has been working with the Public Utilities Board (PUB) to test NEXED on seawater. Following the results of a 50 m³/d demonstration system, which claimed energy consumption of 1.65 kWh/m³ of seawater desalted, Evoqua received approval for a 1,890 m³/d demo plant.

The previous twelve months has seen its application to the US brackish water market, including on RO reject water. Firstly, in February, Evoqua installed a 20 gpm system to treat the RO concentrate stream of a BWRO system at a scientific glass manufacturer in New Hampshire for reuse purposes. The feedwater quality to the RO system varied significantly, causing variations in the reject water too. The NEXED is operating at an average of 82% recov- ▶

“What is going on with NEXED will be interesting to see. From the module technology perspective, this is really something different from the others.”

Wolfgang Neubrand, WBG Kulmbach



the most traction in recent times as an alternative to ED or EDR. The leading proponent of membrane capacitive deionisation, Netherlands-based Voltea (which has coined the abbreviation CapDI), had a strong 2017, including raising more than \$10 million of funding. It focuses on commercial applications such as laundry wastewater and softening boiler feedwater, but towards the end of 2017 it entered the point-of-use market. The product DiUse has the ability to be tuned to produce a desired water conductivity, making it particularly suitable for applications such as beverage brewing. The company is also seeing traction in the municipal market, with the commissioning of a pilot unit at the Cherokee Metropolitan District in Colorado Springs, Colorado. It is being tested side-by-side with an Evoqua MF/RO system and a Suez EDR system on effluent from a membrane bioreactor.

Atlantis Technologies meanwhile, which has a variant on the capacitive deionisation process, is also reporting substantial pull from the market. Its radial deionisation (RDI) product differs from other capacitive deionisation technologies principally because its design allows for water to flow across 1-10 metres of supercapacitor material, compared to about 10cm of material in traditional configurations. It has a close relationship with CDI leader Voltea, from whom Atlantis licenses the technology.

“In essence it’s very similar in performance to Voltea but we use our IP to build a lower priced, higher recovery system,” Atlantis CEO Pat Curran explained to GWI. “It’s a CapDI cylinder but it’s built in an entirely different way. We can process water successfully and economically through 20,000 ppm [parts per million]. Technically we can go above that but our economics are such that we can only compete up to around 20,000 ppm.”

Atlantis is currently closing a series A funding round worth \$3.25 million, where one of the partners includes a US cooling tower manufacturer, which Curran is particularly excited about, labelling the cooling tower market as “the largest market space that we think is available for CapDI.”

Though the water has a relatively low TDS, Atlantis would deploy its technology to save on chemical costs, which represents the major cost of cooling tower water treatment. It will be bringing a capex solution to an opex market.

“The cooling tower manufacturer plans to integrate our CapDI systems into existing and brand new cooling towers as a pretreatment to reduce chemical usage and reduce water usage,” Curran said. ▶

ery on a feedwater that fluctuates between 1,500 and 3,000 µS conductivity, generating a steady feed of 650 µS conductivity.

In September 2017, Evoqua began a two-month demonstration of its NEXED process at El Paso Water’s Kay Bailey Hutchison Desalination plant. The 25 gpm system was treating the feedwater of the existing BWRO system, with TDS of up to approximately 3,000 mg/L. Evoqua describes the NEXED as having a sweet spot operating on brackish waters that have

high silica concentrations, a combination which can be troublesome for RO.

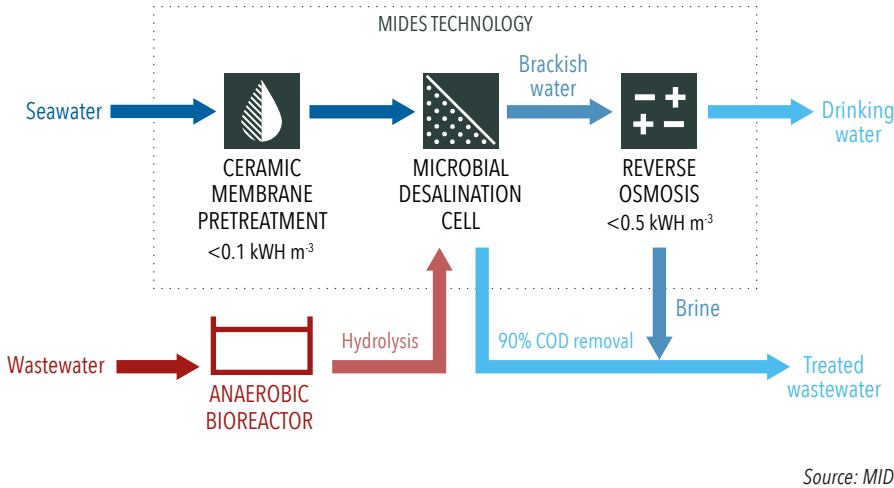
“What is going on with NEXED will be interesting to see. From the module technology perspective, this is really something different from the others,” said Neubrand. “NEXED is something more sophisticated, and it will be interesting to see if it gives the industry a new kick.”

Capacitive deionisation: best of the rest?

Capacitive deionisation (CDI) has gained

THE MIDES TOUCH?

The MIDES project will take the opportunity to trial different kinds of pretreatment to the MDC process, including ceramic membranes. The MDC relies on a source of wastewater that is ideally high in organics.



New kids on the block

New players in the space include Magna Imperio Systems, which has developed an electro dialysis-based technology it has coined Electrochemical Nano Diffusion (END), focusing on maximising recovery while optimising the energy consumption. Magna Imperio CTO Chad Unrau told GWI that while END is based on the principles of electro dialysis, the company has transformed key components of the process, namely the electrodes and spacers between membranes.

“END electrodes are designed to react with ions in the electrolyte rather than split water, which is similar to how electrodes in a battery function,” said Unrau. “What this enables is an ultra-low electrode resistance, which allows us to reallocate the energy that would normally be spent on the electrode resistance towards driving higher recovery in the system.”

Though Magna Imperio is initially focused on treating brackish water, that ED/EDR operate quite comfortably for the partial desalination of water in the upper end of brackish water salinities means

Unrau also sees application in brackish water RO concentrate recovery.

The company is planning to conduct numerous bench and pilot tests in 2018 with commercial demonstrations expected towards the end of the year. A 1 gpm pilot is already underway on brackish groundwater.

Another new technology trying to make a splash is Current Water Technology’s (until recently Enpar Technologies) electrostatic deionisation process, based on capacitive deionisation, which is offered in designs that either remove charged dissolved solids or preferentially remove monovalent ions.

In late 2015 there was significant fanfare around MIT’s discovery of a shock-wave-based desal process, which involves flowing feedwater through a weakly charged, porous ceramic ‘frit’ placed in a channel between two ion-selective membranes. When current passes through the frit, ions migrate toward the electrode, creating an ion depletion zone. When the current reaches a certain point, a shock-wave is generated between the depleted or enriched zones, that increase mass transfer

“We see the strategy of using the microbial desalination cell as pretreatment to RO for market verification but from the results we have from the pre-pilot system, we can completely desalinate seawater and brackish water.

Victor Monsalvo, Aqualia

and create localised desalination within the channel.

MIT professor Martin Bazant updated GWI with progress on the technology, saying that progress was slow but more papers were to be expected in 2018, with a view to beginning commercialisation at the end of the year. Bazant’s research group is focused on lowering the energy cost of the process, which Bazant suggested was one of the main drawbacks of the original prototype, as well as pushing for higher recovery after Bazant’s team “found rather high water recovery without even going for it” with the prototype. He also indicated the technology would complement RO well, rather than replace it. Furthermore, there was a possibility of removing the ion exchange membranes from the process, creating a “membrane-less” separation of ions and particles.

The travails of Okeanos Technologies however, serve to remind newcomers of the protracted process of commercialising a new water technology. The company was trying to commercialise a massively parallel array of microscale desalination “chips” that employ Faradaic electrochemistry to separate ions from water, but ceased operations in 2016 after its supporting venture capital firm collapsed. It could not find a replacement investor that saw its technology as sufficiently “de-risked.”

What is coming from Europe?

Projects funded by the European Union hold particular interest for the fortunes of electrochemical technologies in desalination. The MIDES (MICROBIAL DESALINATION) project, which has ten partners, has the main focus of demonstrating a more affordable desalination technology than reverse osmosis on its own, and overcoming the existing limitations of microbial desal technologies.

On a basic level, the system uses microbes known as geobacter to generate an electrical current, which is used to create a potential across two ion exchange membranes to desalt seawater. The configuration is known as a microbial desalination cell (MDC), which will treat water to brackish water quality before entering a standard RO system (see diagram, above).

“We will be trying to reduce salinity of seawater from 35,000 to 5,700 ppm, then using RO as a polishing step,” explained programme coordinator Victor Monsalvo of Aqualia. The project aims to achieve an energy consumption of 0.5 kWh/m³ during the RO step, much less than current typical levels of 3-4 kWh/m³.

As part of the project, three 3.6 m³/d ▶

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Chad Unrau, Magna Imperio Systems

pilot plants will be set up, one in Spain and one in Chile both treating brackish water, and one in Tunisia desalting seawater. The first demonstration is expected to be online at Aqualia's site at Denia, Spain before the end of 2018.

“We see the strategy of using the MDC as pretreatment to RO for market verification. But from the results we have [obtained] from the pre-pilot system, we can completely desalinate seawater and brackish water,” enthused Monsalvo. However, as with every new water technology, especially in desalination, the challenge in scaling up is not being taken lightly by Aqualia.

“We're at a two litre scale so [we have] a long way to go to industrial applications, but we are hopeful from the pre-pilot results,” said Aqualia's head of innovation Frank Rogalla.

The innovations required for the system to work properly include an anode suitable for growing bioelectrogenic bacteria. Development of such a product has yielded surprising results for the responsible consortium member SGL.

“Compared to other electrodes produced by SGL, these ones are low price and low quality, and usually used for applications such as batteries. But they work very well as a biochemical system for desalination. The performance is good but cost is low,” said Monsalvo.

Another ambitious EU-funded project is REviveD water, which has the bold objective of establishing ED as the “new standard for desalination of seawater”. The project, which will implement numerous pilot demonstrations across Europe and Africa, is focused on developing improved ED systems, including off-grid brackish water desal in developing countries, multistage ED systems for industrial-scale seawater desalination, and combining reverse electrodialysis (RED) with ED or RO. For the multi-stage ED system, members of the project are currently deciding how many

stages to implement. Whatever the decision, the results will be interesting to see how seawater can be desalted economically without an RO process involved.

RED will be applied as a pre-desalination step if a low salinity wastewater stream is available – ions will move naturally from the higher salinity seawater to the lower salinity water, reducing the desalting load on a downstream ED or RO process as well as mitigating energy consumption. “The idea of the hybrid is to enhance the performance of RO by combining it with ED or RED,” project coordinator and Fujifilm innovation manager Natalie Tiggelman told GWI. The pilot testing focused on seawater desalination is anticipated to begin operation by the end of 2018.

The project is also promoting development of new electrodes, stacks and IX membranes, the latter of which have been developed by Fujifilm. The membranes are profiled with a “structured surface” and obviate the need for membrane spacers, which could reduce the risk of membrane fouling.

EDI: the less glamorous cousin

EDI is a different beast to ED and EDR, being utilised as a polishing step downstream of an RO process for ultrapure water in the microelectronics industry or for boiler feedwater in a power plant. EDI evolved from ED to overcome limitations regarding electrical conductivity, using mixed-bed ion exchange resins in addition to ion exchange membranes. The technol-

ogy has evolved somewhat since its conception in the late 1980s, but it continues to be limited to niche markets. Market players see end-users shifting away from decisions based on capital investment, with EDI a much more attractive technology.

“I think that's the primary reason why we're seeing so much growth [in EDI], it's really a much more cost-competitive thing to do now than it was a decade ago, particularly when you start looking at lifecycle cost and not having to deal with acids and caustics,” Hanson told GWI.

One of the advances in EDI came from Aquatech International's subsidiary QUA Group, which developed a fractional electrodeionisation (FEDI) process that tolerates a higher hardness feedwater than other EDI competitors. It has a dual voltage-dual stage process, which QUA claims reduces the risk of scaling compared to conventional EDI. In an FEDI cell, there is one voltage zone dedicated to remove hardness and one for reducing silica, as opposed to the one voltage zone removing all ions. This process enabled EDI to be used downstream of a single-pass RO system, rather than a double-pass RO.

Despite such innovations, and more players active in the market compared to ED, Hanson remains confident that Suez will continue to be one of the leaders in EDI.

“Our design allows us to get really low silica and boron. I think the primary driver that makes ours the EDI of choice for power and microelectronics is those low silica and boron numbers that we're able to get,” he said.

Mega meanwhile currently operates with its EDI system in the power industry, where it is capitalising on a general trend of end-users moving away from simple ion exchange systems for their boiler feedwater. Dornik told GWI that Mega is now looking at selling its EDI systems to semiconductor manufacturers.

Innovations to the process

How can ED or EDI systems be enhanced in the future? As with many water technologies, advances will likely be incremental. Electrodes are not specifically developed ▶

“Normally the frames are very difficult to produce. The development of 3D printing allows you to produce things in a different way. Maybe there will be something leading to cost reductions or new designs of frames.

Wolfgang Neubrand, WBG Kulmbach

Terminology

Anion: a negatively charged ion that migrates to the anode when an electrical potential is applied to a solution.

Anode: the positive electrode through which current flows into an electrolytic cell. (note: the term does not relate to the polarity of the electrode, but the direction of current).

Cathode: the negatively charged electrode through which current leaves an electrolytic cell. (note: the term does not relate to the polarity of the electrode, but the direction of current).

Cation: a positively charged ion that migrates to the cathode when an electrical potential is applied to a solution.

Capacitive deionisation (CDI): an electrochemical desalination process in which water flows between or through charged electrodes, which remove and retain charged ions from solution until the electrode polarity is reversed.

Cell pair: a cation-exchange membrane, a concentrate containing cell, an anion-exchange membrane and a diluate containing cell (in ED/EDR).

Conductivity: the ability of a substance to conduct electricity, which is directly related to the mineral content of water.

Deionisation (DI): the process of removing

ions from water.

Diluate: the feed solution in an electrochemical process.

ED metathesis (EDM): a variation on electrodialysis used for brine concentration that uses two different cell pairs to ensure that magnesium, calcium and the multivalent anions are concentrated separately.

Electrodeionisation (EDI): a process that combines an electrodialysis membrane process with an ion exchange resin process to produce high purity, demineralised water. The electric current is used to continuously regenerate the resin. Also known as continuous EDI (CEDI).

Electrodialysis (ED): the separation of a solution's ionic components through the use of semipermeable, ion-selective membranes operating in a DC electric field.

Electrodialysis reversal (EDR): a variation of the electrodialysis process using electrode polarity reversal to automatically clean membrane surfaces.

Electrolyte: a substance that dissociates into two or more ions when it dissolves in water.

Ion exchange (IX): a chemical process involving the reversible exchange of ions between a liquid and a solid.

Ion exchange membrane (IEM): a membrane that allows transport of dissolved ions across a conductive membrane. Negatively-charged cation exchange membranes (CEM) reject anions, while positively-charged anion exchange membranes (AEM) reject cations.

Permeate: the portion of the feed that passes through a membrane.

Retentate: the portion of the feed solution that is rejected by the membrane, also called "concentrate".

Reverse electrodialysis (RED): an electrochemical process that uses the salinity gradient between two solutions to produce energy.

Resistivity: a measure of resistance to the flow of electricity, used as an accurate measure of a water's ionic purity.

Solute: a substance dissolved in a fluid.

Stack: the building block group of an ED/EDR system in which numerous membrane pairs are stacked upon one another between a single positive and negative electrode.

Ultrapure water: in the semiconductor industry, ultrapure water is considered to be that with a conductivity of 0.055 $\mu\text{S}/\text{cm}$ or a resistivity of 18.2 megohm, measured at 25°C.

for ED purposes, because the money is in fuel cells. Superior electrodes are normally yielded through development of fuel cells, and they can then be found to be well suited for ED systems. One area where real innovation is perhaps most achievable is the development of the spacers between membranes, due to advances in technologies such as 3D printing.

"Normally the frames are very difficult to produce. The development of 3D printing allows you to produce things in a different way," commented Neubrand. "Maybe there will be something going on here leading to cost reductions or new designs of the frames."

Increasing surface area in a stack is also a focus of many of the existing suppliers. Suez is looking at new and improved materials to be used. "The support layers that

support the basis of membrane sheets, it's easier to take them for granted because it's just your starting point and then you apply things to it. But if you look at all these different materials, if you push the limits there, you're able to both improve the efficiency of them in terms of salt cut, and also some of the geometries. If you can make them thinner, you can get more of the surface area into the same space," commented Hanson.

In addition to innovations by Fujifilm, other companies are capitalising on the availability of new types of ion exchange membrane materials, including Saltworks and fellow Canadian startup Ionomr. Saltworks has developed a polyamide acrylate functionalised membrane with an acrylamide coating, allowing them to make a more robust membrane, whose tolerance

to hydrocarbons enables their use in EDR systems in applications such as produced water. Ionomr, spun off from a Canadian fuel cell group in 2015, focuses on membrane manufacturing, notably anion exchange membranes, using polymers from the polybenzimidazole (PBI) family, which is ultra-high strength thin film. CEO Ben Britton claimed that Ionomr has made its membranes very alkaline stable.

"It opens up a lot of industrial wastewater recovery options that were theorised, but you couldn't even make prototypes because conditions were too harsh," Britton explained to GWI. "Benchmarking against the most alkaline stable material currently on the market, we get at least 40 times the lifetime in alkaline-type systems. On top of that, PBIs are quite oxidatively resistant." ■

FIRST REPORT

Taking the suspense out of suspended solids

The age-old conundrum of the most effective way to remove suspended particles from water streams attracts lots of new or adapted technologies. GWI takes a look at a clarifier aimed at the oil & gas sector, and a more novel approach with wider applications.

XELAQUA

MAGNETITE BALLASTED CLARIFIER

North Carolina-based XelaAqua has developed a magnetite ballasted clarifier (MBC) which has been specially designed as a modular and transportable clarifier for the unconventional oil & gas sector in North America. Though the main competitors are Veolia's Actiflo, Suez's Densadeg and Evoqua's CoMag solutions, XelaAqua differentiates itself with a smaller footprint that claims to clarify water and mobilise faster than these solutions. A key differentiator particularly from the CoMag solution claimed by XelaAqua is the use of strong magnetic forces as an adjunct to gravity for separation of solids from the wastewater.

Polymers, usually polyacrylamide, are injected into the influent to create large flocs that, with magnetite added, settle quickly as a magnetite pollutant polymer (MPP) floc. The MPP, even as colloids, adheres to magnetic disks as clean water leaves the system at a high rate, whereby the polymer is then sheared off to go to waste. Magnetite is recovered for reuse in the system.

XelaAqua carries units of two different sizes: the XL-300, which has a maximum flow rate of 300 gpm (1,635 m³/d), and the XL-35000, aimed at the oil & gas sector to treat 35,000 barrels of water per day (5,472 m³/d). For oil & gas applications, the unit can be combined with a dissolved gas flotation (DGF) unit and chlorine dioxide system to create a complete treatment train. The company claims it can reduce turbidity in feedwater from between 600 to 1,000 NTU down to 5 NTU.

The company has conducted three trials in the oil & gas sector as well as one sale in the pharmaceutical industry with a reported time to break even of 10 and 14 months respectively. Another trial on frac' water is upcoming. Its go-to-market strategy involves selling to oilfield water services companies, allowing the latter to offer a whole solution for produced water treatment.

Current CEO Graham Crispin acquired the assets and technology from AquaMag in September 2013, initially investing \$750,000. XelaAqua also has partnered with industrial analytics and business process management platform as a service (PaaS) providers to move forward their interest in applying Industrial IoT concepts to the logistics, optimisation and service management of field deployed water treatment solutions.

Treatment category:



Potential applications:



Potential industries:



USP: High-rate clarification process in a small footprint. Ability to shear polymers off the magnetite, enhancing the amount of magnetite that could be recycled.

Funding stage: Debt and revenue Looking to raise up to \$3 million.

Stage of development: Third-party pilot testing. Patenting process underway.

CEO: Graham Crispin
Website: <http://www.xelaqua.com>

Star rating:

EXPERT COMMENT

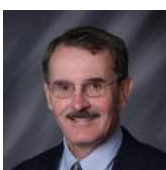
The challenge for ballasted floc processes like XelaAqua is that it is hard to justify the added complexity and cost of using a ballast (magnetite or sand) unless space is severely constrained. Mobility for produced water may be a good opportunity but the standard approach, a simple frac' tank for settling, is a lot cheaper even though it takes up more space.

Joe Zuback, Global Water Advisors

THE EXPERTS



Wolfgang Neubrand
Former head of R&D at Christ Water Technology and expert in ultrapure water treatment, ion exchange membranes and AOP processes.



Joseph Zuback
President and founder of Global Water Advisors, Inc., (www.globalwateradvisors.com), specialising in advanced water and wastewater treatment.



Tom Pankratz
A Houston-based independent consultant and the editor of GWI's weekly Water Desalination Report (www.desalination.com).

For full biographies of our experts, visit: <http://tinyurl.com/cto-experts>

UFRACTION8

CELL SEPARATION TECHNOLOGY

Spun out of Heriot-Watt university in Scotland in 2017, ufraction8 is harnessing microfluidics-based technology for the separation of cells from liquids. The company has developed a stacked and cascaded hydrodynamic focusing system with high throughput for separation and concentration of particles. The use of microfluidics for particle separation in industrial applications has been restricted in the past by low volumes, but ufraction8 has developed a system based on microchannels that exploit hydrodynamic separation effects and stacking a number of devices.

Through a cascading system, sequential removal of particles is enabled before a final stage where the target particle size can be concentrated. The stream to be treated is injected into cascading spiralling rectangular channels, each channel height becoming increasingly smaller within each subsequent geometry. The feed is split into two outlets. A 'focused' outlet contains the particles that need to be removed by that step, so that they do not clog the smaller geometries further along. Smaller particles end up in the 'unfocused' outlet and that stream then enters the next stage.

The microfluidic channel design allows easy access to the inlets and outlets, meaning that, along with a novel manifold, equalised inlet pressure to the stack can be delivered, helping to significantly increase flow rates compared to what inertial focusing has achieved before. Ufraction8's IP lies in the distribution of the flow across a stack of microfluidic chips. It currently has a single module system operating at 6 litres per minute, comprised of 750 passive layers – or microfluidic chips – with only the pump as a moving part. The company claims the unit could currently achieve around 46% solids concentration.

The company is planning to establish a beachhead in the bioprocessing sector, but is eyeing several applications in wastewater. The foremost is the harvesting of algae downstream of a photobioreactor, where it has begun piloting with specialists in wastewater remediation using algae, which can be effective at taking up phosphates. The idea then is to extract proteins and lipids from the algae, leaving phosphate in the biomass for use as fertiliser. It has also received interested from the ballast water treatment sector, where rather than sterilising the water (as is the common technology option at the moment), the technology would remove the organisms for discharge back into the ocean. Market entry into water is anticipated within the next two years.

Go-to-market strategy will be a combination of customised solutions for large industrial end-users, as well as standardised units ready to sell to other service or systems providers that would enhance their offering. The patent lies with Heriot-Watt university, and ufraction8 has obtained a worldwide exclusive perpetual and sub-licensable license with triggers at certain points when investment milestones are reached. It raised its pre-seed funding round with Deep Science ventures, and has a purchase order from paint and chemicals giant Akzo Nobel in a synthetic chemical application.

Treatment category:



Potential applications:



Potential industries:



USP: Sustainable technology with superior scaleability compared to rival technologies such as centrifuges and filters for liquid-solid separation.

Funding stage: Pre-seed but generating revenue. Looking to raise seed funding from VCs.

Stage of development: Lab-scale pilot testing. Patented.

CEO: Brian Miller

Website: <http://www.ufraction8.com>

Star rating:



ICON KEY

Treatment categories:



Oil-water separation

Applications:



Produced water

Industries:



Upstream oil & gas



Ballast water



Suspended solids removal



Wastewater



Pharmaceuticals



Other



Biological treatment



Municipal



Sludge management



Textiles

Star rating system:



Unrated



Interesting



Worth a detour



Worth a journey