

Preliminary study on novel backwash cleaning for reverse osmosis fouling control in water reuse

Jian-Jun Qin, Maung Htun Oo and Kiran A. Kekre

ABSTRACT

We have demonstrated a novel backwash cleaning technique of direct osmosis (DO)-high salinity (HS) for reverse osmosis (RO) fouling control in water reuse. An UF-RO pilot system was continuously (24-h) operated on site with the secondary effluent as the feed over 4 months. The RO plant was run at 75% recovery and at the membrane flux of $17 \text{ l m}^{-2} \text{ h}^{-1}$ (LMH) to simulate the full scale NEWater production when DO-HS treatment was conducted once per day and five times per week during the last two months. Permeability of RO membranes as a function of elapse time of the pilot operation was monitored and compared over different durations. Impact of DO-HS treatment on RO product quality in terms of TOC and conductivity was investigated. It was concluded that the DO-HS treatment preliminarily demonstrated a benefit to low RO fouling rate by 2.5–4 times in 30–60 days without interruption on RO operation and impact on RO product quality.

Key words | fouling control, high salinity, osmosis backwash, reverse osmosis, water reuse

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INTRODUCTION

Reverse osmosis (RO) membrane fouling is a global issue. Colloidal fouling, biofouling, organic fouling and inorganic fouling/scaling are major types of RO fouling. The common fouling factors, typical preventive strategies and their efficiency have been well documented (Byrne 2002; Tang & Leckie 2007; Tang *et al.* 2007; Tang *et al.* 2009; Qin *et al.* 2009a). Some new physical cleaning methods such as air sparging and forward/reverse flushing have showed efficiency for specific fouling control (Cornelissen *et al.* 2006), but cleaning-in-place (CIP) with chemicals is the most commonly utilized to remove foulants and maintain the membrane performance (Kim *et al.* 2002; Chen *et al.* 2003). CIP needs a downtime for frequent RO operation stoppage, resulting in low effectiveness of production. CIP also creates environmental issues related to the waste chemical disposal.

Since spiral-wound RO elements are not back-washable with hydraulic pressure, nowadays forward osmosis (FO) or direct osmosis (DO) backwash cleaning technique for RO has become increasingly attractive as it is a highly efficient and environmentally friendly technique (Rychen *et al.* 1996; Ando *et al.* 2002, 2003; Liberman 2004, 2007; Liberman & Liberman 2005; Sagiv & Semiat 2005; Avraham *et al.* 2006; Sagiv *et al.* 2008), which has been extensively reviewed (Qin *et al.* 2009b). A downtime of RO operation was engaged in the DO backwash investigations (Rychen *et al.* 1996; Ando *et al.* 2002, 2003; Ando *et al.* 2003; Sagiv & Semiat 2005; Avraham *et al.* 2006; Sagiv *et al.* 2008). However, there was no stopping of RO high pressure pump in a new DO cleaning technology development (Liberman 2004, 2007; Liberman & Liberman 2005) where a high salinity (HS) solution was injected into the RO feed over a few seconds. In the new process, a strong driving force for DO backwash (wave of the red

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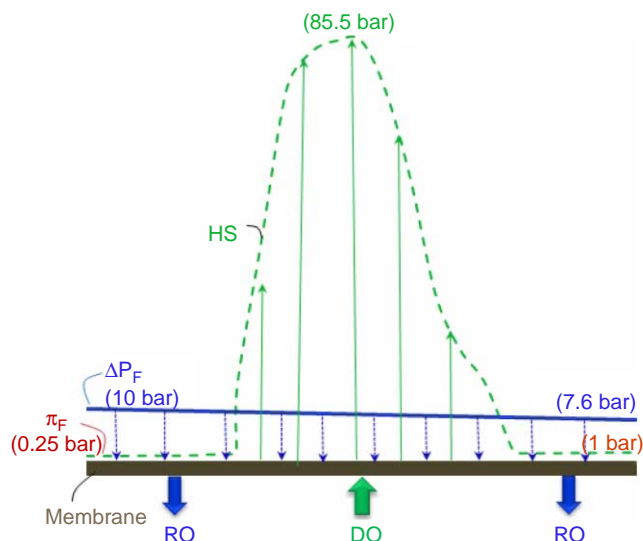


Figure 1 | Schematic of RO and DO with HS injection and driving force profile for DO backwash.

solid line) could be created as shown in Figure 1 (Qin *et al.* 2010) and the foulants could be lift and swapped from the membrane surface and be carried over to the brine as shown in Figure 2 (Lieberman & Lieberman 2005). As a result, high cleaning efficiency could be achieved. The DO-HS technology had been implemented in three full scale brackish water RO plants in Israel (Lieberman & Lieberman 2005).

To date, few studies on the DO-HS method have been reported. In our previous study, the DO-HS technique for RO cleaning was further developed in municipal wastewater reclamation and effects of major parameters and operating conditions were systematically investigated (Qin *et al.* 2010). The objective of this study aimed at demonstrating the efficiency of DO-HS technique for RO fouling control in water reuse for production of high grade water (so-called NEWater) via continuous pilot operation before implementation in a full scale plant.

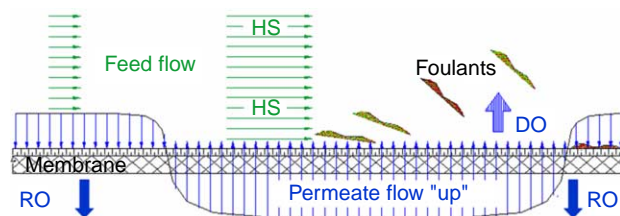


Figure 2 | Schematic of foulants lifting & sweeping during DO-HS cleaning.

EXPERIMENTAL

In this study, an UF-RO pilot system was continuously (24-h) operated on site over 4 months at Changi Water Reclamation Plant (CWRP), Singapore. The secondary effluent from CWRP was used as the raw feed. The RO plant with 3 pressure vessels and six 4-inch elements in each vessel was in 2:1 configuration. The detailed pilot system description and the plant operation for DO-HS treatment were given in the previous study (Qin *et al.* 2010). Table 1 shows typical conditions of DO-HS treatment during the study and Table 2 shows typical operating conditions of the RO plant during DO-HS treatment. Before DO-HS treatment, the RO plant was operated at the membrane flux of 17 LMH and 75% water recovery to simulate the full scale NEWater production. The temperature variation during the operation period was $30 \pm 2^\circ\text{C}$ as it was under tropical conditions.

The RO plant was operated without DO-HS treatment for two months as a baseline study and operated with DO-HS treatment over two months for comparison. New RO membranes were installed for both cases. DO-HS treatment was carried out once per

Table 1 | Typical conditions of DO-HS treatment

Parameter	Unit	Value
Diameter of orifice	cm	4.3
Concentration of HS solution (NaCl)	kg/m ³	136
pH of HS solution	–	6.5
Injection time of HS solution	s	25
Volume of HS solution consumption per treatment	L	15
Maximum conductivity at the RO inlet	mS/cm	158
Maximum conductivity at the RO outlet	mS/cm	60
Maximum brine flow rate	m ³ /h	2.0
Maximum compensated permeate backwash flow rate	m ³ /h	0.7
Total compensated permeate volume per treatment	L	12
Frequency of DO-HS treatment	–	Daily

Table 2 | Typical operating conditions of the RO plant during DO-HS treatment

Parameter	Unit	Value	
		Normal operation	During DO-HS
RO feed flow	(m ³ /h)	3.2	3.2
RO product flow	(m ³ /h)	2.4	1.7
RO feed pressure	(bar)	6.3	10.3
Pressure between Stage 1 & Stage 2	(bar)	5.0	9.0
RO brine pressure	(bar)	4.3	7.6
RO permeate stable pressure	(bar)	0	5.6
RO feed conductivity	(μS/cm)	690	690
RO product conductivity	(μS/cm)	23	24

day except weekends and 5 times per week. HS solution was prepared on site with mixing of industrial grade NaCl and the RO permeate produced from the pilot plant.

RO membrane performance refers to the permeability as defined in Equation (1):

$$\text{Permeability} = \frac{Q}{(A \times \Delta P_{\text{driving}})} \quad (1)$$

where Q is volume flow rate of permeate (L/h), A is effective membrane area (m²), $\Delta P_{\text{driving}}$ is driving force of RO process (MPa) defined as Equation (2).

$$\Delta P_{\text{driving}} = \Delta P - \Delta \Pi = (P_F - P_P) - (\Pi_F - \Pi_P) \quad (2)$$

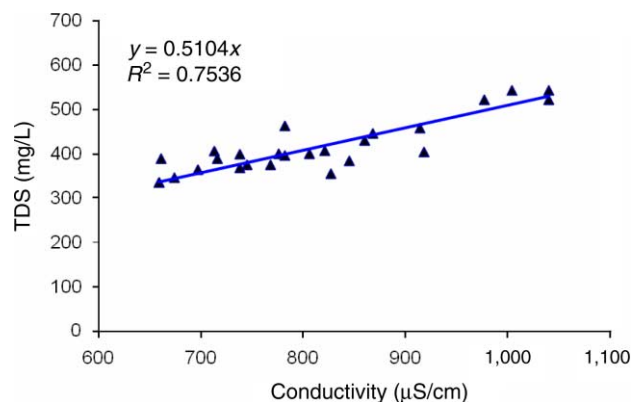
where, P_F is feed pressure; P_P is permeate pressure; Π_F is feed osmotic pressure; Π_P is permeate osmotic pressure.

RESULTS AND DISCUSSION

Effect of DO-HS treatment on RO membrane fouling rate

TDS and conductivity of the RO feed during the study was analyzed and the correlation between TDS and conductivity is shown in Figure 3. The osmotic pressure of RO feed (Π_F) and brine (Π_B) during the plant operation was estimated based to the correction factor of 0.51 obtained from the relationship and an empirical correlation of $\Pi = 1$ psi per 100 mg/L TDS (Byrne 2002). Π_F and Π_B were used in Equation (1) to calculate the permeability of RO membranes.

Figure 4 shows the relative permeability (which is the ratio of permeability at the time over that on Day 1) of RO membranes as a function of elapse time of the plant operation. The slopes in the equations in Figure 4 represent the RO fouling rate. The left set is the baseline of RO performance without DO-HS treatment and the right set is RO performance with DO-HS treatment. The RO fouling rate with the DO-HS treatment was 26, 27 and 39% of that without DO-HS treatment in 30, 45 and 60 days, respectively. The preliminary results indicated that DO-HS treatment indeed demonstrated a benefit to lower RO fouling rate by 2.5–4.0 times in 30–60 days. Moreover, the fresh membranes in the baseline study without DO-HS treatment performed faster fouling rate at the beginning of the plant operation and the fouling rate reduced with the operating time. In addition, no interruption on the continuous RO operation was observed during the DO-HS treatment.

**Figure 3** | TDS vs. conductivity of the RO feed.

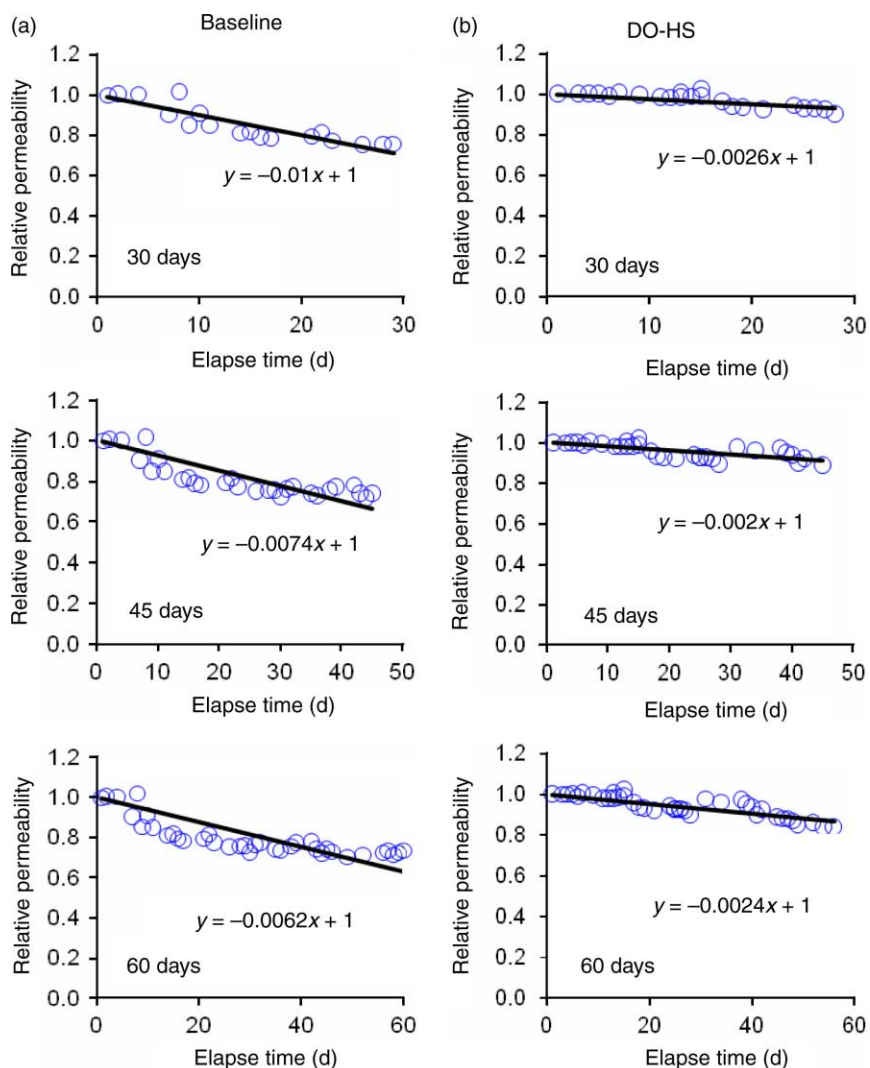


Figure 4 | Comparison of baseline and DO-HS treatment on RO membrane fouling rate (a) Baseline (b) DO-HS.

Impact of DO-HS treatment on RO permeate quality

In Figure 5, the dash-dot line indicates flow rate of the RO permeate before, during and after the DO-HS treatment. When DO-HS initiated, the flow rate of RO permeate started to drop with time because some of permeate production was required for the DO backwash as shown in Figures 1 & 2. When the permeate flow rate showed zero, the RO production rate balanced the requirement for DO backwash. Additional permeate stored in the surge tank was then required to compensate the DO backwash and flowed into the permeate line, which was reverse direction to the normal RO production (the permeate flow rate is

expressed as negative value). The highest compensated permeate flow for the DO backwash was $1 \text{ m}^3/\text{h}$ and at the moment all HS entered the RO membranes and the DO backwash flow through the RO membrane was the highest. Then, the compensative permeate flow rate for DO backwash reduced till zero again. After that, the permeate flow rate increased with time because the RO production could provide enough permeate for DO backwash. The solid line shows on-line TOC of the RO permeate, which is the most concerned parameter for NEWater quality. Change of RO permeate TOC before, during and after the DO-HS treatment was very little. Moreover, RO permeate TOC was even slightly lower after DO-HS treatment due to

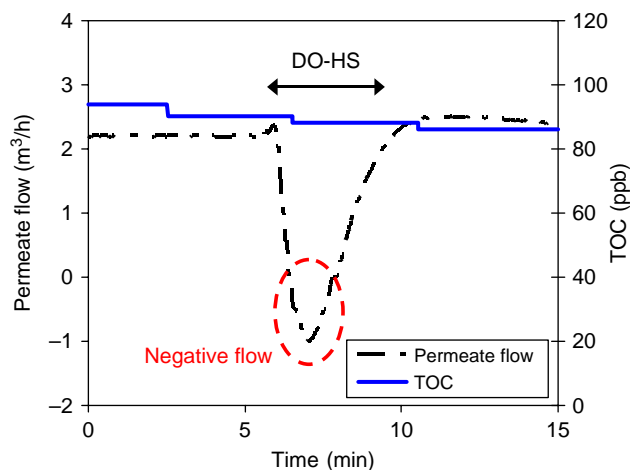


Figure 5 | RO permeate flow rate and TOC during DO-HS.

a higher permeate flow rate than that before DO-HS treatment. The results indicated no impact of DO-HS treatment on RO permeate TOC.

Figure 6 shows permeate conductivity during the DO-HS treatment increased with HS injection time (10, 15, 20, 25 s in the order from the left to the right). In the case of this pilot operation, the permeate conductivity with HS injection time of 25 s was about 200 $\mu\text{S}/\text{cm}$ and the duration last about 2 minutes. There would not be an issue for the overall permeate quality because the impact of permeate conductivity during the DO-HS treatment on the overall product conductivity could be negligible comparing 2 minutes of the DO-HS treatment to 24 hours of normal continuous production.

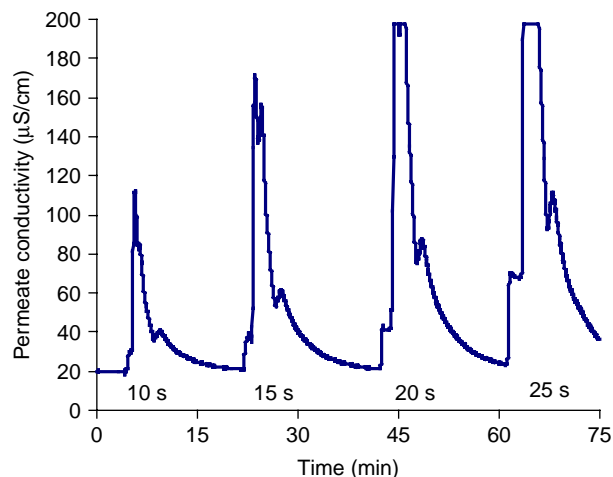


Figure 6 | Effect of HS injection time on permeate conductivity.

Frequency of the DO-HS treatment, HS injection time and HS concentration may be further optimized in order to cut down salt consumption before it is implemented in a full scale NEWater production.

CONCLUSIONS

From the preliminary results of the pilot study, the conclusions can be drawn as follows:

- (1) The DO-HS method demonstrated a benefit to lower RO fouling rate by 2.5–4 times in 30–60 days.
- (2) There was no impact of the DO-HS treatment on RO product quality in terms of TOC and conductivity.
- (3) The DO-HS cleaning method could be easy to implement for RO plants in water reuse without need for plant shutdown.

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