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A new generation of multi-capillary polyethersulfone membrane

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ABSTRACT

The ever-increasing demand for producing drinking water from seawater triggered the development of competitive and advanced pretreatment for seawater reverse osmosis desalination plants. Ultrafiltration as a pretreatment has been optimized to compact design utilizing multi-capillary polyethersulfone (PES) membrane, whereas the DuPont™ Multibore™ membrane with seven capillaries has been employed in numerous large-scale applications with proven durability. The next generation of PES membranes has now been developed: a multi-bore PES membrane with 19 capillaries and an inner diameter of 0.7 mm, called DuPont™ Multibore™ PRO, within the recently launched DuPont™ IntegraTEC™ ultrafiltration portfolio. This new membrane geometry enables more membrane surface area per module, decreasing the number of required modules, hence decreasing the overall physical footprint for membrane modules by up to 17%. As a result, less material usage per m^2 membrane surface area is needed to have a positive sustainability impact on module production, transportation, as well as end-of-life handling, leading to a significant overall reduction of the CO_2 footprint. This study presents the results of the DuPont™ Multibore™ PRO being operated in a surface water and a seawater application. The surface water site is at a river in Germany. The seawater site is located at the Gulf in Qatar. This paper presents results of evaluation tests performed at these two locations with a multi-capillary ultrafiltration membrane. All results show comparable performance in terms of reversible fouling, chemical cleaning pattern, recovery, filtration flux and overall stable operation. At the surface water site, coagulant employed in the same concentration for the DuPont™ Multibore™ with 7 capillaries as for the DuPont™ Multibore™ PRO. Here, the feed water quality fluctuations in terms of turbidity are significantly higher compared to the seawater sites reflecting more stressful operating conditions. Additionally, the organic background level is higher with 5–8 mg/L dissolved oxygen carbon at the river water site. Polyaluminium chloride-based coagulation captures organic components which are then retained by the membranes. Due to the very unfavorable interactions with PES membrane surfaces, the fouling layer of coagulant is completely reversible during backwashes.

Keywords: Polyethersulfone ultrafiltration, Multi-capillary, Coagulation, Seawater, Surface water

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1. Introduction

Multi-capillary ultrafiltration membranes such as the Multibore™ from the DuPont™ IntegraTEC™ portfolio have been shown to produce constant water quality for supplying subsequent reverse osmosis membranes independently from fluctuations in feed water quality such as turbidity fluctuations [1–4]. At the same time, the ultrafiltration needs to be economically competitive. The footprint of the ultrafiltration system is closely related to the number of modules needed for a given design. Thus, the packing density representing the membrane surface area per m^2 floor space required is of outmost importance. With a higher membrane surface area per module, fewer modules are needed resulting in a lower demand for space for the ultrafiltration system.

In the history of membrane and module development, packing density and footprint have always been the focus of enhancements. These improvements could mainly be achieved by optimizing the module and membrane design in terms of module diameter, module length, optimized fiber geometry, and an integrated rack design such as the DuPont™ IntegraTEC™ T-Rack™ rack system [5]. The next generation of modules will be based on 19-capillary fibers with an inner diameter of 0.7 mm, allowing the modules to hold 19% more membrane surface area per module.

This study attempts to demonstrate the performance of multi-capillary fibers with 19-capillaries based on results from two pilot units being fed from a seawater site, and a river water installation at its optimal operating conditions achievable in the presence and absence of coagulation as a pretreatment process.

2. Material and methods

The ultrafiltration (UF) modules used for the study contain Inside-Out DuPont™ Multibore™ fibers with seven and nineteen capillaries. The capillary inner diameter of the DuPont™ Multibore™ fiber with seven capillaries is 0.9 mm. The capillary inner diameter of Multibore™ consisting of nineteen capillaries is 0.7 mm, called MB PRO, with MB standing for Multibore™.

The inner surface of each capillary (internal diameter of 0.9 or 0.7 mm) represents the very thin active filter surface with a pore size of approximately 20 nm. These differences in the numbers of capillaries and diameter can be observed in Fig. 1. Between the capillaries is the foamy supporting structure which has a permeability approximately 1,000 times higher than that of the membrane surface. This ensures an even distribution over the entire cross-section of the fiber. In addition, this unique structure allows a very high stability of the membrane; this is applicable for both Multibore™ geometries. . Details on the structure of the Multibore™ membrane re can be found in Fig. 2

The material of the ultrafiltration membrane is modified polyethersulfone with a high pH tolerance of 1–13, which enables efficient cleanings even under extreme conditions.

There are three module types employed in this study. One is a pilot-scale module with 6.5 m^2 [for both types of Multibore™ fibers. The pilot unit in Qatar is equipped with two module types being equipped with the DuPont Multibore™ PRO. One line is operating with the vertical MB PRO 95 TR module, containing 95 m^2. The other line is equipped with the horizontal 8″ MB PRO 46 H with 46 m^2.

The pilot plants used for the tests were provided by inge GmbH (now IntegraTEC™, both DuPont brands). All units are fully automated and are equipped with a 200 µm self-cleaning disc filter to prevent sharp particles from entering the modules, feed and backwash (BW) pumps with variable-frequency drives to enable constant flow rates, feed and filtrate holding tanks, chemical dosing pumps (coagulant, acid, caustic and chlorine) as well as various measurement devices (pressure sensors, pH and temperature pzrobes, turbidity and flow meters) and automatic data logging.

Unit A, employed at the river water site in Eching at Lake Ammersee, is a small technical scale unit equipped with the 6.5 m^2 modules for the DuPont™ Multibore™ and the DuPont™ Multibore™ PRO membranes. During high flood events, the inlet pump needs to be taken out of the river stream to avoid irreversible damage to the inlet system leading to subsequent downtime. The unit operates with one feed pump supplying the subsequent lines with feed water whereas the coagulation is dosed centrally prior to the feed pump enabling a proper mixing within the pump. Each line employed in this study is flow-controlled individually allowing a comparison at same flux conditions and equal resulting recoveries for all studied lines.

Unit B, employed at the seawater site in Qatar, is a full technical scale pilot unit. It is part of a large seawater RO-based desalination plant in Qatar with a total capacity of several hundred megaliters per day (MLD) for the horizontal UF. All modules in this pilot unit are equipped with DuPont™ Multibore™ PRO fibers. One line is equipped with 4 of the 8″ type module with 46 m^2 (MB PRO 46 H) installed in a horizontal pressure vessel resulting to 192 m^2. A second line is equipped with a vertical module with 95 m^2 (MB PRO 95 TR). The seawater is constantly supplied and pretreated with dissolved air flotation (DAF). After pre-screening the feed water is collected in a feed tank. Separate pumps draw the water from individual suction lines out of the feed tank to the membrane modules. Each line can be operated individually regarding flux, filtration time and backwash regime.

3. Results and discussion

The purpose of the pilot study was to investigate the performance of modules equipped with the Multibore™ PRO fiber. For evaluating that objective, either historical

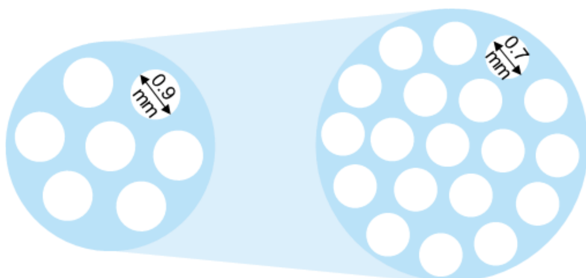

Fig. 1. Schematic of Multibore™ membrane with 7 (left) and of Multibore™ PRO membrane with 19 (right) capillaries, with 0.9- and 0.7 mm inner diameter.

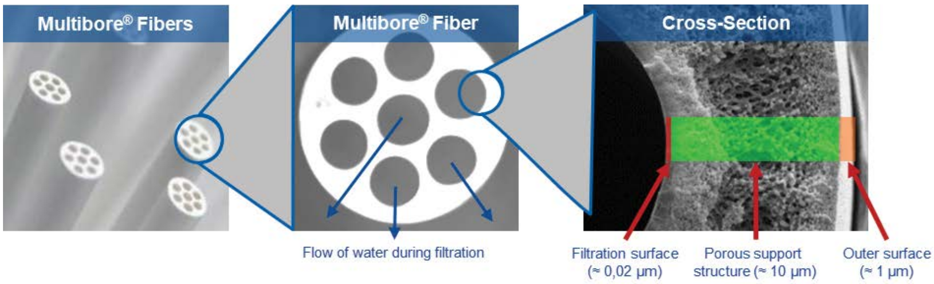

Fig. 2. Structure of Multibore™ membrane.

data of the same site has been considered or side-by-side piloting was conducted.

3.1. Unit A

The upstream river catchment area contains a reservoir, and the floodplains are mainly used for agriculture. Thus, the feed water quality gets the full impact of water quality changes with varying water quality parameters. The water quality main characteristics is described in Table 1.

During the period of testing no clean-in-place (CIP) has been conducted for either module.

The graphs in Figs. 3 and 4 show the operating data and water quality data during pilot operation based on 4 h average values. Due to the averaged values not all peaks in turbidity can be shown here although peaks of up to 150 NTU have been reached and partly breached during events of increased turbidity. Flux and filtration time have been kept constant at 80 L/(m²·h) and 60 min for either line. Additionally, chemical enhanced backwash (CEB) cycles and pattern, backwash times and recoveries have been kept equal. The permeability is normalized to a temperature of 20°C.

It can be seen from the graphs that after an initial permeability drop the MB 0.7 PRO and the MB 0.9 reach a stable and comparable level of operation after around 11 d of operation indicating the stabilization of the fouling layer. After this initial period both membranes react comparably to changes in feed water quality. Turbidity peaks occurred after 51, 57, 59, 65, 82, and several times after 98 d causing similar behavior in permeability drops and, more importantly, also recovery in terms of permeability level. It can be concluded that both types of fiber performed equally well.

3.2. Unit B

Piloting of the MB 0.7 PRO has commenced at the end of January 2022. Historical data based on the large-scale plant and a former piloting is summarized here as a performance benchmark.

The water quality is expected to be in the same range as in previous years can be observed in Table 2.

The permeability range of the MB 55 H modules of the commercial plant is expressed here as average permeability before and after CIP with 117 ± 26 and 256 ± 64 L/(m²·h·bar) for 2019–2021, respectively. Permeability range of the MB 80 TR module [over a pilot period of 9 months resulted in a permeability range of 100 to 500 L/(m²·h·bar) for April 2020 till January 2021]. Flux and filtration time

Table 1
Water quality at river site

Parameter	Average value	Peak
Turbidity, NTU	<10	150
Dissolved oxygen carbon, mg/L	6	10
UV_{254}, 1/m	30	84
Temperature, °C	4–23	

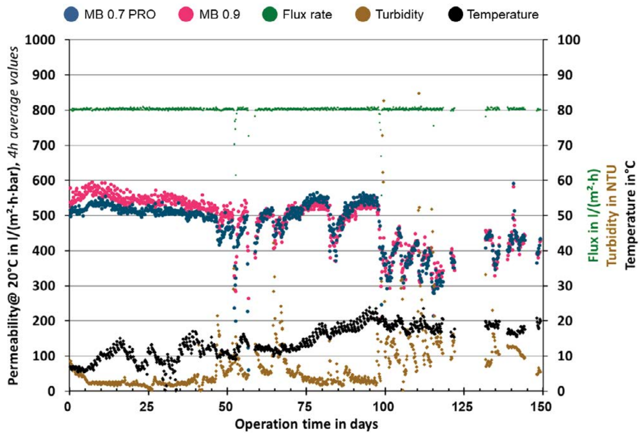

Fig. 3. Operating DuPont™ Multibore™ and DuPont™ Multibore™ PRO over a period of 150 d, shown as permeability, turbidity, flux and temperature.

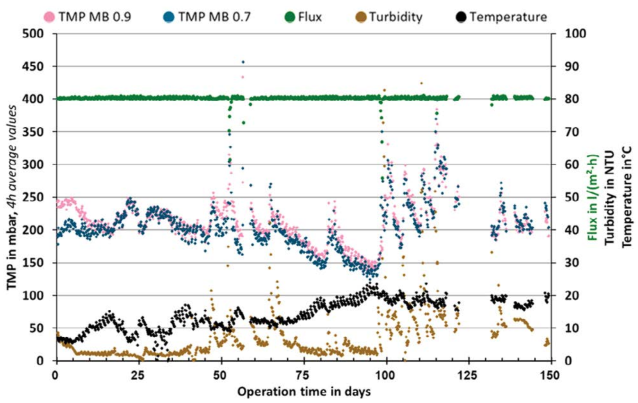

Fig. 4. Operating DuPont™ Multibore™ and DuPont™ Multibore™ PRO over a period of 150 d, shown as transmembrane pressure (TMP), turbidity, flux and temperature.

Table 2
Historic water quality data 2020–2021

Parameter	Average value	Peak
Turbidity, NTU	<3	7
Temperature, °C	20–37	

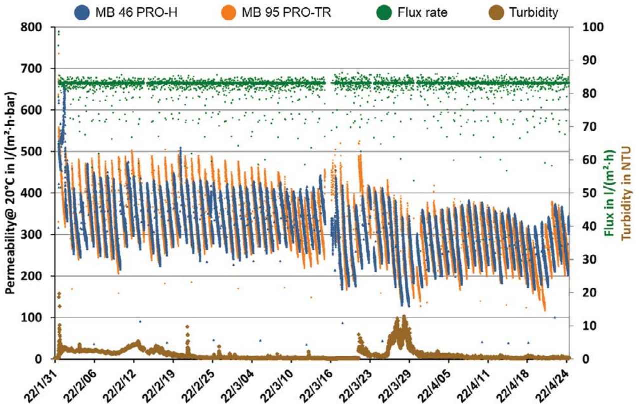

Fig. 5. Permeability, flux and turbidity from two module types equipped with MB 0.7 PRO.

have been kept constant at 83 L/(m^2·h) and 60 min for both lines. Additionally, CEB cycles and pattern (1 per day, caustic at a pH of 9.5 and 200 ppm Cl, followed by acidic at pH of 2.3), backwash times and recoveries have been kept equal. The permeability is normalized to a temperature of 20°C. The resulting recovery is 95.1%. Turbidity is on average 1.6 with a standard deviation of 1.2 and a peak end of March of around 12 NTU, exceeding historic periods. The water temperature climbed from 20°C end of January to 22°C end of April.

It can be concluded from the graphs in Figs. 5 and 6 that both module types equipped with the MB 0.7 PRO fibers operate within a comparable range of the large-scale plant and previous piloting with MB 0.9 fibers. The permeability of the horizontal modules lies between 130 and 500 L/(m^2·h·bar). The permeability of the vertical module performs in the range of 120 and 500 L/(m^2·h·bar).

The turbidity event had a similar impact on both module types. Important to notice is that both modules recover in the same manner. A subsequent slight fluctuation in permeability can be attributed to the fact that hypochlorite and sodium hydroxide injection points were affected by local scaling, which inhibited a continuous cleaning process. Nevertheless, the overall level of permeability remained stable.

During the period of testing no CIP has been conducted for either module.

Transferring the results into a design of a large-scale plant, fewer modules are required to gain the same membrane surface area per rack, which in turn leads to significant savings in footprint and connecting equipment. For example, the largest DuPont™ IntegraTEC™ T-Rack™ consisting of 120 modules of the MB 80 TR contains 9.600 m^2 membrane surface area based on the Multibore™ with 0.9 mm capillaries. With the DuPont™ Multibore™ PRO the largest DuPont™ IntegraTEC™ T-Rack™ can be equipped with 104 modules, resulting in 9.880 m^2 membrane surface area. When comparing the same filtrate flow based on nearly the same flux, 100 of the MB PRO 95 TR modules can produce a volumetric flow comparable to that of 120 of the MB 80 TR modules. Consequently, the footprint of the T-Rack™ can be reduced by 16.6% and the corresponding T-Rack™ parts for 20 modules can be omitted.

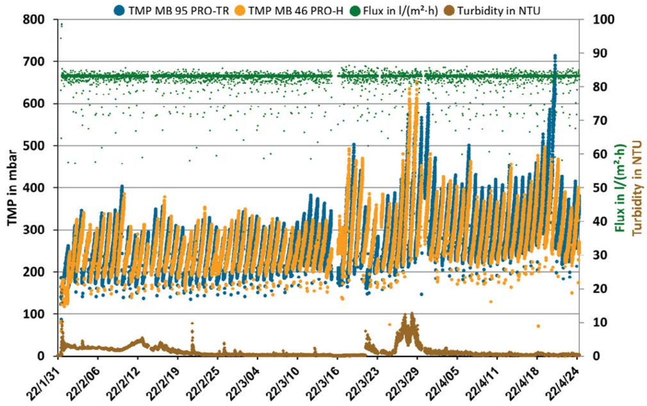

Fig. 6. TMP, flux and turbidity from two module types equipped with MB 0.7 PRO.

4. Conclusions

Results for river water validate that the ultrafiltration system demonstrates similar stable operation while maintaining identical recovery above 95%. Fluctuations in feed water quality, especially in terms of turbidity, had the same impact on the performance of both tested fibers; significantly, both types of fiber recovered equally well.

The seawater piloting shows a very stable operation in terms of performance for the DuPont™ Multibore™ PRO membrane with 0.7 mm capillaries. In the first three months of operation constant permeability level has been attained for both employed types of modules, whether the installation was vertical or horizontal.

In conclusion the operation with an increased membrane filtration area based on Multibore™ PRO operates equally as well as the established and many times employed Multibore™ for the tested types of water. Considering a higher packing density of membrane surface area per required floor area of the MB 0.7 PRO, and the on average lower turbidity levels of seawater, the MB 0.7 PRO will have a significant impact on the design of seawater desalination plants. Footprint savings of up to 16.6% can be achieved with up to 20 fewer modules per T-Rack™, considering a 1% higher flux rate. This leads to the positive effect of less material usage per m^2 membrane surface area with fewer modules produced, less transportation weight, as well as less end-of-life handling. As a result, the effects of using the DuPont™ Multibore™ PRO membrane tend towards reducing the overall CO_2 footprint of an ultrafiltration module.

References

[1] M. Galloway, J. Mahoney, Ultrafiltration for seawater reverse osmosis pretreatment, Membr. Technol., 2004 (2004) 5–8.
[2] M. Badruzzaman, N. Voutchkov, L. Weinrich, J.G. Jacangelo, Selection of pretreatment technologies for seawater reverse osmosis plants: a review, Desalination, 449 (2019) 78–91.
[3] S. Kim, I.S. Lee, K.J. Kim, D.M. Shon, L.S. Kang, Dual media filtration and ultrafiltration as pretreatment options of low-turbidity seawater reverse osmosis processes, Desal. Water Treat., 33 (2011) 329–336.
[4] R. Valavala, J. Sohn, J. Han, N. Her, Y. Yoon, Pretreatment in reverse osmosis seawater desalination: a short review, Environ. Eng. Res., 16 (2011) 205–212.
[5] M. Heijnen, R. Winkler, P. Berg, Optimisation of the geometry of a polymeric Multibore® ultrafiltration membrane and its operational advantages over standard single bore fibres, Desal. Water Treat., 42 (2012) 24–29.