Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2017.21448

90 (2017) 54–62
September

Design challenges of the Jamnagar SWRO plant – from piloting to commissioning

Alex Drak[a,*], Denis Vial[b], Franz Heigl[b], Roland Winkler[b], Peter Berg[b], Tomer Efrat[a]

[a]*IDE Technologies Ltd., Hamatechet St. Hasharon Industrial Park, P.O. Box 5016, Kadima 6092000, Israel, Tel. +972 9 8929835; emails: alexd@ide-tech.com (A. Drak), tomere@ide-tech.com (T. Efrat)*
[b]*inge GmbH, Flurstrasse 27, 86926 Greifenberg, Germany, Tel. +33 7 79 49 61 32; email: denis.vial@basf.com (D. Vial), Tel. +49 8192 997 700; emails: fheigl@inge.ag (F. Heigl), rwinkler@inge.ag (R. Winkler), pberg@inge.ag (P. Berg)*

Received 29 June 2017; Accepted 14 September 2017

ABSTRACT

Nowadays, ultrafiltration is commonly considered as an ideal stand-alone pretreatment technology to treat seawater and to produce a constant quality treated water to a reverse osmosis step for desalination purposes. End of 2013, IDE Technologies has been awarded a contract for a new seawater desalination plant located in Jamnagar, Gujarat state, India's arid north-western region, to supply the refinery complex with up to 168,000 m³/d (44.4 million gallons per day) of process water from seawater of the Gulf of Kutch. In 2014, inge GmbH has been awarded a contract to supply its ultrafiltration membrane technology as pretreatment to the reverse osmosis. The design of the plant had to meet particularly difficult requirements, both for pretreatment and post-treatment. The pretreatment stage is one of the key factors in the success of reverse osmosis desalination. It must remove the main impurities from the seawater and thus ensure a reliable operation of the reverse osmosis. This is even more important when seawater contains high concentrations of organic matter and is subject to frequent algal blooms. In order to have a smooth operation of the plant over the long-term, different steps were to be considered from pilot testing to start-up and commissioning. This paper deals with the design implications and then the ways to replicate this during a pilot phase. Piloting results presented confirm that the ultrafiltration modules could meet the very ambitious targets in terms of process stability, filtrate quality and yield, especially during the monsoon period and finally impact the process design. The paper also presents commissioning challenges.

Keywords: Algae bloom; Commissioning; Seawater; System optimization; Ultrafiltration; Seawater reverse osmosis

1. Introduction

Nowadays, seawater is one of the sources of water so as to produce water intended for human consumption or for industrial purposes. In 2002, Furukawa [1] projected the global total installed capacity of desalination plants at the end of 2003 to be in the range of 10 million m³/d. Ten years later, Bennet [2] estimated the worldwide installed capacity of desalination plants to be 80 million m³/d by the end of 2012, bringing the worldwide number of desalination plants to more than 16,000. Typically, in seawater desalination plants, seawater is pretreated using conventional technology consisting of clarification, sand filtration, and cartridge filters prior to reverse osmosis (RO) membranes. Since 1988, microfiltration and ultrafiltration (UF) membranes have been considered as an alternative solution to conventional water treatment technologies for municipal drinking water production treating underground or surface water. In the late 90's – early 2000, UF started to be employed as an alternative process but also complementary to conventional treatments for seawater reverse osmosis (SWRO) plants. In 2010, Busch et al. [3] calculated that of about 40 large-scale seawater desalination plants are using or are planning to use UF as SWRO pretreatment.

Feed water conditions and critical importance of pretreatment in SWRO processes demand a particularly well adapted

* Corresponding author.

Presented at EuroMed 2017: Desalination for Clean Water and Energy: Cooperation around the World, 9–12 May, Tel Aviv, Israel, 2017.

1944-3994/1944-3986

and robust pretreatment. Generally, the pretreatment design is based on a multi-stage barrier approach and is mainly impacted by the feed water quality parameters such as organic content and suspended solids (TSS) concentration. Besides the average concentration, the height and duration of the peaks also have a significant impact on the pretreatment design. Therefore, in many cases, with fluctuating water quality or high TSS concentrations (>100 mg/L), UF pretreatment is considered as a stand-alone or a part of the pretreatment. In addition, the quality requirements of the filtrate with respect to dissolved parameters affect the decision to install further treatment steps prior to UF. For those, the pretreatment to UF will have an influence on both the UF performance and the quality of the ultra-filtered water feeding the RO [4,5] and will influence in different ways the biofouling of the RO membranes [6,7].

Compared with conventional pretreatments (clarification, dissolved air flotation (DAF), and multimedia filtration), UF membranes have demonstrated an incomparable long-term and stable operation treating all types of water, from underground water, surface water, secondary effluent wastewater to seawater.

2. Pretreatment selection

Jamnagar SWRO plant is intended to supply 168,000 m^3/d process water to the refinery complex. Continuous process water supply at the required water quality demands high availability of the plant. Pretreatment step is one of the important stages in SWRO plant that should protect RO membranes from different types of fouling and scaling and ensure the stable operation of RO membranes at all feed water quality conditions. The main factor that influences the selection of pretreatment is feed water quality variations. The pretreatment design of 168,000 m^3/d Jamnagar SWRO plant was based on the seawater quality provided by the client and is shown in Table 1.

Table 1
Jamnagar seawater quality

Parameter	Minimum value	Maximum value
Temperature, °C	20	33
pH	7.8	8.1
TDS, mg/L	39,665	41,100
Turbidity, NTU	5.4	100
TSS, mg/L	4.0	100
Oil and grease, mg/L	0	3.0
TOC, mg/L	5.0	10.0
COD, mg/L	180	250
BOD, mg/L	5	7
Iron, mg/L	0.30	0.65
Aluminum, mg/L	0.03	0.90
Manganese, mg/L	0	0.01

TDS, total dissolved solids; TSS, total suspended solids; TOC, total organic carbon; COD, chemical oxygen demand; BOD, biological oxygen demand.

As can be seen from Table 1, the seawater in Gulf of Kutch is characterized by high organic content and high suspended solids concentration. This challenging seawater quality was one of the reasons that all previous seawater desalination plants supplied by IDE in this area were based on thermal desalination technology. Such high load of organics and suspended solids requires very robust and comprehensive pretreatment. Generally, the pretreatment that is based on multi-stage barrier approach and comprising flocculation, clarification, DAF, and gravity media filtration (GMF) is sufficient for this type of seawater. However, the peaks in seawater quality during monsoon period and the effect of a significant difference between high and low tides of 6 m in this area may require additional polishing step such as UF before RO membranes.

The IDE proposed pretreatment, comprised of flocculation, clarification, DAF and GMF, is characterized by extremely high reliability and robustness since it is based on the multi-stage barrier approach. In case of failure in one of the pretreatment stages, other pretreatment stages will complete the required mission. Additional advantages of IDE pretreatment are (1) easy access and maintenance since all process units are located in the same structure while the equipment, valves, and instruments are located on the sides, (2) conservative filtration velocity and hydraulic loading design, (3) upgraded in-house DAF system design, and (4) highly efficient filter backwash design.

Table 2
Seawater quality required at the entrance to RO membranes

Parameter	Value
TSS, mg/L	<0.1
Turbidity, NTU	<0.1
SDI	<3.0
TOC, mg/L	<3.0
COD, mg/L	<10.0
Iron, mg/L	<0.05
Aluminum, mg/L	<0.05

The selected pretreatment should meet that required by RO membrane suppliers, seawater quality at the entrance to RO membranes. The required quality is shown in Table 2.

The ability of the selected pretreatment to supply abovementioned seawater quality to the RO membranes and the necessity of UF polishing step was decided to examine during the pilot study.

3. Pilot plant study

To verify the pretreatment performance during the year and especially during the monsoon period, a pilot plant was run on site with the same process design as the full-scale plant. The pilot plant flow diagram is shown in Fig. 1. The water for the pilot is supplied from a seawater open intake. The pilot plant consisted of flocculator, lamella clarifier, DAF, and GMF. The filtrate of GMF was divided to two streams, one was further treated by UF prior to RO membrane and another was taken directly to RO without UF polishing step. This configuration enables to evaluate not only the performance of different pretreatment stages but also the effect of UF polishing step on RO performance.

UF selected for pilot study was supplied by inge. The UF pilot plant is a fully automated unit and basically consists

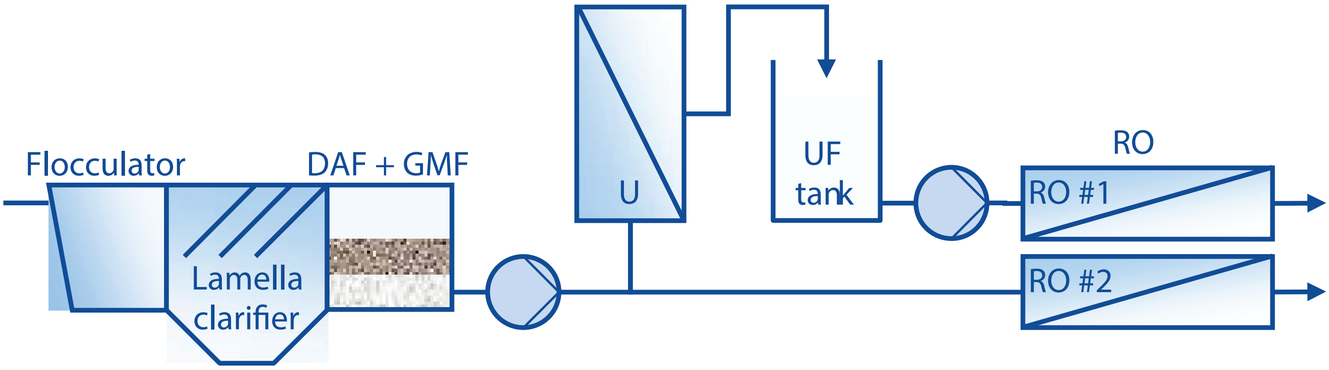

Fig. 1. Pilot plant flow diagram.

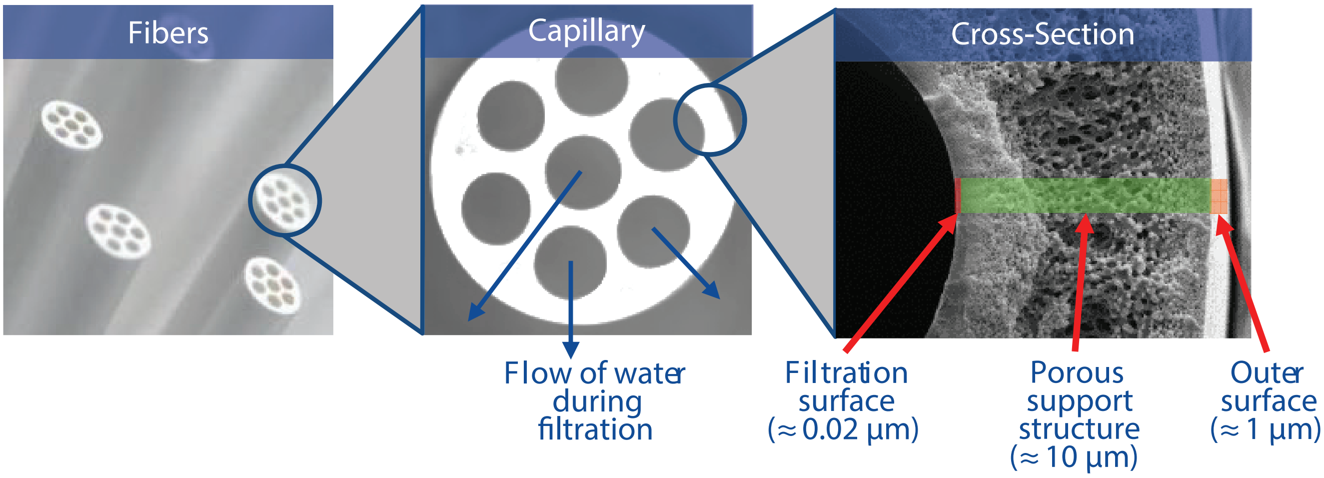

Fig. 2. Multibore® membrane.

of modules, feed pump, backwash pump and filtrate tank, chemical dosage pumps for three different chemicals, and different measurement devices (pH, turbidity, flow rate, pressure, and temperature). All pumps are controlled by frequency converters to ensure a stable flow rate.

Modules used are dizzer® XL modules containing the Multibore® membrane and developing a filtration area of 70 m². The Multibore® membrane, shown in Fig. 2, is a fiber made from modified polyethersulphone (PES) with a high pH tolerance from 1 to 13 which allows efficient cleanings even in extreme conditions. It consists of a foamy homogenous support structure containing seven capillaries or channels. The inner layer of the seven capillaries represents the very thin active filtration surface. The foamy support structure in between the capillaries shows a permeability that is around 1,000 times higher than that of the filtration surface so that an equal distribution throughout the whole cross-section of the fiber can be guaranteed. The foam-like support material is porous enough to ensure a slight loss of transmembrane pressure, which makes this material unique on the market. The inner diameter of each individual capillary is 0.9 mm. The nominal pore size of the filtration layer is approximately 20 nm and thus substantially smaller compared with most other membranes. Due to the PES characteristics, the material is tuned in regard of the porosity resulting in substantial lower driving pressures despite the smaller pores. This unique multi-channel structure enables a very high stability to the membrane resulting in virtually no fiber breakage.

Filtration with Multibore® membranes takes place in a pressure-driven “inside-to-out” mode through the capillaries. This procedure assures an ongoing and equal overflow on the feed side on which a cake layer is formed. The backwash is carried out on a regular basis (from 20 to 120 min) for relatively short time periods (30–60 s) with only a small amount of permeate. The backwash is composed of two steps during which treated water (permeate) is sent under pressure inside the fibers. During the first step, backwash waste water exits from the bottom end of the module while during the second step, the backwash waste water is wasted via the upper end of the module. Thanks to this protocol, the cake layer is loosened and removed out of the module at every backwash. Operation modes are shown in Fig. 3. Air scouring is not applied which saves energy and downtime especially for de-aeration steps.

During the pilot study, part of the seawater parameters was monitored continuously and part on a daily basis. Four seawater parameters, TSS, turbidity, oil and grease, and iron, exceeded their maximum values defined by the client. The turbidity and TSS values increased almost every morning, during the low tide, to values higher than the design

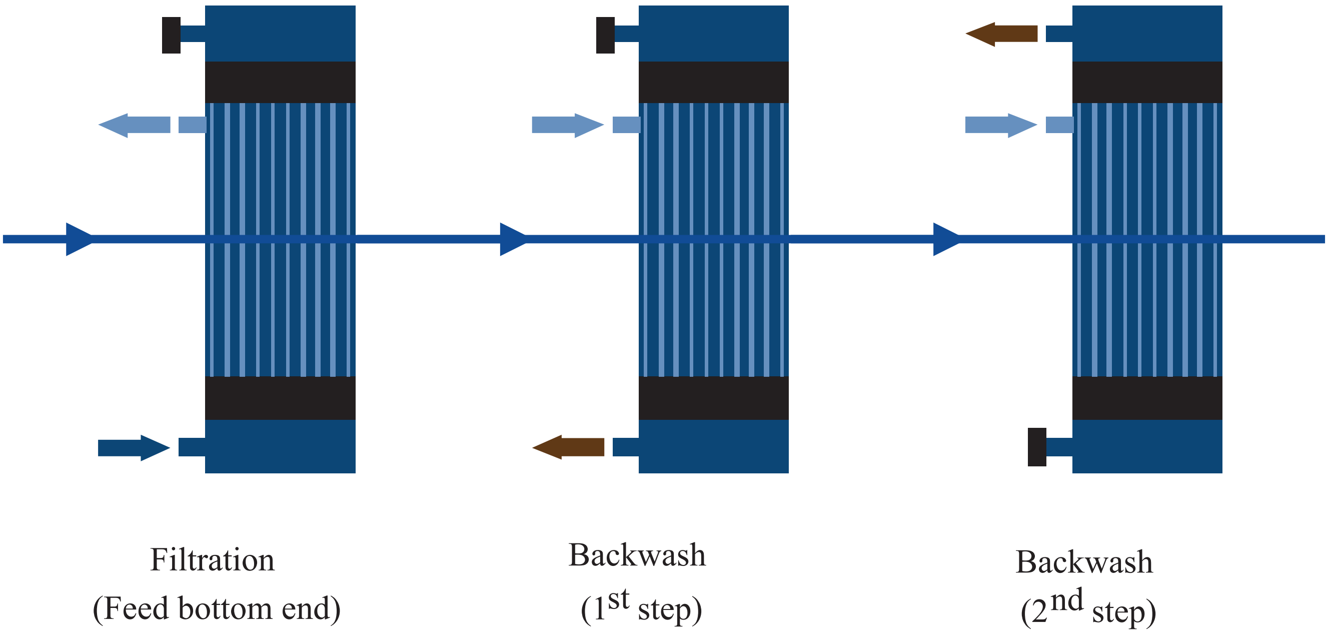

Fig. 3. Direction of flow in a Dizzer® module during filtration and backwash mode.

maximum values. The maximum turbidity of 846 NTU was measured. Oil and grease concentration as high as 7.5 mg/L was measured during the pilot study. The maximum iron concentration of 2.75 mg/L was measured.

The main purpose of UF was to remove organic material and suspended solids that went through the media filter. During the pilot, the UF was operated at filtration flux of 70–90 liter per square meter per hour (LMH), filtration time of 50–65 min, backwash duration of 35 s, chemically enhanced backwash (CEB) was performed once per day, the recovery achieved was above 95%, no flocculant was used prior to UF system.

The UF system performance was according to expectations. The differential pressure on the UF membranes was 100–400 mbar most of the time, in accordance with the design values. The UF filtrated water quality met the design requirements which are turbidity < 0.1 NTU, TSS < 0.1 mg/L, silt density index (SDI) < 3.0, COD < 10 mg/L, Fe < 0.05 mg/L, Al < 0.05 mg/L.

Most of the time no significant effort to remove suspended matter was required from UF system since UF feed TSS/turbidity load was very low. The major job of UF system was to remove COD concentration.

Fig. 4 shows the COD concentration changes during the year in the seawater, UF feed, and UF filtrate. As can be seen, the COD concentration in the seawater was varied between 30 and 50 mg/L, much lower than the design limits of 180–250 mg/L. The COD concentration was reduced to 20–30 mg/L prior to UF and to almost 5 mg/L after UF. Based on the fact that UF succeeded to reduce COD by 70%–90%, it can be concluded that most of the COD in the seawater is colloidal particles in the range of 0.02–1 μm that pass filtration paper of 0.45 μm, and therefore counted as dissolved matter but is stopped by UF that has filtration grade of 0.02 μm.

Fig. 5 shows the turbidity of seawater and SDI values before and after UF. It can be seen that the UF filtrate SDI was less than 3.0 (almost 100% of the time) and less than 2.0 (70% of the time) in accordance with the design requirements. UF feed SDI was measured only during the first 6 months and the values were between 2 and 6. The measurements were stopped after 6 months of operation due to the failure in the second RO system that was fed directly by GMF filtrate.

The effect of pretreatment on RO performance was evaluated by comparing the differential pressure and the normalized permeate flow of RO#1 pretreated by UF with the differential pressure and the normalized permeate flow of RO#2 pretreated by GMF. No significant difference was found in normalized permeate flow between two types of pretreatment. The differential pressure of RO#1 pretreated with UF was 0.2 bar lower than the differential pressure of RO#2 pretreated with GMF. However, no changes in differential pressures of both RO were observed during the first 6 months of operation. The differential pressures of RO#1 and RO#2 are shown in Figs. 6 and 7.

Finally, it can be concluded that the UF polishing step enables adequate pretreatment performance achieving the required RO feed characteristics. Based on the pilot study, it was decided to add UF polishing step to the pretreatment of Jamnagar SWRO plant.

4. Full scale plant design

The design of full scale UF system was based on findings of the pilot study. The UF system is designed to treat almost 20,000 m^3/h feed flow. The UF system is shown in Fig. 8. The UF system is constructed of three rows, every row consists of 11 trains, so that the total number of trains is 33. Every train consists of 124 dizzer® XL inge modules. Net filtration flux is around 70 LMH, filtration time varies between 45 and 60 min, CEB frequency is between 12 and 48 h. Feed water to UF system was pretreated by disk strainers of 130 micron size.

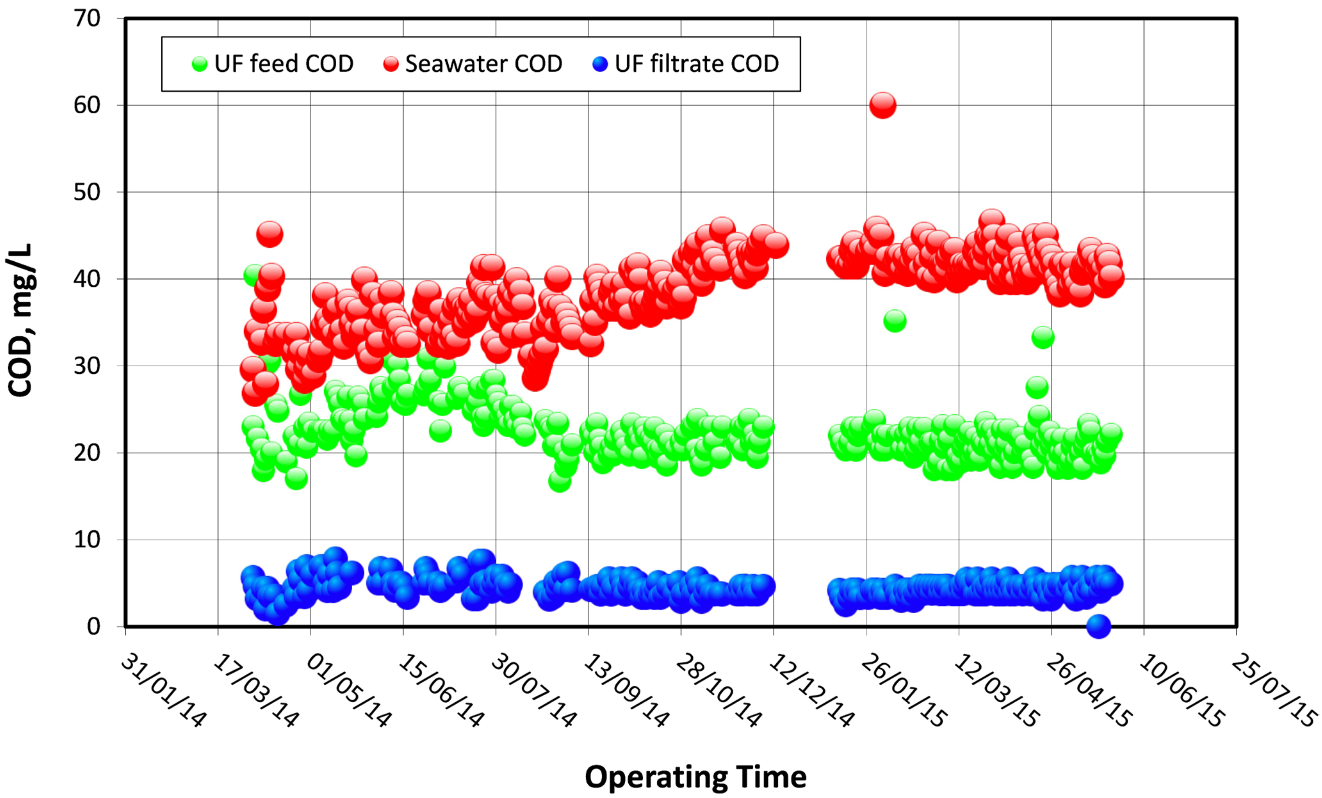

Fig. 4. COD concentration in seawater, UF feed, and UF filtrate.

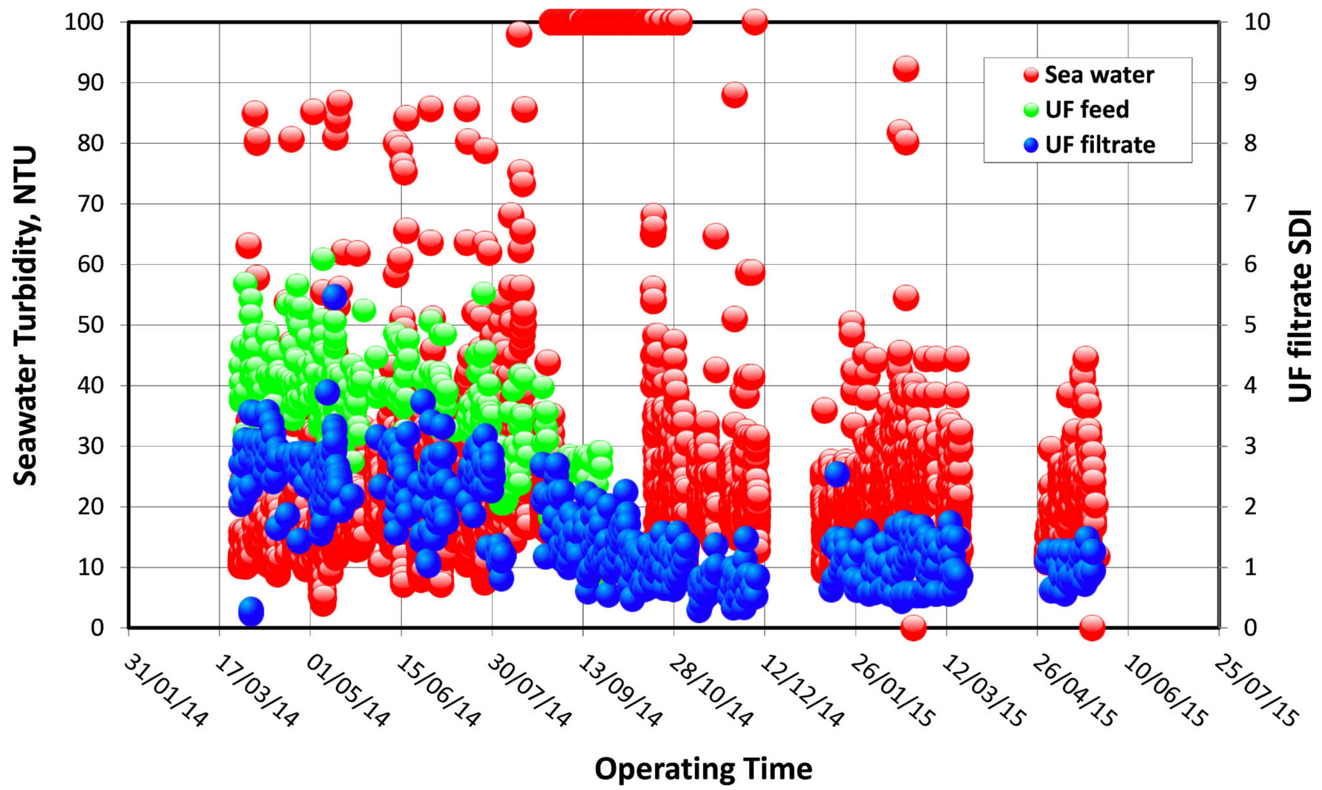

Fig. 5. Seawater turbidity, UF feed, and filtrate SDI values.

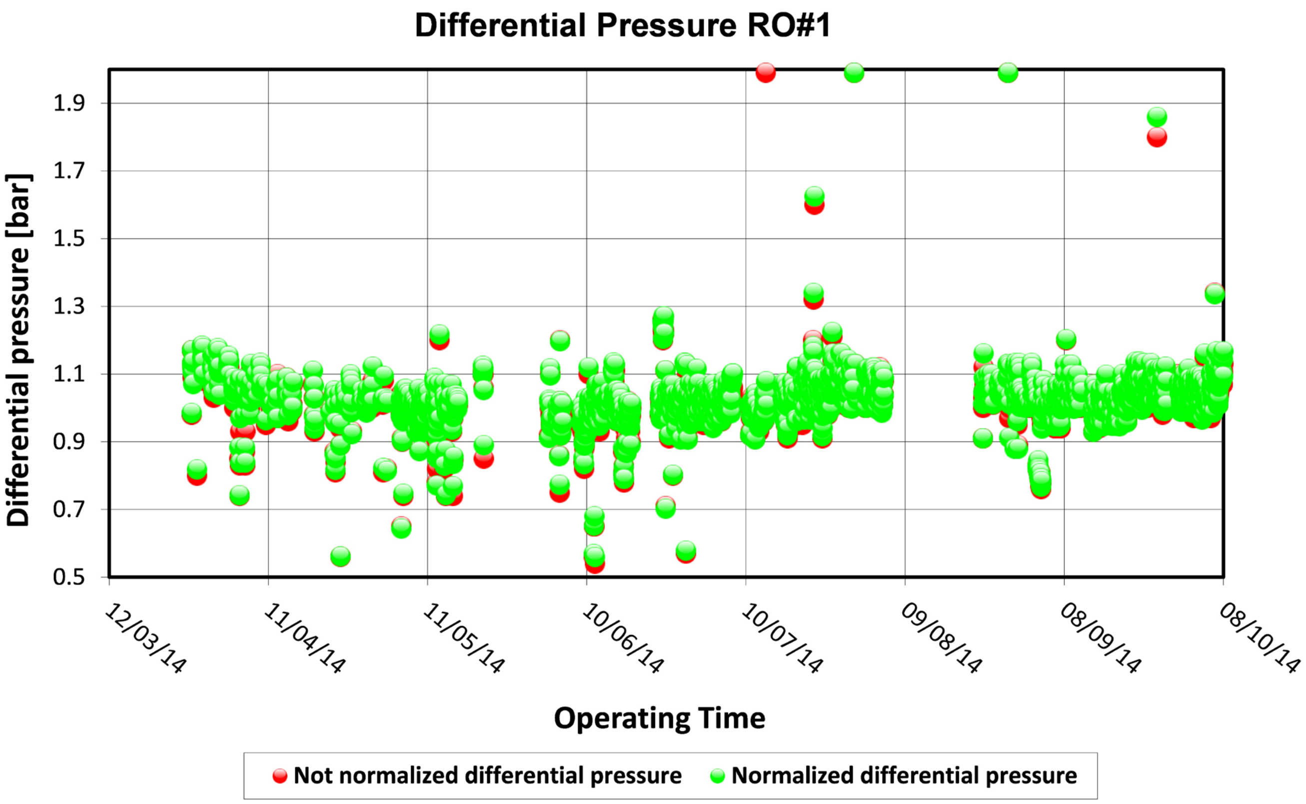

Fig. 6. Differential pressure in RO#1 pretreated by UF.

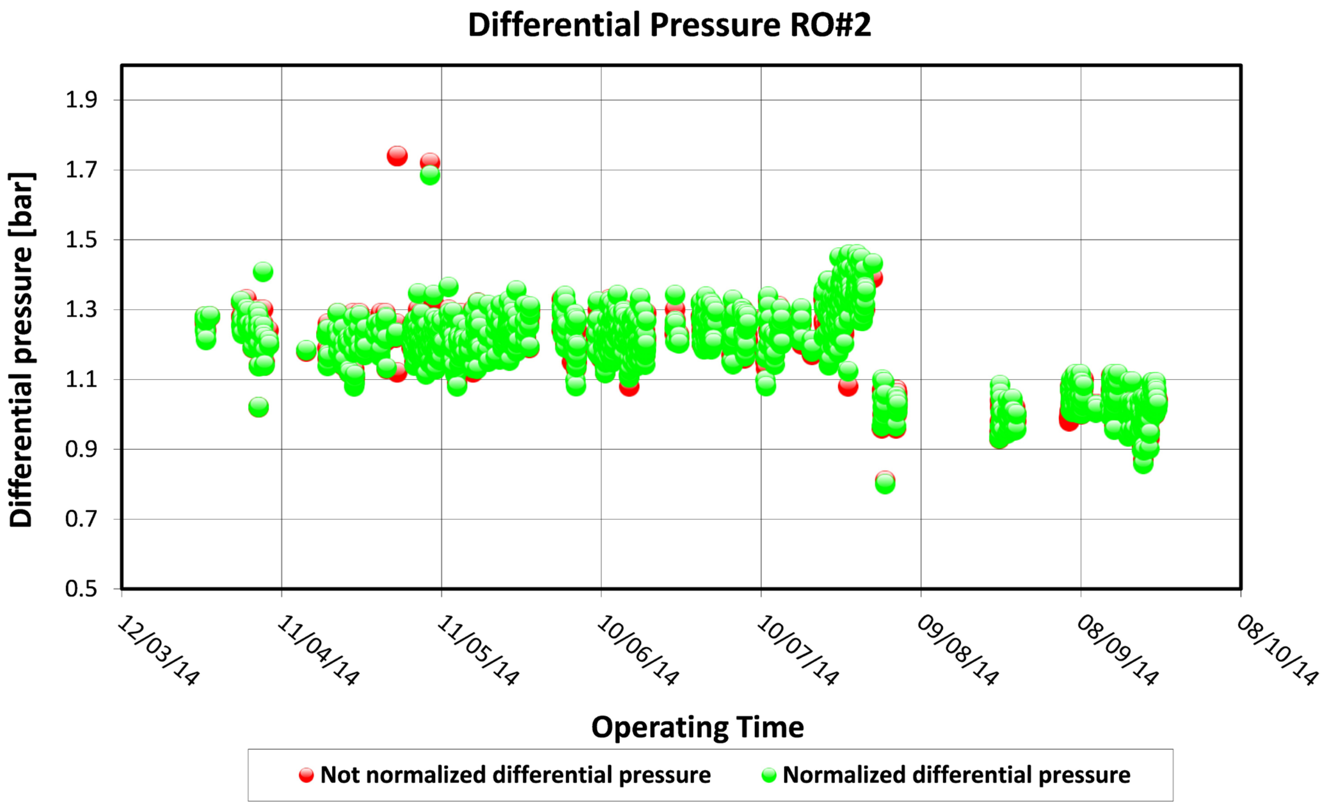

Fig. 7. Differential pressure in RO#2 pretreated by GMF.

5. Preliminary commissioning results

The preliminary commissioning results are shown in Figs. 9–11. It can be seen that UF system improves significantly the feed water quality to RO system. Seawater turbidity is reduced from 10–100 NTU to 0.1–1.0 NTU by clarification, DAF, and gravity filtration and further reduced to almost 0.01 NTU by UF system. Seawater COD is reduced from 20–40 mg/L to 10–20 mg/L by clarification, DAF, and gravity filtration and further reduced the COD to less than 10 mg/L by UF system. SDI measurements after UF system are shown in Fig. 11, it is seen that SDI values are lower than 3.0 almost 100% of the time.

6. Summary

IDE Technologies has completed construction and commissioning of seawater desalination plant located in Jamnagar, Gujarat state, India's arid north-western region, to supply the refinery complex with up to 168,000 m^3/d (44.4 million gallons per day) of process water from seawater of the Gulf of Kutch.

Due to the challenging seawater quality in this area, the special emphasis was placed on the pretreatment design of this plant. The pretreatment is one of the key factors in the success of reverse osmosis desalination plant. It must remove the main contaminants from the

Fig. 8. UF system – Jamnagar SWRO plant.

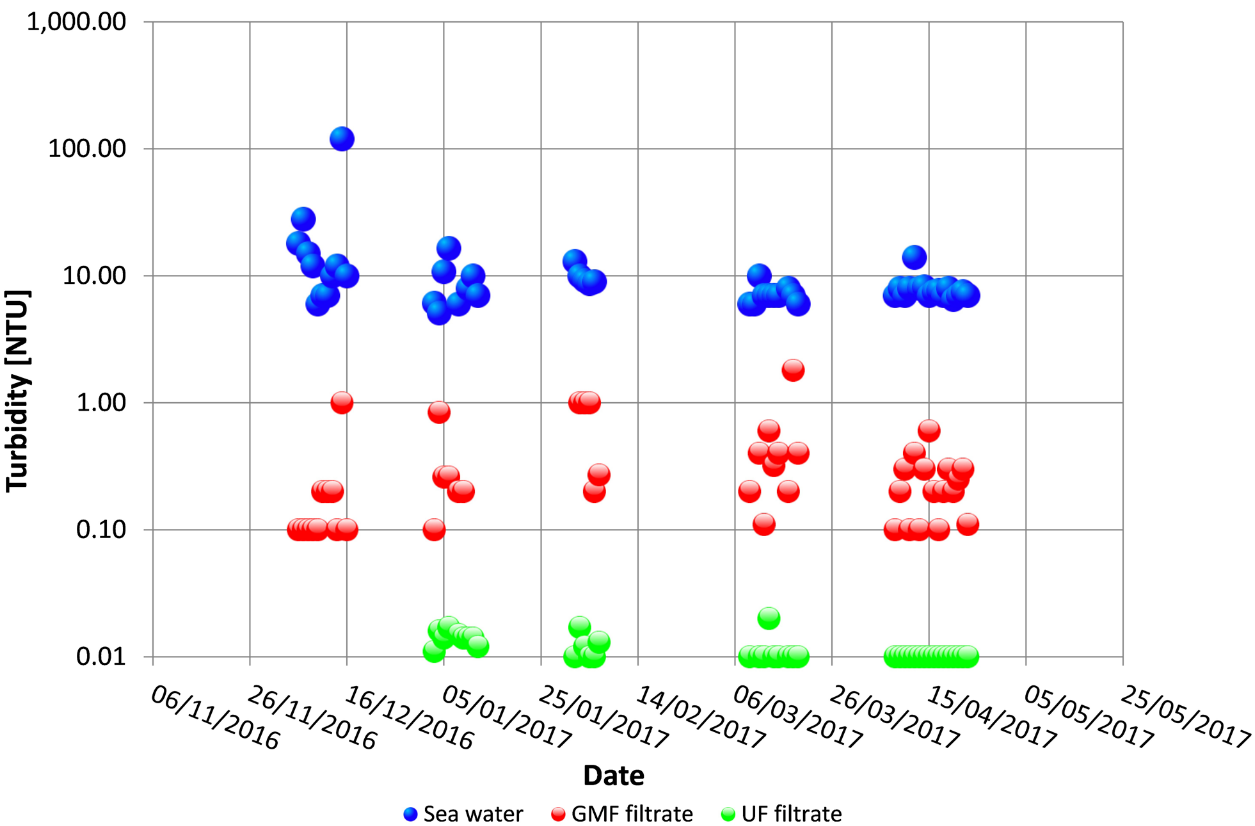

Fig. 9. Turbidity measurements during the commissioning.

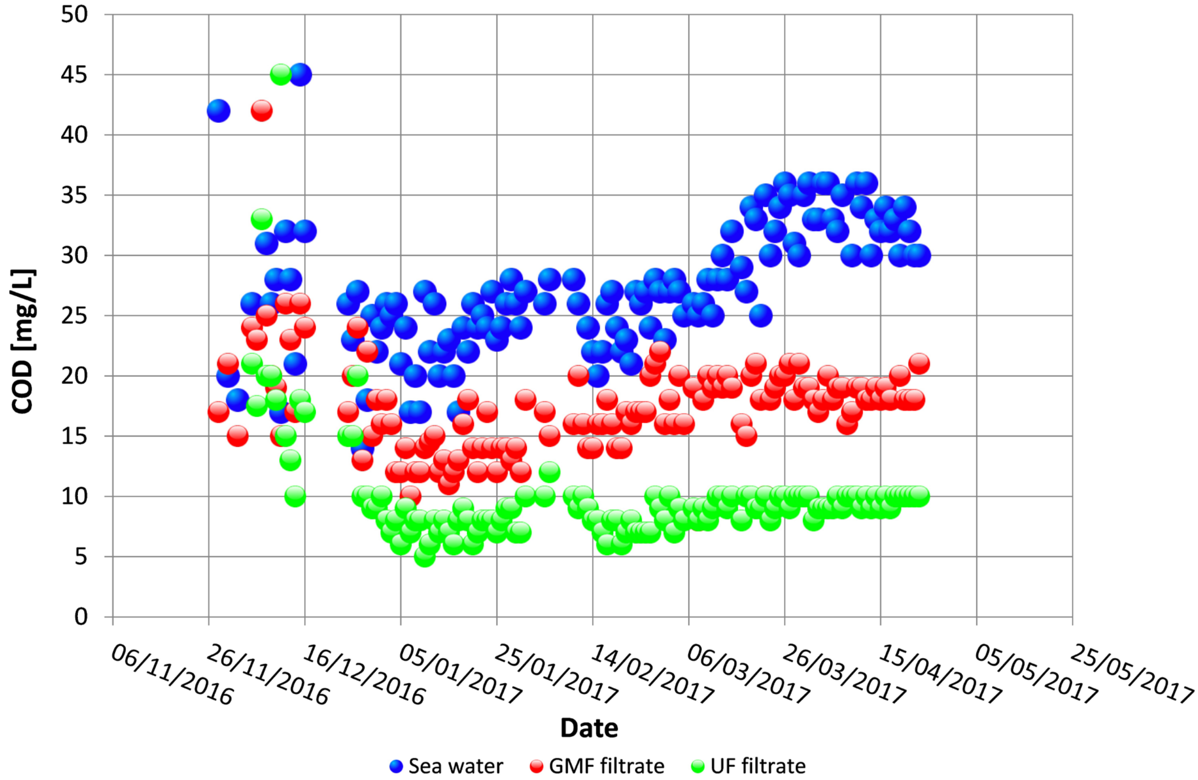

Fig. 10. COD measurements during the commissioning.

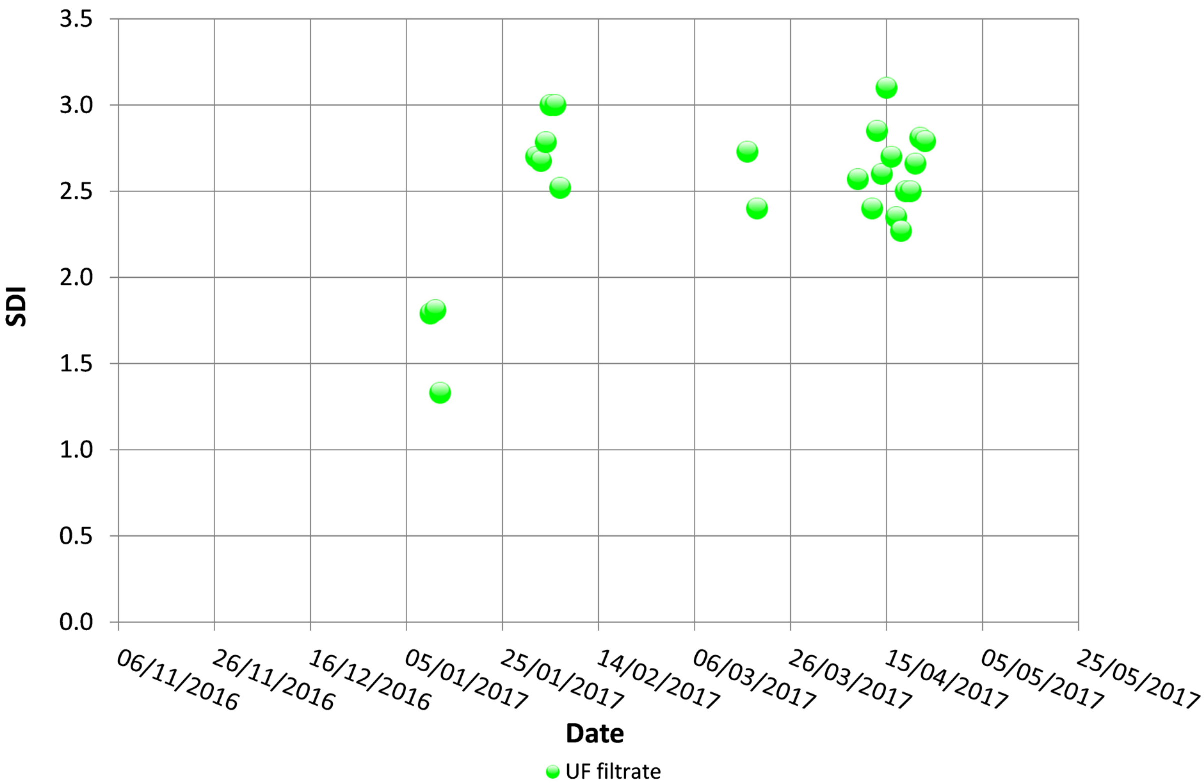

Fig. 11. SDI measurements during the commissioning.

seawater and thus ensure a reliable operation of the reverse osmosis.

Based on the commissioning results, it can be concluded that the selected pretreatment design that consists of flocculation, clarification, DAF, GMF, and UF is adequate and robust, ensuring the smooth operation of the plant over the long-term period. Multiple stage barrier design allows passing the contaminants load from stage to stage by adjusting and minimizing the dosing rate of the pretreatment chemicals.

The results confirm that the UF system could meet the very ambitious targets in terms of process stability, filtrate quality and yield. In addition, the UF has proven efficiency in removing colloidal substances that cause fouling in RO membranes.

Regardless the challenging seawater quality, RO part of the plant operates smoothly meeting the requirements of the client.

References

[1] D.H. Furukawa, Global status of microfiltration and ultrafiltration membrane technology, Watermark, 17 (2002) 2–4.

[2] A. Bennett, 50th Anniversary: desalination - 50 years of progress (Part 2), Filtr. Sep., 50 (2013) 32–39.

[3] M. Busch, R. Chu, S. Rosenberg, Ultrafiltration Pretreatment in Seawater Desalination: Cost-Savings and Performance Advantages, WaterWorld, 26 (2010) 14.

[4] N. Voutchkov, Seawater Pretreatment. Water Treatment Academy, Bangkok, Thailand, 2010.

[5] N. Voutchkov, Considerations for selection of seawater filtration pretreatment system, Desalination, 261 (2010) 354–364.

[6] A.R. Guastalli, F.X. Simon, Y. Penru, A. de Kerchove, J. Llorens, S. Baig, Comparison of DMF and UF pretreatments for particulate material and dissolved organic matter removal in SWRO desalination, Desalination, 322 (2013) 144–150.

[7] H. Huang, K. Schwab, J.G. Jacangelo, Pretreatment for low pressure membranes in water treatment: a review, Environ. Sci. Technol., 43 (2009) 3011–3019.