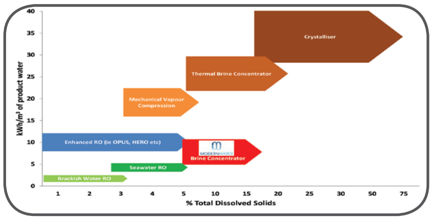
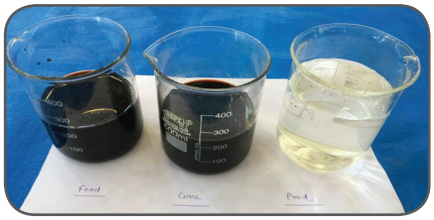
Novel Technology for Concentration of Brine Using Membrane-Based System





Membrane-based brine concentrator is a major technological breakthrough in brine concentration technology that can help reduce the brine volumes and significantly cut down the operating cost of ZLD plants. Read on...

By Soham Mehta & Peter Nicoll

Waste brine, whether from a process or from RO-based recycling or desalination, is a major disposal concern that often necessitates expensive thermal treatment leading to Zero Liquid Discharge (ZLD). Traditional Seawater Reverse Osmosis systems are generally employed to concentrate brines to about 7-9% NaCl equivalent, limited by hydraulic pressure that the membranes can withstand. More recently, some Plate & Frame and Disc-type RO configurations which can withstand much higher pressures than traditional spiral-wound Seawater RO membranes have been developed, but challenges remain in overall system design and sourcing of system components at those high operating pressures, limiting their applications. This paper presents an innovative and novel approach towards brine concentration, developed by UK-based Modern Water plc out of their pioneering work on forward osmosis and osmotically-driven membrane processes, with its first full-scale prototype successfully built and operated in India.

While 'brine' is any water that is salty in a given context, the water industry usually refers to it as the reject water from seawater RO membranes or regeneration liquid from ion-exchange systems, which can not be subjected to further concentration in traditional membrane systems. There is no such generalisation of the word 'brine' in the wastewater industry and it covers the entire spectrum of salinity from cooling tower blow-downs to saturated solutions from production processes in the chemical industries. What is common though to both water and wastewaters is that the effluent disposal standards do not permit any waters higher than 2100 mg/L of Total Dissolved Solids (TDS) to be discharged into surface waters or the land. Higher TDS levels are permitted for marine discharges, but by providing outfalls deep into the sea with properly designed diffusers to dilute the concentrated brine multiple times so as not to adversely affect the marine biota around the disposal point. In either case, disposal of brine is a serious environmental issue, attracting more and more focus from authorities, courts and people at large.

When brine disposal is not permitted or restricted, its treatment starts with the concentration of the brine, followed by the separation of the salts by thermal processes. The simplest and most cost-effective method of brine concentration is to 'desalinate' the brine solution using Reverse Osmosis, after essential pre-treatment to take care of sparingly soluble salts that can scale the membranes or particulate matter that can foul the membranes. The effort always is to maximise the recovery through the RO process in order to reduce the quantity of waste brine reaching the significantly expensive thermal treatment step. With proper pre-treatment and intermediate treatments for removal of sparingly soluble salts, heavy metals and organics, the traditional seawater RO membranes are often used to concentrate the wastewater brines to about 50-70,000 mg/l (5-7%) NaCl equivalent concentration, though theoretical possibility being somewhat higher at 9%. Since the concentrated brine can not be discharged as per Government of India environmental laws, industries rely on thermal treatments like Multiple Effect Thermo-compressor Evaporators or Mechanical Vapour Compressor (MVC) Evaporators to distil out the water from the concentrated brine, thereby yielding wet salt that is then disposed to a secured landfill. Thermal Evaporators are often staged as a first stage Brine Concentrator and second stage Crystalliser – the former using a more economical falling film configuration to concentrate the brine upto saturation level while the latter adopting a scaling-resistant forced circulation regime to precipitate out the dissolved salts from super saturated brine.

The Falling-film Brine Concentrator Evaporator, whether using a thermo-compressor or MVC, works on the principle of formation of a thin liquid film in the inside surface of the heat transfer tube of the calandria. In practice, unless the concentration of sparingly soluble salts and silica is kept below the saturation levels, the film formation is disturbed by scaling of the tubes and the evaporation capacity drops significantly. Concentrated brines are corrosive and hence most often, titanium (Ti) tubes and Ti bonded tube-sheets are used in the calandria and pre-heaters. However, other system components such as piping, valves and recirculation pumps are often not supplied in corrosion resistant exotic metal alloys due to high cost and hence users end up with reoccurring maintenance and replacements. In effect, the Thermal Brine Concentrators require a significant quantity of thermal energy and are often a nightmare to operate continuously and reliably.

Since the operating costs of Thermal Brine Concentrators are many-fold as compared to RO-based brine concentration, a lot of effort has been done to find solutions to reduce the costs. From solar pans to salinity gradient solar ponds, solar stills to psychometric evaporators, or Membrane Distillation to Capacitive Deionisation, much effort has been expended to concentrate the brine from the RO step, but with limited success that has not proved to be techno-economically viable and dependable for commercial usage. Recently, high pressure Plate & Frame and Disc-type RO modules which can handle very high pressures have been developed, that can be used as an additional stage to concentrate the brine. However, getting suitable components for the system as a whole, such as high pressure pumps, valves, piping and instruments are still a challenge, as are the capital and operating costs. The impasse now gets broken with a successfully tested full-scale prototype of an all new non-thermal membrane-based brine concentration technology, developed by UK-based Modern Water plc and built by Advent Envirocare in India.

The membrane-based brine concentration technology has evolved out of the Forward Osmosis - Reverse Osmosis based seawater desalination technology, invented and patented by Modern Water, a process that has been in commercial operation since 2009 at multiple sites, in the Mediterranean and in Oman. Forward Osmosis, or simply Osmosis, is nature's way of attaining osmotic equilibrium when two fluids of different osmotic pressure, or different concentrations of dissolved constituents, are separated using a semi-permeable membrane. Osmosis is a natural phenomenon first scientifically recorded by the French scientist and clergyman Albert Nollet in 1748, while Reverse Osmosis was invented in the 1950s as a method of desalination.

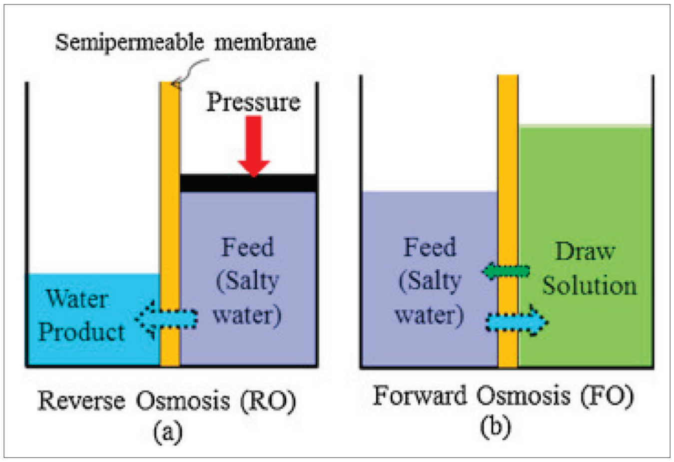


Figure1: RO & FO Concept

Forward Osmosis, on the other hand, has only seen commercial applications in the last decade and is characterised by employing a specific draw solution or osmotic agent to extract water from the feed.

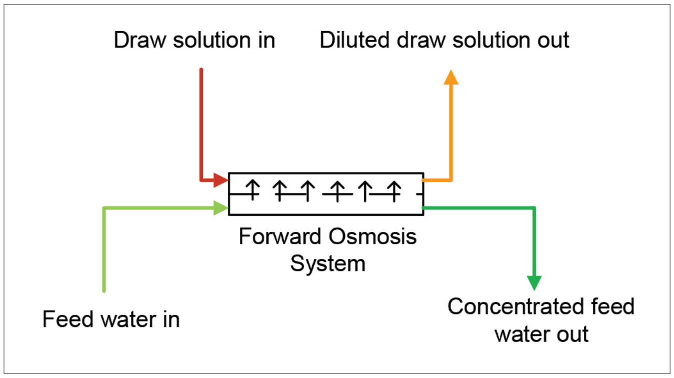


Figure2: Forward Osmosis Process

Desalination using Forward Osmosis employs a Reverse Osmosis step to concentrate back the draw solution or osmotic agent to required strength.

Modern Water has over 100 patents in the field of Forward Osmosis and osmotically driven membrane processes. This expertise, from both a practical and technical perspective, has allowed the development of a new patented process, utilising osmotic principles, specifically aimed at brine concentration. The

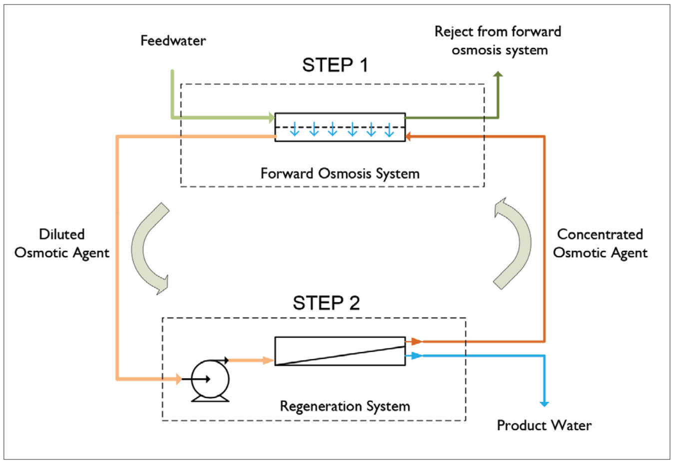


Figure3: FO-RO Desalination Process

RO process in Figure 3 is replaced with this novel process or indeed can be deployed on its own, depending on the nature of the brine to be concentrated. The process uses only electrical energy and does not require any thermal energy or vapour compression. The operating pressures are similar to that of seawater desalination RO systems, and so are all appurtenances such as valves and instrumentation. The pre-treatment requirements for membrane-based brine concentration are similar to that of a RO system, taking care of impurities that can scale or foul the membranes. Chemical dosing and membrane cleaning systems are also similar. Hence this novel process has similarities with conventional membrane plant, is simple to operate and maintain without any additional operating expertise.

The first prototype of the membrane-based brine concentrator was built in India and tested successfully in late 2016 / early 2017 at Ahmadabad (See Figure 4). The containerised system is designed to handle a large range of feed TDS, from 3% to 9% NaCl equivalent. At the lowest feed concentration of 3%, it can handle as much as 75 m3/d of brine. The proof-of-concept trials were conducted with a synthetic feed of 7% NaCl, and achieved 46% recovery resulting in a concentrated brine TDS of 12.65%, all as predicted by the mathematical modelling of the process. Subsequent to the successful proof-test, the system was shipped to a major dyestuff manufacturer for a pilot test on brine generated from a dye-desalting Nanofiltration system. The trials were successful with a feed TDS of 4-5% being concentrated to 13.5%, thereby yielding 67% average recovery. Figure 5 shows the feed, brine and permeate samples from the plant during the large scale pilot testing.

Figure 4: Prototype plant in Ahmedabad

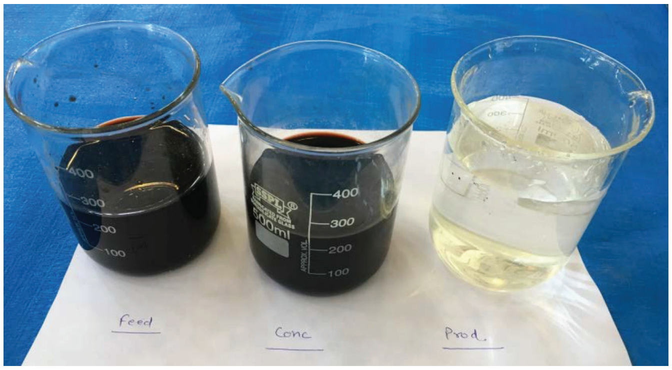


Figure 5: Dye waste water feed, concentrate and permeate

The full scale plant to handle 14 m^3/h brine having 4-5% TDS is under installation and slated to be commissioned in February, 2018. In the meanwhile, pilot trials are ongoing for an agrochemical waste brine having 6-7% TDS, mainly sodium sulphate, with a target concentration of concentrated brine as 16%. Later, the pilot plant will be shipped to a Common Effluent Treatment Plant for trials on water recovery from a brine having 3-4% TDS.

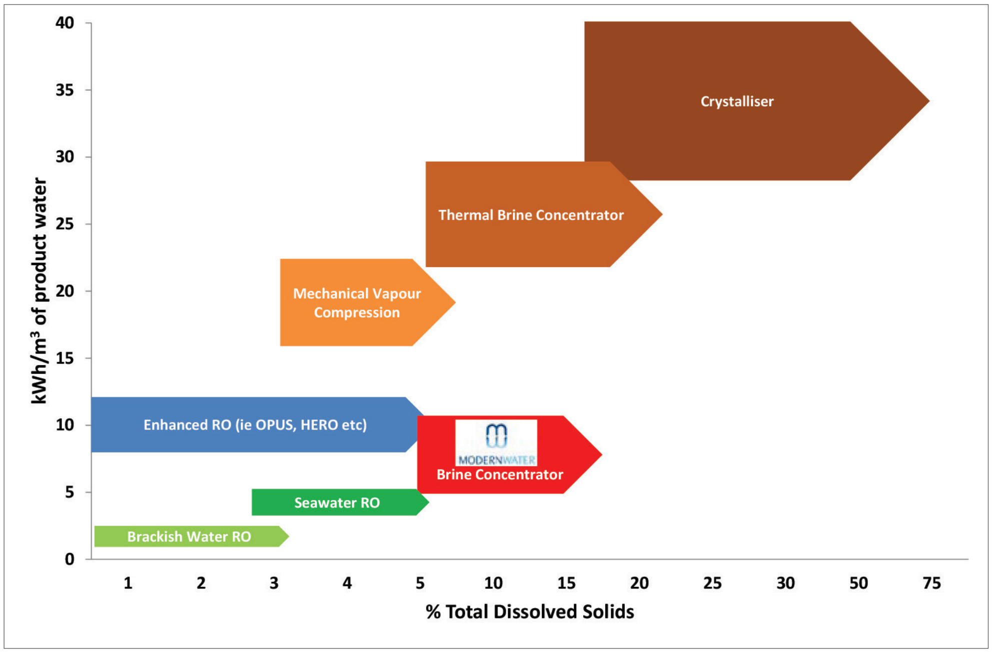


Figure 6: Specific Energy Consumption of Salt Concentration Systems

The membrane-based brine concentrator consumes a fraction of the energy consumed by a thermal brine concentrator or MVC Evaporator. Typical specific power consumption of 7-11 kWh/m3 permeate with the use of energy recovery devices at 7% feed, depending upon the degree of concentration desired. For feeds with TDS lower than 7%, the power consumption would still be less. Compared to this, a triple-effect falling film evaporator would consume roughly 300-350 kg of steam and 18-20 kWh per m^3 of water evaporation. When the steam cost is 20% of the power cost, this translates to 78-90 kWh per m^3 of water evaporation, or 8-11 times more than the membrane-based brine concentrator. Another interesting application of the membrane-based brine concentrator is in seawater desalination projects. It can produce more water from the reject brine that is being thrown back to the sea. This can help facilities expand their production of water without having to invest in expanding intake structures and headworks. In applications where salt production is integral to seawater desalination, the membrane-based brine concentrator is a perfect fit in producing more water from an existing facility while generating a highly concentrated brine of 16%, or even higher with specially designed additional stages of treatment. The membrane-based brine concentrator also finds application in handling mining industry wastewaters and scrubbing liquid in flue gas desulphurisation (FGD) plants, with the first plant of its type currently be constructed for a power station in China.

Concentrator Type	Feed water TDS (mg/l as NaCl)	Max brine TDS (mg/l as NaCl)	Concentration factor	Product water TDS (mg/l as NaCl)	Indicative energy consumption kwh per m^3 of product water
Type 1 (2 stage)	70,000	128,000	1.83	250	10.5
Type 1 (3 stage)	70,000	165,000	2.36	350	14.7
Type 2 (2 stage)	70,000	128,000	1.83	250	6.8
Type 2 (3 stage)	70,000	165,000	2.36	350	11.3
Type 2 are systems incorporating energy recovery systems					

Table: 1 Membrane Brine Concentrator Performance

To summarise, the Membrane-based Brine Concentrator is a major technological breakthrough in brine concentration technology that can help reduce the brine volumes and significantly cut down the operating cost of ZLD plants. It is a non-thermal system using just electrical energy and consumes a fraction of energy as compared to thermal systems. It feels and operates like standard RO systems and does not call for expert operations.

The Membrane Brine Concentrator is not merely a concept in theory, but has been tested successfully with full size membranes and has been deployed in real life situations for elaborate pilot studies, with proven ability to concentrate the brines upto 16% concentration. It can even be deployed at seawater desalination facilities to produce more water from the reject brine, or for treating mining effluents and FGD system bleeds. The Membrane Brine Concentrator exemplifies the "Make in India" enthusiasm that the country has embraced, and addresses the dire need for a cost-effective solution to the challenging brine concentration need of industries.

About the Authors

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Peter Nicoll leads the multi-disciplined technical team at Modern Water plc, where he has been instrumental in the development, design and successful deployment of Modern Water's FO based technologies. He is the inventor of a number of FO and related processes. A graduate of the University of Glasgow, he is a Chartered Engineer and a Fellow of the Institution of Mechanical Engineers. His previous experience includes Director of Business Development for Fichtner Consulting Engineers Ltd where he was responsible for leading the business development and sales functions. He has extensive broad expertise in all the major desalination processes, having held a number of senior roles, both technically and commercially, at Weir Westgarth. He can be reached at peter.nicoll@modernwater.co.uk