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Ten years operation of ultrafiltration and reverse osmosis in the Limassol Desalination Plant in Cyprus – challenges and performance

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ABSTRACT

The Episkopi integrated ultrafiltration (UF) and reverse osmosis (RO) seawater treatment plant is located in the district of Limassol (Cyprus) and is operated by MN Limassol Water Company (a consortium of Mekorot Development & Enterprise Ltd., Israel and Netcom Ltd., Cyprus). The plant was designed to produce 40,000 m^3/d of permeate with a boron content below 0.5 mg/L and total dissolved solids content below 420 mg/L. The facility uses DuPont™ ultrafiltration (UF) and DuPont™ FilmTec™ reverse osmosis (RO) membranes as core desalination technology and DuPont™ AmberLite™ PWA10 boron selective resin as a polisher to help meet the strict boron quality requirements. The DuPont™ ultrafiltration system consists of 6 UF trains, each with 176 DuPont™ IntegraTEC™ ultrafiltration SFP-2880 modules. UF filtrate is stored in a tank. After the tank, the water passes through 100-micron strainers and feeds 5 seawater reverse osmosis trains. Each of these trains contains 120 pressure vessels with 8 elements. The pressure vessel configuration consists of an internally staged design with 4x FilmTec™ SW30XHR-440i and 4x FilmTec™ SW30HRLE-440i elements each. The system operates in permeate split mode. The rear portion of the RO permeate is sent to an ion exchange system for selective boron removal. The product water is mixed with the front permeate and is finally polished in a remineralization system. The plant was commissioned in 2012 and, after a period in standby, it was put in operation in 2014. During the 11 y of plant operation, the plant operated at variable capacity with some prolonged periods of shutdown. This paper will present the strategy and techniques that were implemented to preserve UF and RO elements during long-term shutdown periods and the performance of both UF and RO membranes during the 11-y period. Additionally, the ultrafiltration system is now experiencing partial renovation using high permeability IntegraTEC™ ultrafiltration SFP-2880 XP (with XP fibers). The benefits of using XP fibers will also be presented.

Keywords: Seawater; Membranes; Brine recovery; Brine mining; Sustainability development goals

1. Introduction

Water scarcity is recognized as one of the main threats that mankind is facing globally [1]. Reverse osmosis (RO) membrane technology has developed as a promising solution to address this problem, holding roughly 44% market share, and growing among all the desalinating technologies [2]. This increase has been driven as materials are improved, and costs dropped [3].

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The world is currently facing water scarcity issues, which are aggravated by population increase and economic development [4]. All these factors, together with the favorable energy-to-product quality ratio that seawater reverse osmosis (SWRO) offers, have situated this technology as one key driver to sustaining population living standards in Middle East countries [5].

Cyprus is the third-largest and most populated Mediterranean island, with 1.2 million inhabitants. It has a great mixture of culture, beautiful coastal landscapes and amazing gastronomy. Cyprus is classified as a water-poor island as it suffers from a very high level of water stress, particularly during years of excessive drought due to the former heavy reliance on rainfall as the main source of water supply.

The two main water consuming sectors in Cyprus are irrigation and domestic use. This can be shown in Table 1 and in Fig. 1. In 2018, agriculture accounted for 64% of the total water use. Domestic and tourism accounted for 21.4 and 6.7%, respectively. The total water demand in Cyprus was 302.3 million m^3 in 2018 and it is estimated that by 2025 water demand will increase to 313.7 million m^3 mainly because of the increasing use of domestic water and the expansion of tourism [6].

To meet this demand, Cyprus used to rely heavily on precipitation, the exploitation of dams and seawater desalination. However, the intermittent rainfall, the increase in population, tourism, and climate change incentivized Cyprus to close the gap between the demand and supply with the construction of additional dams, the start of sewage recycling for irrigation, the implementation of water conservation campaigns and the construction of new desalination plants [6].

Currently, the desalination plants supply around 50% of the domestic water in Cyprus. Therefore, this paper will detail some key attributes of one of the key desalination plants in Cyprus, the Limassol plant [6].

2. Methods

2.1. Limassol desalination installation

The Limassol desalination plant was built and operated by MN Limassol Water Company. The plant was started up in 2012 and has a capacity of 50,000 m^3/d. An aerial view of the plant can be seen in Fig. 2, while the plant quick facts is summarized in Table 2 [7].

The plant configuration is described next, and it is summarized in Fig. 3. The seawater from the open intake passes through a 300 μm strainer to the DuPont ultrafiltration modules. The filtrate water goes to the one pass SWRO which contains DuPont™ FilmTec™ elements. The rear permeate finally goes to a boron selective removal IER system so that the mixed permeate meets the strict permeate water quality requirements at all the applicable temperature conditions.

Limassol feed and permeate water quality parameters are described in Table 3.

Table 1
Water demand in Cyprus in 2018

Sector	Water demand (millions m^3)
Agriculture	193.47
Domestic	64.69
Tourism	20.25
Industry	8.77
Environment	15.12
Total (Mm^3)	302.3

2.2. Ultrafiltration system

The ultrafiltration system is arranged in six skids, with 176 modules per skid operating at a design flux of 65 LMH and 94% recovery. The unit operates so that when one skid goes into a cleaning regime, the others compensate the production to keep the amount of filtrate water constant. Due to the plant's design, the modules were occasionally operated under very long filtration cycles.

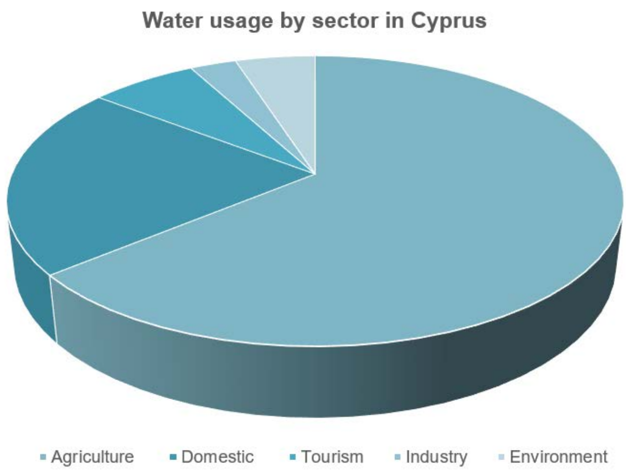

Fig. 1. Water usage by sector in Cyprus.

Fig. 2. Air view of Limassol desalination plant. Courtesy of MN Limassol Water Co.

Table 2
Quick facts of Limassol desalination plant

Location	Limassol, Cyprus
Construction	MN Limassol Water Company, Cyprus (Consortium formed by Mekorot Development & Enterprise Ltd., Israel, and Netcom Ltd., Cyprus) Sub-contractors: - Nirosoft Industries Ltd., Cyprus (UF/RO system design and construction) - Treitel Chemical Engineering Ltd., Cyprus (Boron selective IER system design and construction)
Operation	MN Limassol Water Co.
End-user	Water Development Department of Cyprus
Water source	Sea water (open intake)
Plant capacity	50,000 m^3/d drinking water
Start-up	2012

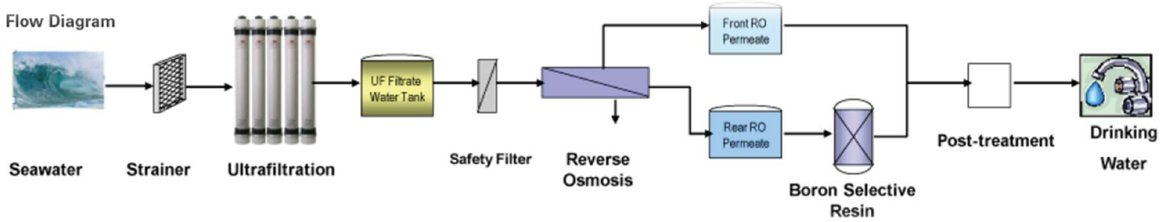

Fig. 3. Limassol desalination plant schematics.

Table 3
Limassol feed and permeate water quality parameters

Parameter	Feed water quality	Permeate water quality
Temperature	16°C–30°C	
Total dissolved solids	41,000 mg/L	≤420 mg/L
pH	8.1	
Boron	5.1 mg/L	≤0.5 mg/L
Turbidity	<15 NTU	
Total suspended solids (TSS)	<15 mg/L	

The modules are made of polyvinylidene fluoride (PVDF) fibre. This material offers high fouling and oxidation resistance and high recovery through the lowest backwash water needs due to the outside-in configuration, diversity, and adaptability through different fibre designs and module sizes. A scanning electron microscopy image of a hollow fibre cross-section can be observed in Fig. 4.

2.3. Reverse osmosis system

The reverse osmosis system consists of five seawater reverse osmosis skids with 120 pressure vessels, each vessel containing 8 reverse osmosis membranes, producing in total 50,000 m^3/d of desalinated water. The seawater reverse osmosis water recovery is set to 45%. It is worth noting that no second pass is needed as there is a boron selective ion exchange (IER) resin that enables the plant to meet its designated boron target in the produced water. This is achieved with an innovative system that consists of a front and rear permeate water split, where only the needed water is sent to the boron selective resin through the permeate rear split. The reverse osmosis system diagram can be seen in Fig. 5. A picture of the installation can be found in Fig. 6.

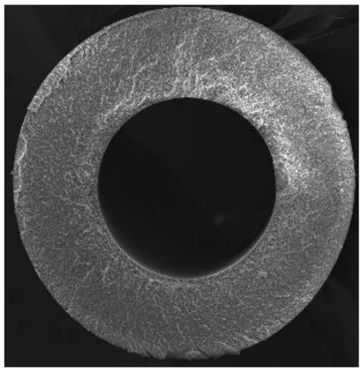

Fig. 4. Scanning electron microscopy image of a hollow fiber cross-section.

3. Results

3.1. Ultrafiltration results

The Limassol plant has been up and running since 2012. During for this full period, the plant operated at variable capacity with some prolonged periods of shutdown, with the longest one occurring during 2020 and half of 2021. This was due to a temporary decrease in the demand as COVID-19 pandemic hit. Throughout this time,

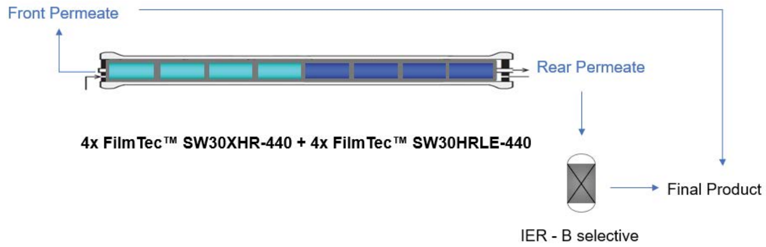

Fig. 5. Reverse osmosis system diagram.

Fig. 6. Photo of the Limassol installation.

Fig. 7. Transmembrane pressure and chemical enhanced backwashes evolution over time in the ultrafiltration installation.

the modules were preserved in 1% sodium metabisulfite (SMBS) to protect them against fouling growth. The initial transmembrane pressure (TMP) of the system at start-up was 0.43 bar and after 11 y the average TMP value of the overall plant is 0.81 bar. Although this value is twice the initial TMP value, it is nevertheless a very modest increase. However, upon examination of the average number of chemical enhanced backwashes (CEB) per year during the latest years of operation, it is possible to observe a significant increase in 2022, which is an indication of the presence of irreversible fouling. This TMP from 0.43 bar during the start-up, to 0.81 is a remarkable achievement after more than 11 y of operation. The evolution of TMP over time, together with the CEBs performed can be observed in Fig. 7.

As a key takeaway, it can be concluded that IntegraTEC™ SFD-2880 UF modules have been in operation for more than 11 y with long filtration cycles producing the required capacity. Also, the IntegraTEC™ SFD-2880 UF modules have delivered expected filtrate water quality over the 11 y of operation. Finally, PVDF fibres showed outstanding robustness over more than 11 y without replacements in the ultrafiltration system.

3.2. Ultrafiltration replacement study

A new type of ultrafiltration membranes called IntegraTEC™ SFD-2880 XP membranes are studied to replace the 11-year-old membranes. These membranes offer the benefits of providing 35% higher permeability fibers than standard DuPont UF fibers, having a higher pore density, smaller pores, new PVDF fiber formulation, as well as having the same module format using proven module and skid configuration. A picture of these modules can be found in Fig. 8.

The study of the advantages of this replacement is depicted in Table 4. From this study, it can be observed that if the ultrafiltration plant is upgraded with DuPont™ IntegraTEC™ SFD-2880 XP membranes, this will enable the plant to either increase its production by 22%, or lower its energy consumption by 22%, or reduce the plant footprint by 20%. This will provide considerable savings to the plant, depending on the factor that is to be prioritized in optimizing.

The Limassol desalination plant is planned to be in operation for at least an additional 10 y. If the ultrafiltration membranes were to be upgraded with the new DuPont™ IntegraTEC™ SFD-2880 XP membranes starting in the year 2023 according to the scheme detailed in Table 5, this will enable a decrease in the average membrane age (AMA) from 10 y down to 2.8 in 2026, going back to 8.8 on year 2032. The evolution of membrane age over time can be better visualized in Fig. 9.

3.3. Reverse osmosis results

Thanks to the split design of the Limassol plant, it is possible to meet boron requirements across the yearly range of ambient temperatures. This can be observed in Table 6, where after more than 10 y of operation, boron concentration in the produced water is at 0.48 mg/L, which is below the plant target requirement of 0.5 mg/L. Also, the permeate produced has a total salinity of 312 mg/L, which is also below to the plant requirement of being below 420 mg/L. Since FilmTec™

Table 4
Benefits of upgrading the ultrafiltration membrane system with DuPont™ IntegraTEC™ SFD-2880 XP membranes

Case	SFD-2280 (standard fiber)	SFD-2280XP (new fiber)
Higher production (same number of elements and same footprint)	3,900 m^3/h (176 modules/skid)	5,000 m^3/h (+22%)
Lower energy consumption (same production and same number of elements)	0.46 bar (17°C)	0.36 bar (17°C) (–22%)
Lower footprint (same production an same TMP)	176 modules/skid	140 modules/skid (–20%)

Table 5
Replacement strategy for the ultrafiltration membranes

	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Skids replaced	0	2	2	1	1	0	0	0	0	0	0
Average age of the plant	10	7	4.3	3.5	2.8	3.8	4.8	5.8	6.8	7.8	8.8

Fig. 8. DuPont™ IntegraTEC™ SFD-2880 XP module.

Table 6
Reverse osmosis operating results

	Real data (after 10 y)	Expected performance
Flow factor	0.75	0.7 (A.M.A.* > 4 y)
Feed pressure (bar)	62.5	63.6
Blended total dissolved solids (mg/L)	312	<420
Blended boron* (mg/L)	0.48	<0.5

*A.M.A.: Average membrane age.

reverse osmosis elements with internally staged design (ISD) and split permeate configuration, as well as the use of a boron selective ion exchange resin, provide the required capacity and permeate water quality across the yearly temperature range, there is no need to have a second pass.

4. Conclusions

This paper highlights the combined performance of DuPont ultrafiltration and reverse osmosis combined outstanding performance. It showed how DuPont™ IntegraTEC™ SFD2880 ultrafiltration modules have

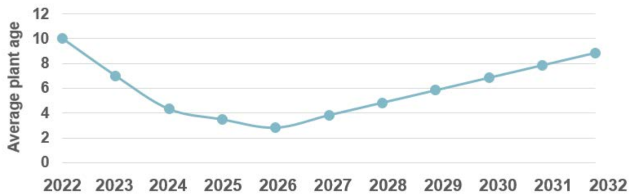

Fig. 9. Evolution of ultrafiltration membrane plant average membrane age as membranes get replaced.

operated for more than 11 y with long filtration cycles producing the required capacity and filtrate water quality. It also highlights that PVDF fibres showed outstanding robustness over 11 y without replacements. Finally, the use of FilmTec™ RO elements with ISD design and split permeate configuration provides the required capacity and permeate water quality throughout the year, regardless of temperature, without requiring a second pass.

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