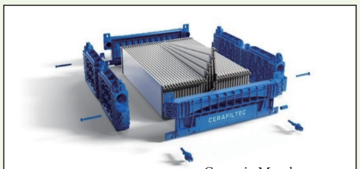
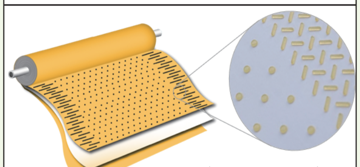
Advanced technologies for Secure & Sustainable Water Supply

Australia, the driest inhabited continent, faces mounting pressures on water security due to climate change, with increasing variability, droughts, floods, and extreme weather events challenging both municipal and industrial water users. Membrane-based treatment technologies, particularly desalination and purified recycled water (PRW), are increasingly adopted as climate-independent sources of high-quality water. However, these processes are traditionally associated with high energy demand, creating tension with the water industry's need to decarbonise in line with national Net Zero commitments. In response to this requirement to reduce the energy consumed in water treatment processes, Osmoflo has been investigating, developing and integrating a range of innovative technologies all designed to reduce the specific energy consumption of the treatment process. Specifically, three recent technologies are described herein, which include (1) a ceramic membrane technology, (2) a unique 3D printed spacer RO (Reverse Osmosis) membrane and (3) a Low Pressure Isobaric Pressure Exchange Energy Recovery Device (LP-PX). The energy savings of the 3 innovative technologies are evaluated and compared against traditional membrane treatment processes at an operational brewery wastewater facility in Queensland, Australia.



Ceramic Membrane



3D Printed Spacer RO membrane

Low Pressure PX (Pressure Exchanger)

Keyword
Advanced Membrane Technology, Desalination, Reverse Osmosis, Water, Energy, Carbon, Energy Recovery

Increasingly Water Utilities and Industries are turning to "Climate Independent Sources" to secure water supplies as the effects of climate change cause stress to existing catchments and infrastructure. Desalination – whether it be from Seawater or brackish water sources (which can include tertiary Treated Effluent or as is now often called Purified Recycled Water of PRW) is a known and robust technology that is well suited and commercially available technology that can meet this need immediately. However, it is also an energy driven process, and if the power is supplied from predominantly fossil fuel-based generators or grids, then the carbon dioxide emissions must be considered in an increasingly carbon constrained world.

Three innovative technologies have been selected and propose to offer significant reductions in the Specific Energy Consumed or required to desalinate a given source. These three technologies are described below:

- **Ceramic filtration** which are robust, rigid filtration media used in submerged MF(Micro Filtration)/UF(Ultra Filtration) applications. The membranes are typically manufactured from aluminium oxide (Al_2O_3) flatsheets or silicon carbide (SiC). The membranes are very hydrophilic with a low contact angle (~30° for Al_2O_3), and high voids volume, both resulting in high permeability (1500-3000 LMH/bar) and consequently operate at lower transmembrane pressure (TMP) (typically 0.05 to 0.2 bar) when compared with traditional polymeric MF/UF, resulting in lower pumping energy requirements.
- **3D-Printed Spacer** technology to replace traditional mesh feed spacers that have been used for decades as a rudimentary device for flow turbulence and mixing in RO elements. Printed spacers function with reduced energy losses along the element, and enable increased element surface area. This provides significantly improved performance, demonstrating a range of benefits from reduced energy consumption (~20%) and fouling (and the associated chemical consumption), to increased plant capacities (~20%).
- **Low Pressure, Isobaric Pressure exchanger (LP-PX)** for recovering energy from brackish

water brine waste streams and reducing energy requirements by up to 22%.

■ Outline of device / Purpose

Ceramic membranes in collaboration with Cerafiltec

Osmoflo has made use of Cerafiltec's submerged ceramic membrane modules that utilise flat-sheet elements made from Al_2O_3 or SiC. Unlike pressurised polymeric MF/UF systems, these modular systems combine multiple ceramic plates to form towers which are immersed directly in the feedwater tank (**Figure 1**). Suction/vacuum is applied through the membrane to draw filtrate at relatively low driving pressure. The plates are periodically backwashed using filtrate and periodic coarse bubble aeration/ scouring helps to control fouling. The plates are chemically cleaned as required.

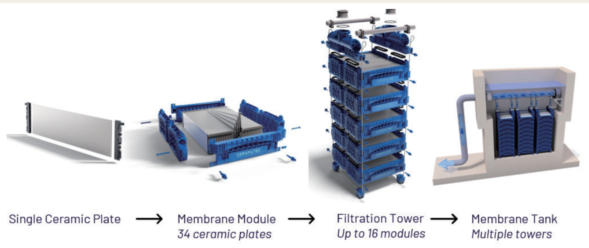


Figure 1　Ceramic membrane system- modular design

The intrinsic properties of the ceramic plate results allow a more energy efficient process as the ceramic plate is very hydrophilic and highly permeable (1500-3000 LMH/bar) and therefore able to operate at high flux (150-350 LMH). The plates also operate at relatively low TMP (typically 0.05 to 0.2 bar) due to the high voids volume and relatively thin membrane coating compared with the membrane body/substrate (**Figure 2**).

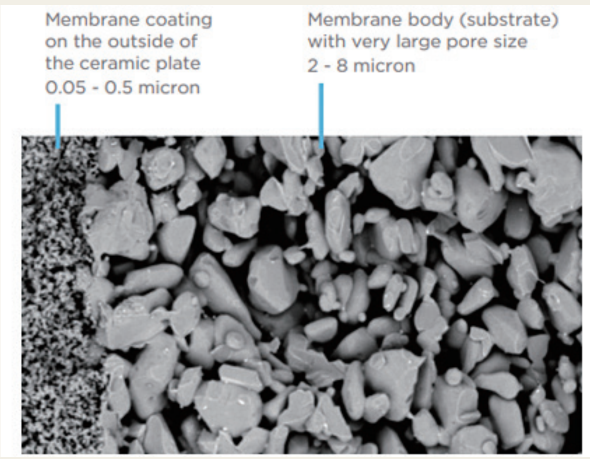


Figure 2　Ceramic membrane microstructures

The ceramic systems have demonstrated:

- **Mechanical and chemical durability**: The membranes can withstand extreme pH ranges, oxidants and abrasive particles, enabling more aggressive cleaning and longer membrane life.
- **Lower energy demand**: Low TMP operation relying instead on modest suction and aeration. This reduces overall specific energy consumption for filtration.
- **Stable flux and recovery**: Ceramics maintain high permeability and resist irreversible fouling, resulting in fewer cleanings and stable TMP.
- **Compact and resilient**: Higher packing density and tolerance to feedwater shocks (suspended solids, turbidity spikes) reduce the need for costly pre-treatment steps.

3D printer spacer RO membranes in collaboration with Aqua Membranes

3D Printed Spacer technology replaces the plastic 28- or 34-milli-inch mesh spacer used in the feed-brine channel of commercial reverse osmosis (RO) membranes. Standard mesh spacers have been ubiquitous in desalination since the development of the spiral wound RO element in 1964 by General Atomics.

Osmoflo commenced piloting of elements with 3D printed spacers in 2023 and has since leveraged their benefits in numerous full-scale systems.

The optimization involves 3D printing of the spacer (light reactive resin "dots" of specific patterns) directly onto commercially available flat sheet membrane. These dots act as integrated spacers, creating controlled micro-channels in the feed path. The patterns can vary in size, shape, and density depending on the target hydraulic conditions. The printed spacer demonstrates:

- **Improved Hydrodynamics**: The flow distribution across the membrane surface is optimised, reducing dead zones where fouling and concentration polarization would normally occur.
- **Turbulence promotion**: Localised mixing is promoted without the high pressure drop associated with conventional mesh spacers.
- **Channel height definition**: The dots set the

exact gap between adjacent membrane leaves, ensuring consistent feed channel thickness and predictable hydraulics.

- **Increased membrane surface area**: The printed design allows for approximately 20% more membrane area to be packed inside a commercial spiral-wound RO element.

The benefits when compared to conventional mesh feed spacers include:

1. **Reduced pressure drop (ΔP)**: Flow channels are more open and uniform, lowering energy requirements across the element by ~10%.
2. **Higher net driving pressure (NDP)**: With lower ΔP losses, more of the applied feed pressure is available for water permeation, which improves flux balance across the RO array/stages.
3. **Improved fouling resistance**: Better mixing and the ability to operate at higher cross flow velocity limits biofilm growth and scaling by minimising stagnant zones (**Figure 4** and **Figure 5**).
4. **Energy savings**: In full-scale installations, these membranes have shown reductions in specific energy consumption (SEC) compared with standard mesh spiral-wound RO.

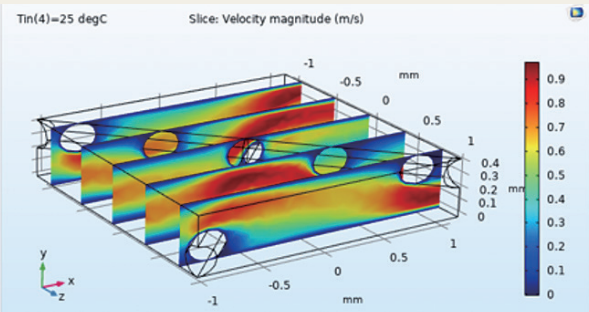


Figure 3 CFD model of feed flow velocity in mesh elements

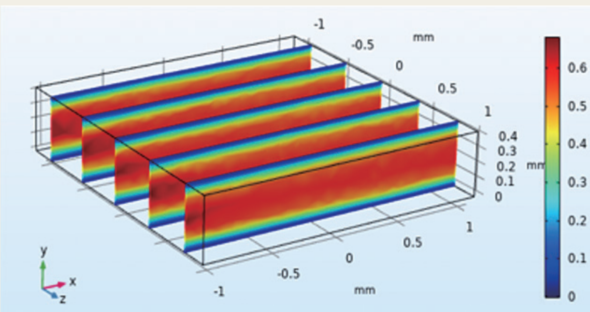


Figure 4 CFD model of feed flow velocity in printed elements. Less obstruction to flow and thinner channel results in increased velocity

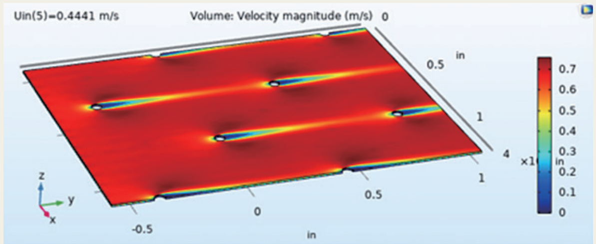


Figure 5 CFD model showing very small areas of low flow behind the printed dots

Low Pressure-PX (Pressure Exchanger) in collaboration with Energy recovery Inc. (ERI)

The low-pressure PX is an isobaric energy recovery device designed for brackish water reverse osmosis (BWRO) systems operating at pressures up to 31 bar. Demonstrating typical isobaric efficiencies exceeding 95%, it achieves 20–30% reductions in SEC making it highly applicable for both municipal and industrial plants to deliver cost-effective and sustainable water production and reuse.

The PX transfers hydraulic energy directly from the pressurised brine stream to the low-pressure feed stream without converting it to mechanical shaft work. The core of the PX consists of a cylindrical rotor with multiple longitudinal ducts that rotates inside a sleeve (**Figure 6**).

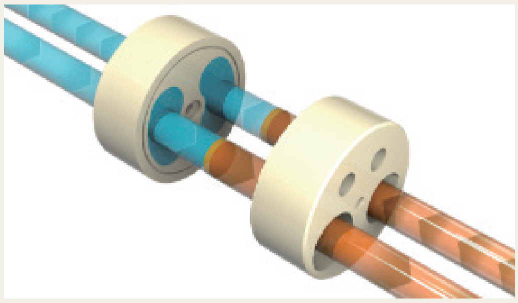


Figure 6 PX Rotor

As the rotor turns, each duct alternately connects to the high-pressure brine port and the low-pressure feed port. Brine enters and displaces the feed water inside the duct, transmitting pressure almost instantaneously through direct fluid–fluid contact. In the subsequent half-rotation, the duct aligns with the feed discharge port, expelling the now pressurised feed stream toward the RO membranes. This continuous switching enables near-isobaric pressure transfer with minimal energy loss.

Although brine recovery efficiencies can exceed 98%, there are some minor losses in energy (internal leakage, mixing and hydraulic losses), these reduce the overall PX efficiency to ~92–95% in practice.

In a classic configuration (**Figure 7**), the PX unit is typically used together with a circulation (booster) pump. As the PX unit transfers pressure but not net flow, the volumetric feed flow exiting the PX must be balanced with the brine flow entering it. The small high-pressure circulation pump is therefore used to equalise pressure differences and provide make-up flow, ensuring stable operation and maintaining the target pressure to the RO membranes.

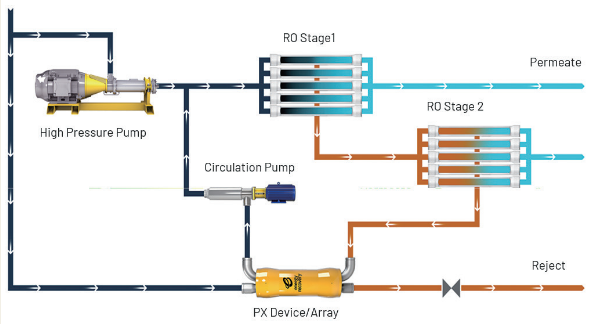


Figure 7　LP-PX in classic configuration

Specification / Case study

Brewery wastewater plant

Osmoflo have an existing RO followed by an Osmoflo Brine Squeezer (OBS) asset at Carlton and United Breweries in Yatala, QLD. The OBS is used to further concentrate the brine or reduce the volume of Brine being discharged to sewer from site. These are the final stages of a multitude of treatment steps in the brewery wastewater processing plant, which includes a polymeric MF system followed by the RO and OBS. The Wastewater facility has the ability to recover up to 4 MLD, and makes the brewery one of the most water efficient in the world. (**Figure 8**).

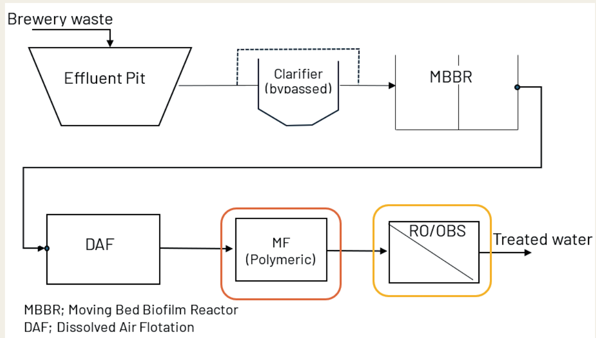


Figure 8　Process Flow Diagram – Brewery wastewater plant

A ~40.4 % reduction in MF/RO SEC can be realised if:

- The existing polymeric MFs are replaced with a submerged ceramic system utilising Cerafiltec Al_2O_3 membranes.
- The existing RO membranes are replaced with Aquamembranes (AQM) (3D printed spacer)- Model AM-BW505- ECO1.0
- The RO trains are modified to include an LP-PX L140 with a small circulation pump in a classic configuration.

The existing polymeric MF system is estimated to have a SEC of 0.13 kWh/m^3 of filtrate produced. The implementation of the ceramic system will reduce this to 0.04 kWh/m^3 due to:

- Primarily, the significant reduction in pumping energy requirements (higher permeability membrane, lower TMP operation)
- No requirement to heat the CIP (Clean in Place) solution
- The use of positive displacement pumps which operate more efficiently.

The replacement of the conventional RO membranes with 3D printed RO modules will result in a ~12% reduction in RO SEC from 0.72 kWh/m^3 to 0.62 kWh/m^3.

This reduction is primarily due to the reduction in feed pumping requirements, reducing by ~12.8% (feed pressure 15.2 bar vs 13.26 bar) and the RO ΔP across both RO stages decreasing by ~44% (1.5 bar vs 0.84 bar). This is considered a conservative reduction as empirical evidence would suggest that the existing system suffers from high rates of organic fouling, necessitating frequent chemical cleaning, and operates for extended periods at significantly higher DP's. Reduced fouling rates expected from the use of 3D Printed spacers will likely translate to further energy reductions in an operational mode, and testing is currently underway to validate this differential.

Taking this a step further, the brine stream exiting the RO still has considerable energy that can be recovered. By incorporating a LP-PX (L140 for this application) to recover a large portion of energy form this waste stream, the RO SEC can be further reduced to 0.48 kWh/m^3, reducing the overall plant SEC to 0.53 kWh/m^3 and a reduction of 156 tonnes/year in CO_2 emissions (**Figure 9** and **Figure 10**).

Figure 11 shows the Sankey diagram for the power to permeate production for the current RO process.

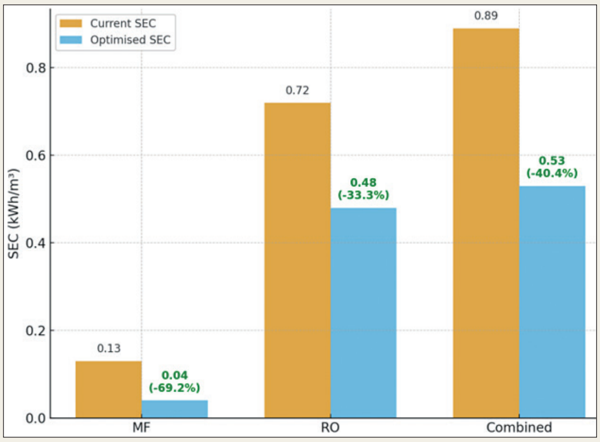


Figure 9　SEC reduction

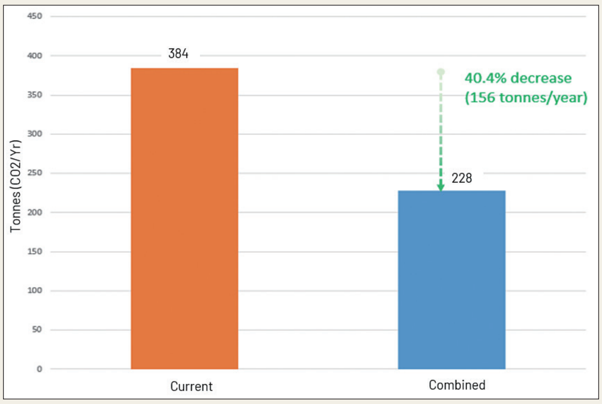


Figure 10　CO_2 emissions

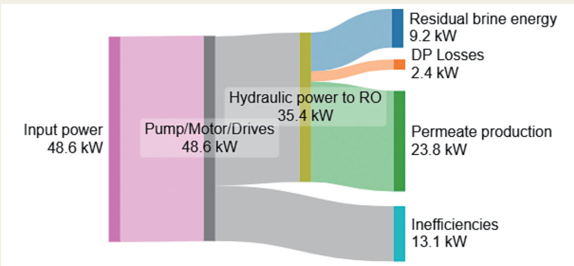


Figure 11　Sankey diagram for power to RO permeate

Figure 12 shows the Sankey diagram for the power to permeate production with the implementation of the AQM 3D printed spacer membranes and the incorporation of the LP- PX for energy recovery from the brine stream.

In comparison to the base case (**Figure 11**), there is a reduction in permeate energy requirement (21.54 kW vs 23.8 kW) due to the increased surface area in the AQM membrane modules in addition to reduced RO ΔP losses from the improved hydrodynamics (1.35 kW vs 2.4 kW).

A significant portion of the residual brine energy is also recovered by exchanging it into a portion of the raw feed stream, reducing the input power requirements from 48.6 kW to 32.02 kW.

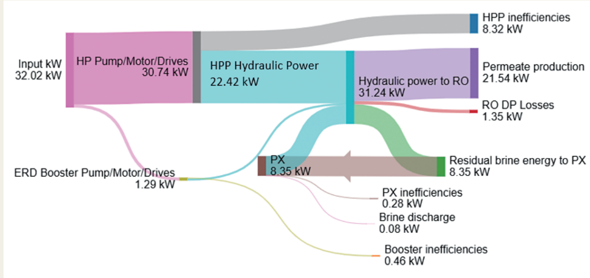


Figure 12　Sankey diagram for power to RO permeate with the implementation of advanced technologies

Conclusion

Membrane based water treatment technologies are increasingly deployed to secure Climate Independent sources, however they are traditionally associated with high energy requirements. With all sectors of the economy now required to decarbonise to meet Global Paris Agreement obligations, federally legislated reductions and Net Zero aspirations, businesses and governments alike must consider innovative technologies in order to deliver to the clients, and expand their asset base of water treatment facilities, whilst not exacerbating the problem associated with high energy use and proportional carbon emissions.

As detailed herein, and as applied to a brewery wastewater facility in Queensland, the application of 3 new innovative technologies can reduce the Specific Energy Consumption by >40%. These technologies include a highly permeable and robust ceramic pre-treatment membrane, an alternative 3D printed spacer developed for existing RO membranes and modules, and a low pressure Isobaric Pressure Exchanger or Energy Recovery Device. Respectively the Specific Energy Consumption savings of each technology are 0.09 $kWhr/m^3$, 0.10 $kWhr/m^3$ and 0.14 $kWhr/m^3$ - which translates to a CO_2 emission reduction also > 40% (or about 156 tonnes/annum at this site)

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