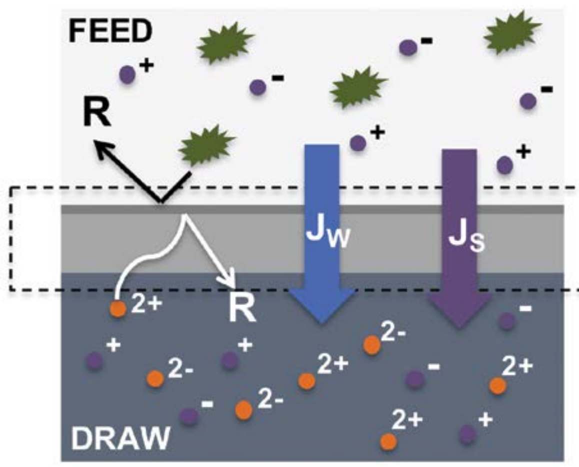
Improved Resource Recovery from Zero Liquid Discharge (ZLD) Processes Using Novel Forward Osmosis (FO) Membranes

Since the industries account for around 20% of global freshwater consumption, and tend to be cash-rich in comparison to other freshwater consumers, the governments are increasingly tightening regulations on industrial wastewater disposal. Besides augmenting water supplies, wastewater disposal limitations have the added benefit of protecting aquatic environments.

By Mark Perry



Why are ZLD Processes on the Rise?

Water is no longer a given. Under great publicity, the 'Day Zero' was narrowly avoided in Cape Town during 2018 and now Chennai in India and many towns in Australia face the same crisis. When economic growth and public health face systemic risks, the economic burden of imposing stricter water treatment and water recycling regulations is dwarfed by the consequences of the status quo.

Since the industries account for around 20% of global freshwater consumption, and tend to be cash-rich in comparison to other freshwater consumers, the governments are increasingly tightening regulations on industrial wastewater disposal. Besides augmenting water supplies, wastewater disposal limitations have the added benefit of protecting aquatic environments.

Zero Liquid Discharge (ZLD) is the ultimate wastewater management that eliminates any liquid waste leaving an industrial plant, and - as such - also carries the highest price tag in terms of capital and operational costs.

According to the work by Elimelech and co-workers in "The Global Rise of Zero Liquid Discharge for Wastewater Management: Drivers, Technologies, and Future Directions", countries at the forefront of imposing ZLD regulations include the United States, China, and India. Whereas the power sectors are the main contributor to the ZLD markets in the United States and China, the textile industry is one of the main drivers in India's ZLD adoption.

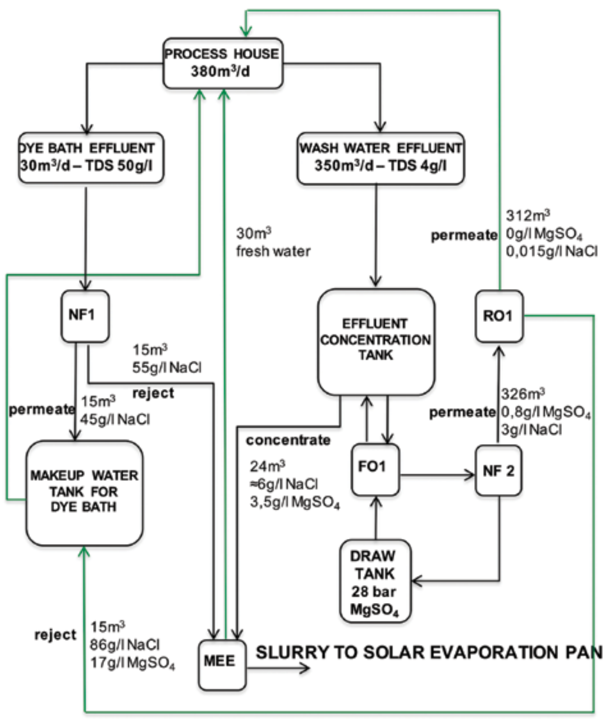
The Potential for Lowering the Operating Cost of ZLD

Traditional ZLD processes are based on water evaporation and are therefore exceedingly energy-intensive. Typically, Mechanical Vapor Compression (MVP) evaporators use 20-25 kWh/m^3 of high-grade electric energy to reach brine concentrations of 250,000ppm. In the last stage of ZLD, brine crystallizers use upwards of 70 kWh/m^3.

The final stage of evaporation is largely unavoidable hence strategies for lowering the operating cost of ZLD focus on brine pre-concentration to reduce capacity demand for evaporators and crystallizers. In comparison, membrane-based Reverse Osmosis (RO) processes consume 2-3kWh/m^3 and, therefore, represent an excellent option for energy reduction of ZLD processes. Having said that, RO processes are limited by brine concentration and become less feasible above 70,000 ppm.

Hence, a window of opportunity exists for low-energy technologies capable of concentrating brines from 70,000 ppm to 250,000 ppm. A variety of membrane-based technologies have shown potential in this ppm-range, including Osmotically Assisted Reverse Osmosis (OARO), Membrane Distillation (MD), Electro-Dialysis (ED), and Forward Osmosis (FO). The remainder of this article will focus on how FO can be utilized to improve ZLD ROI.

The Slope of Enlightenment



- Makeup Water: 8m^3/d
- Makeup Salt (NaCl): 930kg/d
- Draw Replenishment (MgSO4): 344kg/d

System Summary:
- Total Wash Water Demand: 350m^3/d
- Total Dye Bath Water Demand: 30m^3/d
- Total Salt Demand in Dye Bath: 2900kg/d
- Total Salt Demand in Wash Water: 0kg/d
- Recycled Wash Water: 342m^3/d
- Recycled Dye Bath Water: 30m^3/d
- Recycled Dye Bath Salt: 1970kg/d
- Volume to be Treated by MEE: 39m^3/d

Forward osmosis technologies have always been a favorite among membrane researchers. But it is fair to say, that the commercial FO field took a hit - and experienced some disillusionment - when it became clear the technology would likely never revolutionize seawater desalination.

Jeffrey R. McCutcheon's recent work "Avoiding the Hype in Developing Commercially Viable Desalination Technologies" aptly describes how the use of forward osmosis for seawater desalination has followed Garner's hype circle and currently resides somewhere in the region between the "Trough of Disillusionment" and the "Slope of Enlightenment".

Economical Parameters	NF/RO/MEE	FO/NF/RO/MEE
Total System Cost (USD)	447000	671000 (+50%)
Daily CAPEX Cost (USD)	123	184
Daily O&M Cost (USD)	502	427 (-15%)
Daily Cost of Draw Solution (USD)	0	72
Daily Water Revenue (USD)	584	677
Daily Salt Revenue (USD)	169	413
Yearly Total Profit (USD)	47000	149000
Payback Period (Years)	9,5	4,5

Table 1

These days, surviving commercial FO players are now largely looking to occupy spaces where conventional RO is not applicable and where incumbent - and typically thermal based - technologies are much easier to beat.

Hence, commercialization of forward osmosis technologies is gravitating towards niche applications, which makes much more sense than aiming for the competitive and - from a membrane point of view - commoditized desalination sector.

How Can Forward Osmosis Improve ZLD Processes?

Contrary to traditional pressure-driven membrane technologies, forward osmosis uses chemical energy in the form of osmotic pressure to drive water transport across a semi-permeable membrane along the osmotic pressure gradient between feed (impaired water source with low solute concentration = low osmotic pressure) and draw (engineered solution with high solute concentration = high osmotic pressure) streams.

Being powered by an osmotic gradient, the energy requirement of water transport across a forward osmosis membrane is up to 90% less than that of reverse osmosis. Hence, FO has traditionally been viewed as a potential low-energy pre-concentration technology in ZLD applications. However, the low-energy ZLD argument only holds in the case where the engineered draw solution is of a sufficiently high osmolarity (above 300,000ppm NaCl equivalent) and can be regenerated through processes with low energy requirements (e.g. thermolytic regeneration using low-grade thermal energy).

In order to decouple the value proposition of FO from engineered draw solutions and regeneration methods, which may or may not turn out to be commercially viable on industrial scale, my suggestion is to start exploring the potential of FO to selectively recover valuable solutes from waste streams.

NF-Type FO Membrane Concept

Conventional FO membranes are designed to extract water from feed streams while rejecting virtually all other compounds. However, by tweaking the pore size of the FO rejection layer using the same piperazine-based chemistry known from Nano-Filtration (NF) membrane technologies, it should be fairly straightforward to achieve FO rejection layers with high rejection for divalent salts (e.g. $MgSO^4$) and low rejection for monovalent salts (e.g. NaCl).

What we end up with then, is an NF-type FO membrane capable of de-watering waste-water streams while simultaneously recovering monovalent salts (e.g. NaCl).

A window of opportunity exists for low-energy technologies capable of concentrating brines from 70,000 ppm to 250,000 ppm. A variety of membrane-based technologies have shown potential in this ppm-range, including Osmotically Assisted Reverse Osmosis (OARO), Membrane Distillation (MD), Electro-Dialysis (ED), and Forward Osmosis (FO). This article focuses on how FO can be utilized to improve ZLD ROI.

In addition, the NF-type FO membrane would likely enjoy a higher water flux and less concentration polarization.

Everything else equal, the added value from the recovered salt should improve overall system ROI. But how much improvement can potentially be gained?

I recently published a desktop study on ForwardOsmosisTech.com based on the work by Vishnu and co-workers ("Assessment of Field Scale Zero Liquid Discharge Treatment Systems for Recovery of Water and Salt from Textile Effluents." Journal of Cleaner Production 16.10 (2008): 1081-1089.).

The desktop study demonstrates clear operational and economic benefits of including an NF-type FO sub-system in ZLD treatment of wastewater from textile dyeing processes.

In conclusion, FO membranes capable of extracting both water and monovalent salts, hold potential for improving ZLD ROI.

Challenge Accepted?

Within today's conservative water industry, commercializing the forward osmosis technologies is very much an exercise in identifying applications with huge customer pains (the low hanging fruits), where current technologies are either not applicable, massively inefficient, or extremely expensive.

The use of forward osmosis for combined dewatering and resource recovery definitely seems to fit the bill. What remains to be done is for commercial players to start developing industrial NF-type FO membranes. Challenge accepted?

Countries at the forefront of imposing ZLD regulations include the United States, China, and India. Whereas the power sectors are the main contributor to the ZLD markets in the United States and China, the textile industry is one of the main drivers in India's ZLD adoption.

About the Author

__Mark Perry__ currently works at the Royal Danish Embassy in Singapore as Commercial Advisor where he mainly assists Danish CleanTech companies in their efforts towards capturing new business opportunities in Singapore.

He has a CleanTech background from heading BD & Sales in Aquaporin Asia Pte Ltd, a Singapore-based CleanTech company. In addition, he has worked as a Membrane Developer, Project Manager, and Business Developer for Aquaporin A/S in Denmark.

He holds a Master's Degree in Physics and Cellular/Molecular Biology from the Southern University of Denmark and an Executive MBA from DTU Business.

He shares his years of experience in forward osmosis membrane development & commercialization on ForwardOsmosisTech.com - the go-to portal for general information on forward osmosis membranes, systems, technologies, and applications. Forward Osmosis Tech's vision is to become the leading independent branch specific portal in the FO field with a clear commercial and application-driven focus and a strong passion for promoting and facilitating open innovation, collaborations, partnerships, and co-developments.