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Sustainable performance of NF-SWRO pilot plant with low fouling NF membrane

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ABSTRACT

NF membrane fouling is a major obstacle in the smooth implementation of this technology. Hence, attempts were made to identify the best NF membranes which can handle fouling and also are capable of maintaining its specific ion rejection properties, which are usually affected by fouling, chemical cleaning, and long-term operation. In this study, low fouling NF membranes were used in a 2:1 configuration, the product of which was used as feed to a SWRO unit as well as make-up to MED unit at different combinations. Moreover, SWRO reject was also used as make-up to MED unit. NF and SWRO operations conditions were mainly directed by the requirement of MED unit. NF unit was most of the time operated at a recovery of 70% and SWRO unit which was fed by the NF product was operated mostly at a recovery of about 48%. NF unit received pretreated seawater which was taken from an open intake located at Gulf Seawater. The pretreatment includes disinfection by chlorine, coagulation using $FeCl_3$, and antiscalant dosing, where feed water passes through two dual media filters arranged in series. NF membranes were operated at an average flux of 21 LMH at the normal recovery of 70%. A total of four chemical cleanings were only performed during the period of 3 years in operation. A total of only seven NF membranes were only replaced during the test period which amounts to an average of 13% annual membrane replacement rate which is quite acceptable in membrane industries. Some of the chemical cleaning and membrane replacement could have been avoided if problem with isobaric ERD would not have happened. End membrane elements were replaced on two occasions due to heavy $CaSO_4$ scale, which occurred due to failure of isobaric ERD system. NF unit was most of the time operated at feed pressure of <15 bar and it increased up to 25 bar only during the occurrence of scaling. NF product quality was maintained constant in the narrow range of TDS between 36,600 and 37,600 ppm from a feed TDS of about 45,000 ppm despite large variation in feed temperature. Even the concentrations of scale-forming divalent ions were in the narrow range. These properties of NF membrane were better and much different from that was used at Ummlujj and resulted in steady performance of SWRO unit which received NF product as feed. SWRO membranes which received NF product as feed was mostly operated at recovery of 48% with an average flux of 13.5 LMH. The performance of SWRO membranes was excellent as expected due to very clean feed water as well

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as moderate flux operation. During the three years period no chemical cleaning and membrane replacement were carried out due to its excellent performance. The product conductivity was mostly below 400 μS/cm despite large seasonal variation in feed water temperature, which ranged between 17 and 36˚C. The present study revealed excellent performance of NF membrane, especially its ability to maintain its performance regardless of fouling, cleaning, and long-term operation, which reflected in the outstanding performance of SWRO unit which received feed from NF unit.

Keywords: Nanofiltration; Seawater desalination; Pretreatment; Fouling

1. Introduction

Saline Water Conversion Corporation's (SWCC) research arm, namely, the Desalination Technologies Research Institute is the pioneer in developing applications of nanofiltration (NF) pretreatment for seawater desalination. Initial work on a pilot plant scale resulted in its application in one of the commercial SWRO plants at Ummlujj, currently in operation since September 2000. Since then, a significant amount of research has been carried out by SWCC SWDRI to improve the process economics as well as the performance of NF [1]. To achieve these objectives, several research studies were undertaken which addressed to improve overall recovery, control NF fouling, lower energy consumption, and to optimize NF membrane flux.

Like most of the membrane processes, NF membranes are also prone to fouling which could lead to reduction in its performance. It is reported that membrane fouling is one of the major impediments in the application of NF system [2]. Moreover, several studies carried out at SWCC using NF membranes for pretreatment of seawater confirm the finding that organic fouling is one of the major concerns [3–6]. Unlike the RO membranes, the NF membrane's specificity to rejection makes it difficult to deal with, especially reduction in rejection of hardness ions such as Ca and Mg during the course of long-term operation. Moreover, these ions are responsible for scaling which ultimately decides the recovery ratio of SWRO system. Membrane fouling tends to change the specific rejection properties of the membrane, especially the rejection of hardness ions like Ca and Mg ions and to some extent to total dissolved solids (TDS) [3]. Fouling could be tackled by either prevention or by remediation. Remediation measure is usually carried out when fouling occurs on the membrane and is done mostly by chemical cleaning. However, chemical cleaning changes the rejection properties of NF membrane and ultimately deteriorates NF product quality, which has significant effect on the operation conditions of the subsequent desalination unit, whether membrane or thermal. Although, it has been found that the rejection of sulfate does not change much, the Ca, Mg, and TDS rejections do deteriorate with each chemical cleaning. Hence, efforts are to be made either to avoid chemical cleaning or to modify the membrane surface chemical characteristics in order to overcome this particular problem.

As NF membrane fouling is found to be a major obstacle in smooth implementation of this technology, efforts were made to identify its cause and to find a suitable solution. One such effort was the identification of best NF membranes that are available in the market which can withstand fouling and also are capable of maintaining its specific ion rejection properties, which are usually affected by fouling, chemical cleaning, and long-term operation. One such NF membrane identified was used in a long-term operation of about 3 years in a tri-hybrid combination of NF-SWRO-MED desalination system where SWRO reject along with NF product was used as make-up for MED that was operated up to an unprecedented TBT of 125˚C [7].

2. Experimental setup

In this study, low fouling NF membranes were used in a 2:1 configuration, the product of which was used as feed to a SWRO unit as well as make-up to a MED unit in different combinations. Moreover, the reject from SWRO was used as make-up to MED unit. NF and SWRO operations conditions were mainly dictated by the requirement of MED unit. NF unit was most of the time operated at a recovery of 70% and SWRO unit which was fed by the NF product was operated mostly at a recovery of about 48%. NF unit received pretreated seawater which was taken from an open intake located at the east coast of Saudi Arabia. The pretreatment includes disinfection by chlorine, coagulation using $FeCl_3$, and antiscalant dosing, where feed water passes through two dual media filters arranged in series. The SDI of pretreated seawater was most of the time <4. NF unit consisted of 18 NF membranes of standard size of 8´´ × 40´´ fitted in nine pressure vessels and arranged in 2:1 brine stage configuration. A high pressure booster pump was fitted in between the stages to increase the pressure to the second stage. Similarly, SWRO unit consisted of 12 membranes of standard size of 8´´ × 40 fitted in six pressure vessels. Both NF and SWRO units are equipped with isobaric energy recovery devices (ERD) with the aim of reducing energy consumption.

3. Results and discussions

Both NF and SWRO units were operated as a part of research program where tri-hybrid system NF–$SWRO_{reject}$–MED is being evaluated. Hence, the operation of both NF and SWRO units were controlled by the tri-hybrid system operating parameters. NF membranes were operated at an average flux of 21 LMH at the normal recovery of 70% and the operating conditions and performance of NF unit for about 1,050 d are given in Fig. 1. The initial feed pressure was about 11 bar at feed temperature of 30˚C, with total product conductivity of about 55,000 µS/cm. The feed pressure remained steady up to 300 d of operation and after that it rose suddenly to a value

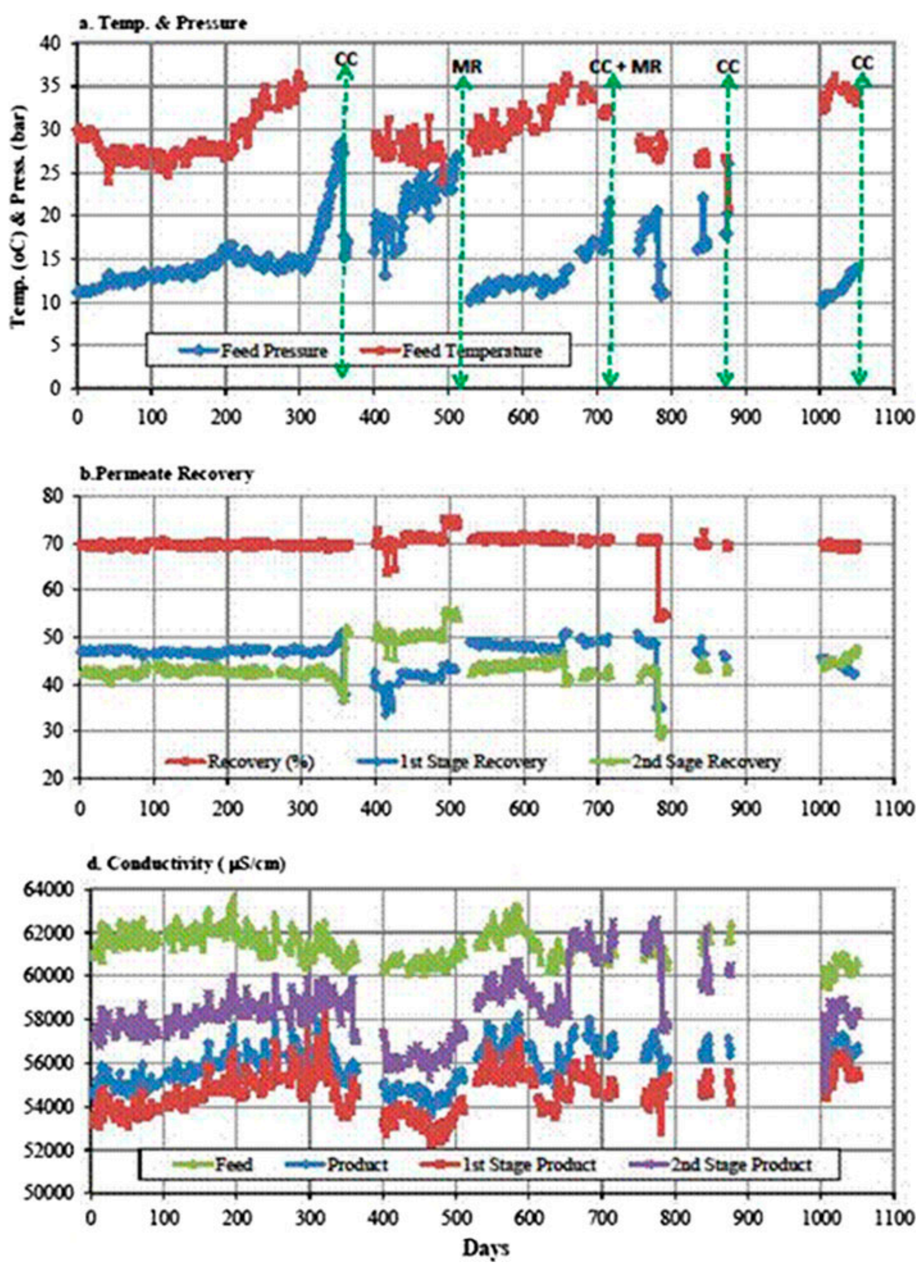

Fig. 1. Performance of NF unit coupled to SWRO unit and MED pilot plant in a tri-hybrid system (CC = chemical cleaning and MR = membrane replacement).

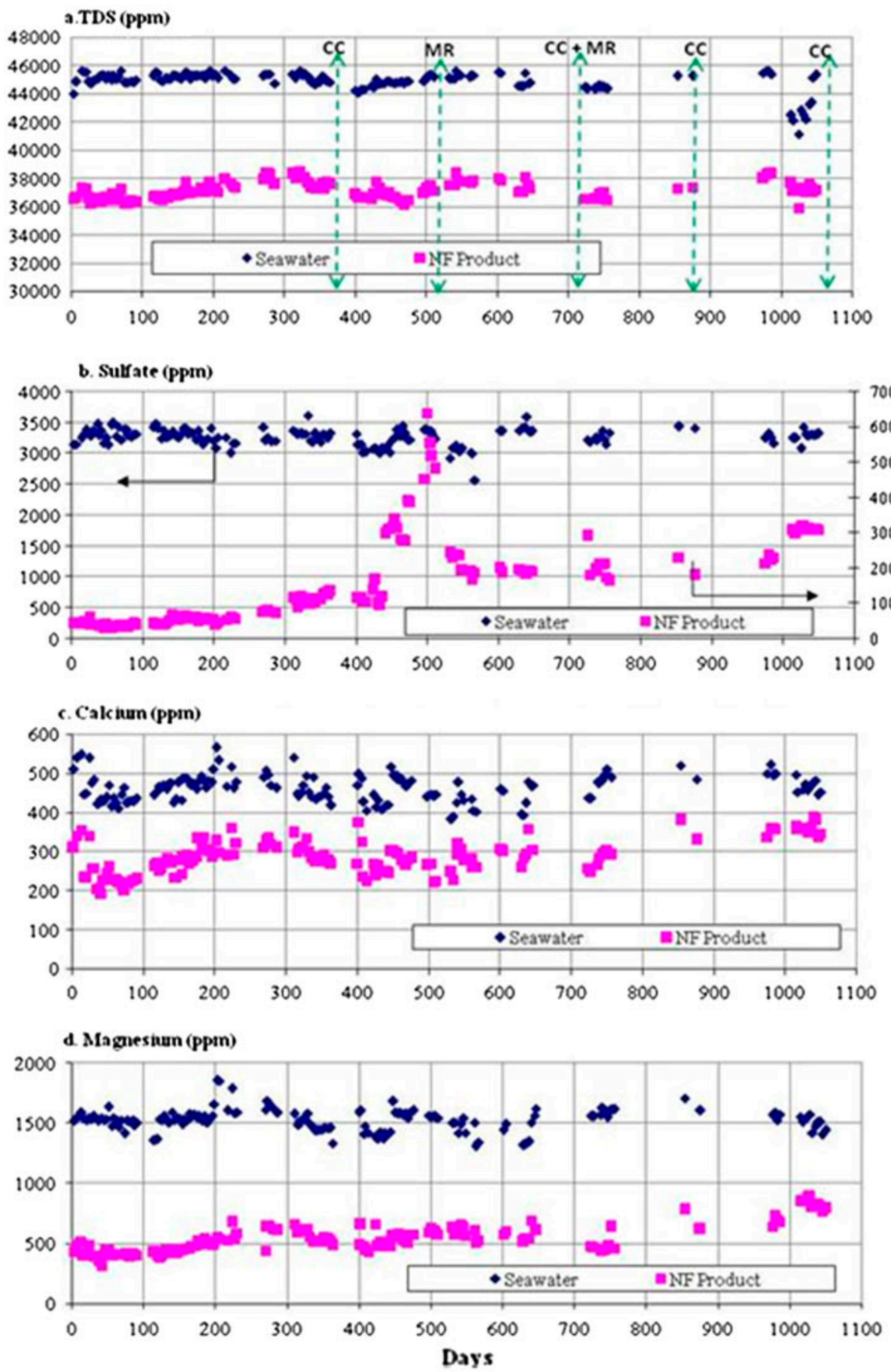

Fig. 2. Chemical analysis (TDS, Sulfate, Ca, and Mg) results of NF unit coupled with SWRO and MED in a tri-hybrid system (CC = chemical cleaning and MR = membrane replacement).

>25 bar. This abnormal rise in pressure was investigated and was found to be due to scaling of tail-end membranes which occurred due to the failure of ERD system. Scaling was found due to deposition of $CaSO_4$ which was chemically cleaned and the performance was restored to some extent. Since the scaling occurred in the second stage, only the second stage of the NF unit was subjected to chemical cleaning. The chemical cleaning procedure consisted of a high pH cleaning using a mixture of sodium dodecylsulfate and ethylene diamine tetra-acetic acid followed by a low pH cleaning using only hydrochloric acid (HCl).

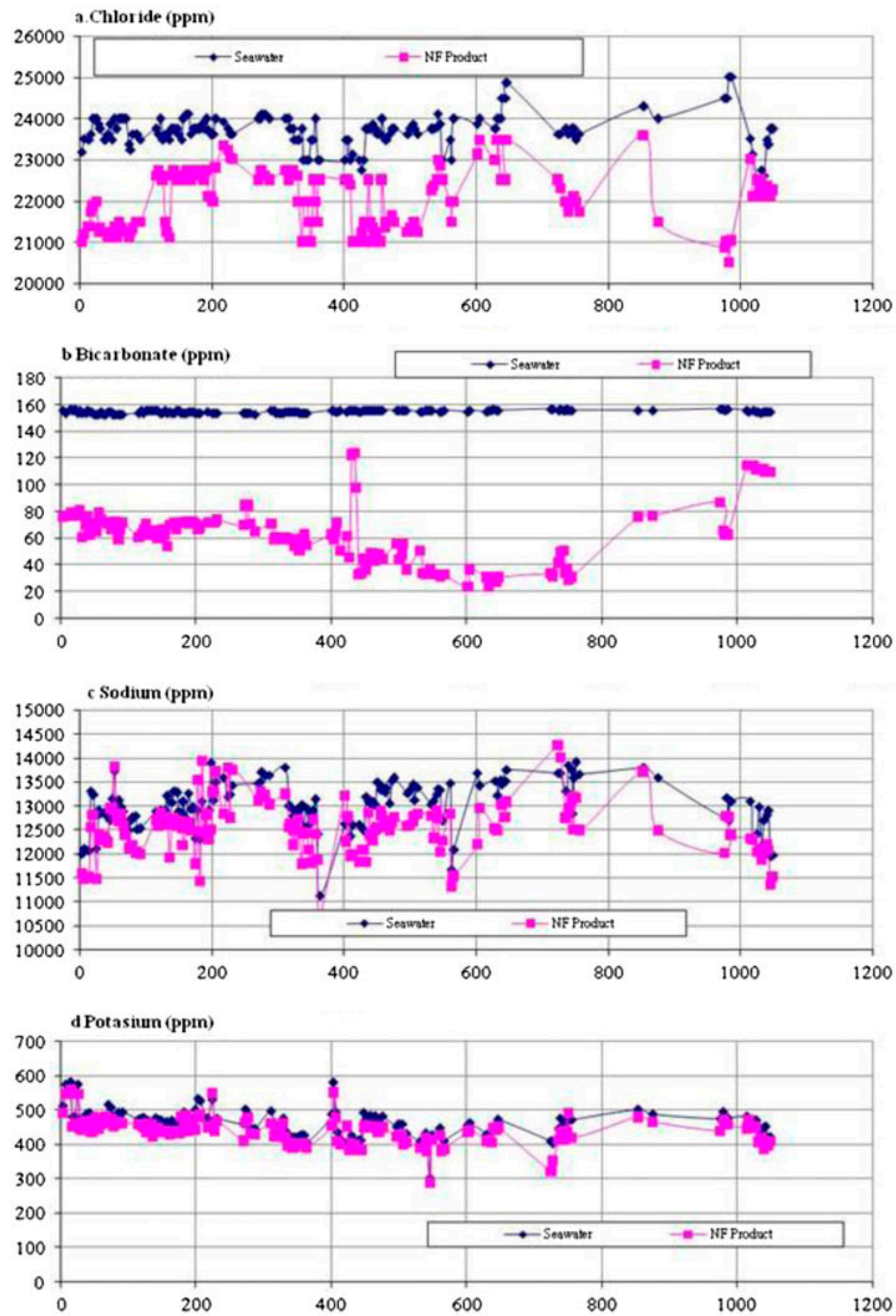

Fig. 3. Chemical analysis (chloride, bicarbonate, Na, and K) results of NF unit coupled with SWRO and MED in a tri-hybrid system.

This cleaning resulted in increased recovery of second stage compared with the first stage as can be seen in Fig. 1. This could be due the fact that the flow resistance due to scaling was removed by chemical cleaning performed in the second stage. However, as there was no chemical cleaning done on the first stage, there existed some resistance for the flow due to probable fouling on the membranes in the first stage. Even after chemical cleaning, the feed pressure slowly increased to 25 bar at about 530 d of operation due to which 2 NF elements each from the feed side elements and 2 elements from the end side were replaced (a total of 6 elements) with new ones. This amounts to a 33% of membrane replacement which was executed after

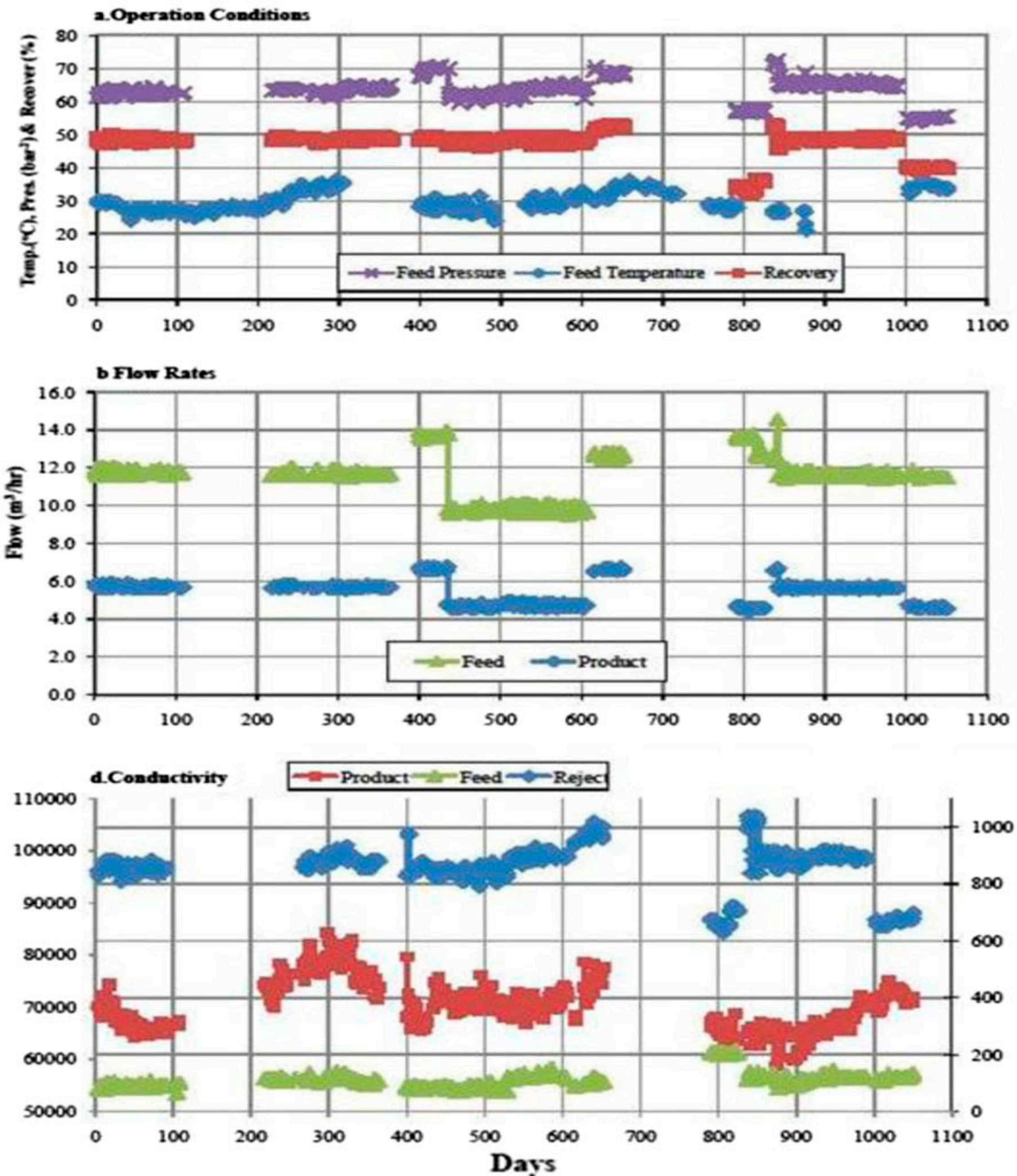

Fig. 4. Performance of SWRO unit receiving feed from NF unit coupled with MED in a tri-hybrid system.

about 1.5 years of continuous operation. Following the membrane replacement, the feed pressure was reduced to the initial value of about 10 bar and performance was continued to be steady with only a gradual increase in feed pressure, which is obvious due to slow membrane fouling. However, at about 700 d of operation pressure, it suddenly rose from 15 to 22 bar which indicated a scaling on the end element, which was confirmed by membrane inspection. Hence, chemical cleaning was conducted on both first and second stages followed by the replacement of one end element. This amounts to a mere 6% membrane replacement after about 2 years of operation. Following that a total of two more chemical cleanings were only conducted when feed pressure was found to increase.

A total of only four chemical cleanings were performed on the NF unit during the entire period of 3 years in operation. Also, a total of only seven NF membranes were replaced during the test period which amounts to an average of 13% annual membrane replacement rate which is quite acceptable in membrane industries. Nevertheless, some of the chemical cleaning and membrane replacement could have been avoided if problem with isobaric ERD would not have happened. Tail-end membrane elements were replaced on two occasions due to deposition of heavy $CaSO_4$ scale which occurred due to the failure of isobaric ERD system. NF unit was most of the time operated at feed pressure of <15 bar and it increased above this value which was up to 25 bar, only during the occurrence of scale deposition on end elements. NF product quality was maintained constant in the narrow range of TDS between 36,600 and 37,600 ppm from a feed TDS of about 45,000 ppm despite large variation in feed temperature (Fig. 2). This amounts to a TDS rejection in the range of 16–19%. Even the concentrations of scale-forming divalent ions such as Ca^{++}, Mg^{++}, and SO_4^{-} were in the narrow range. However, rejection of SO_4 was significantly reduced whenever scaling occurred in the second stage due to ERD failures. Rejection of mono-valent ions such as chloride, bicarbonate, sodium, and potassium was very low as can be seen from Fig. 3. This is typical of NF membrane rejection properties. These properties of NF membrane were better and much different from that was used at Ummlujj [8] and resulted in steady performance of SWRO unit which received NF product as feed.

SWRO unit which received NF product as feed was mostly operated at a recovery of 48% with an average flux of 13.5 LMH. The performance of SWRO membranes was excellent as expected due to very clean feed water as well as moderate flux operation as shown in Fig. 4. Feed pressure was varied between 60 and 70 bar based on the recovery ratio which was governed mainly by the requirement of tri-hybrid system. During the three years period, no chemical cleaning or membrane replacement were carried out due to excellent membrane performance. The product conductivity was mostly below 400 μS/cm despite large seasonal variations in feed water temperature, which ranged between 17 and 36˚C.

4. Conclusions

It can be concluded that the NF membranes used in this study had excellent performance, especially its ability to maintain its performance regardless of fouling, cleaning, and long-term operation. This remarkable performance of NF membrane was also reflected in the excellent performance of SWRO unit which received feed from NF unit. Moreover, the feed pressure requirement was low (<15 bar) for the NF unit. Hence, the NF membrane used in this study is recommended to be used for the pretreatment of seawater prior to either membrane or thermal desalination system which can result in low maintenance as well as low cost.

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