Optimization of Direct Osmosis-High Salinity Cleaning for RO Fouling Control in Water Reuse

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Abstract
This paper focuses on the systematic approach adopted towards optimizing the salt consumption when using direct osmosis-high salinity (DO-HS) cleaning method for RO membranes in water reuse application. Trials were carried out on a pilot RO system with a capacity of 50 m^3/day. Initially, proof of concept for the DO-HS method in water reuse application was established wherein the profile of osmotic driving force for DO backwash, DO backwash flow during HS injection, removal of foulants with DO-HS treatment and lower RO fouling rate with the DO-HS method were demonstrated. 6 months of trials further demonstrated that RO membrane fouling rate and CIP frequency could be significantly reduced with the DO-HS method and there was no impact on the performance of RO membranes. Further trials were carried out focusing of salt requirements and it was found that salt injection duration could be reduced by 68% while the 48-h interval of salt injection was not recommended. Currently, the salt consumption has been reduced from the initial at 0.5 ton to the current at 0.16 ton as per 10,000 m3/day production. The study is ongoing to achieve the target of 0.05 ton for ease of operation.

Keywords Direct osmosis; salinity solution; backwash cleaning; reverse osmosis; fouling control; water reuse.

INTRODUCTION

Reverse osmosis (RO) membrane fouling is a global issue in all RO plant operation. Although some new physical cleaning methods such as air sparging and forward/reverse flushing have been investigated, cleaning-in-place (CIP) with chemicals is still the most commonly applied to remove foulants and maintain the membrane performance (Byrne, 2002; Chen *et al.* 2003; Qin *et al.* 2009a). All the current cleaning methods require shutdown for the RO operation and the most of the downtime of plant operation for maintenance is attributed to CIPs, resulting in low effectiveness of production. CIPs also shorten the membrane lifetime and create environmental issues related to the waste chemical disposal.

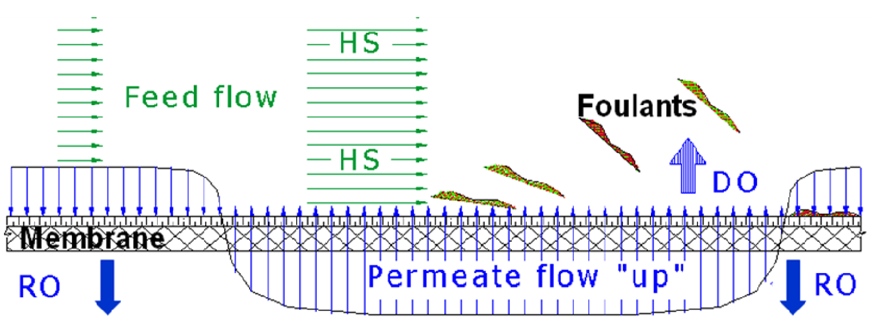

Figure 1 Schematic of foulants removal during the DO-HS cleaning

Over the last decade, investigations on direct osmosis (DO) backwash cleaning technique for RO membranes have been increasingly attractive as spiral-wound RO elements are not back-washable with hydraulic pressure, which has been extensively reviewed (Qin *et al.* 2009b). However, downtime for RO operation was also required in those DO backwash investigations (Ando *et al.* 2001; Ando *et al.* 2003; Sagiv & Semiat 2005; Avraham *et al.* 2006; Sagiv *et al.* 2008). Whereas, there was no need for RO train shutdown in the new development of direct osmosis-high salinity (DO-HS) cleaning technique (Liberman 2004; Liberman & Liberman 2005; Liberman 2007). The DO-HS concept utilizes the direct osmosis (a natural process) to draw water from the permeate side to the feed side by injecting a high salinity solution in to the feed stream over a few seconds during the RO train operation. The reversible flow helps to dislodge any foulants and scaling on the membrane surface as illustrated in Figure 1 (Liberman & Liberman 2005). As a result, an online cleaning purpose could be achieved. The DO-HS technique had been implemented in three full scale RO plants for desalination of brackish groundwater in Israel (Liberman & Liberman 2005).

The objective of this study is aimed at optimization of the DO-HS cleaning method for RO fouling control in water reuse application. Since the salt (NaCl) is only consumable with the DO-HS method, salt consumption is the major concern for implementation in full scale plant. Therefore, a test schedule as shown in Table 1 was planned to minimize the quantity of salt required from three aspects: 1) is to cut down salt injection duration, 2) to decrease salt concentration and 3) to increase the interval of salt injection. The salt consumption has been reduced by 68% from the initial at 0.5 ton to the current at 0.16 ton as per 10,000 m3/day production. The studies are continuing with the aim of further reducing the salt consumption.

Table 1 Test schedule to reduce salt consumption

S/N	Salt injection duration (second)			Salt concentration (%)		Interval of salt injection (hour)				Status/ Study duration	Predicted salt consumption for 10,000m^3/d production (Ton)
Test 1	25			12		24				Complete (2 months)	0.5
Test 2	25			12					48	Complete (1 month)	0.25
Test 3		15		12		24				Complete (6 months)	0.3
Test 4			8	12		24				In progress (Apr-Sep 2010)	0.16
Test 5			8		6	24				6 months	0.08
Test 6			8		6		30			3 months	0.06
Test 7			8		6			36		3 months	0.05

PROOF OF THE DO-HS CONCEPT IN WATER REUSE

For proof of the concept, various operating conditions for DO-HS treatment were tested and trials were carried out with a containerized pilot RO system of 50 m^3/day capacity as shown in Figure 2. The pilot plant was operated on site with the UF/MF filtrate as the feed that was produced from the secondary treated effluent. The RO pilot plant was in 2:1 configuration with two stages and was operated at 75% recovery during the study to simulate the full scale NEWater production (Qin *et al.* 2010).

Figure 2 Containerized pilot RO plant

Step 1 - Demonstration on profile of osmotic driving force for DO backwash

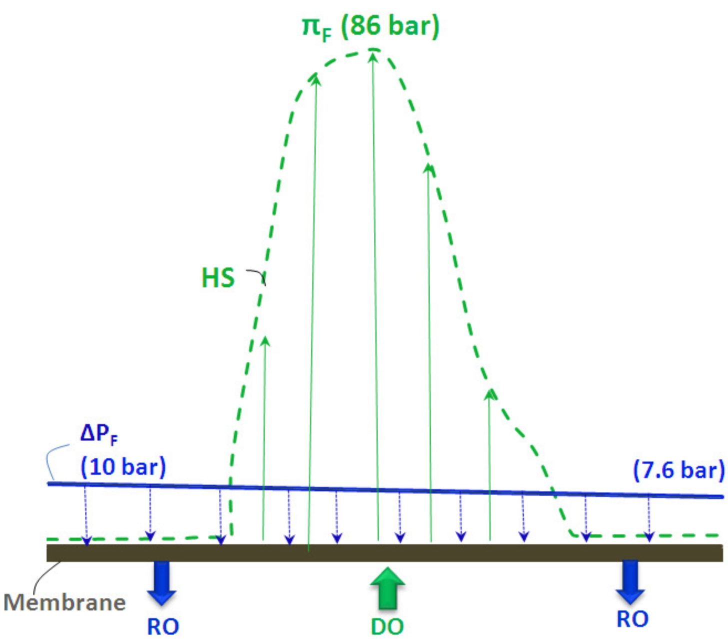

Figure 3 Profile of osmotic driving force for DO backwash

The profile of the osmotic driving force during DO-HS treatment has been demonstrated as shown by the green dash line in Figure 3. The maximum natural driving force was 86 bar while the RO operating pressure presented by the blue solid line was below 10 bar. However, their directions are opposite. This observation indicated that when a HS solution was injected into the RO feed, there would be a huge natural force to induce the DO backwash to dislodge the foulants from the membrane surface.

Step 2 - Demonstration on DO backwash flow during HS injection

Figure 4 shows RO permeate flow rate of Stage 1 and Stage 2 vs. time during DO-HS treatment. When DO-HS initiated, the permeate flow rate S1 (blue line) at Stage 1 started to decrease with time because partial RO permeate was required for the DO backwash as shown in Figure 1. When the permeate production balanced the requirement for DO backwash, S1 showed zero. After that, S1 became negative and reached the minimum at the time of 0.5 minute, then returned to zero while the permeate at Stage 2 (S2, purple line) compensated the DO backwash of Stage 1. In turn, when DO backwash happened at Stage 2, S2 followed the previous S1 trend while S1 compensated the DO backwash of Stage 2. However, there was a period of time from Minute 3 to 4.5 during which the permeate production at Stage 2 balanced the requirement for its DO backwash and S2 remained zero while S1 slightly increased. The results demonstrated DO backwash indeed took place at both stages of RO during HS injection.

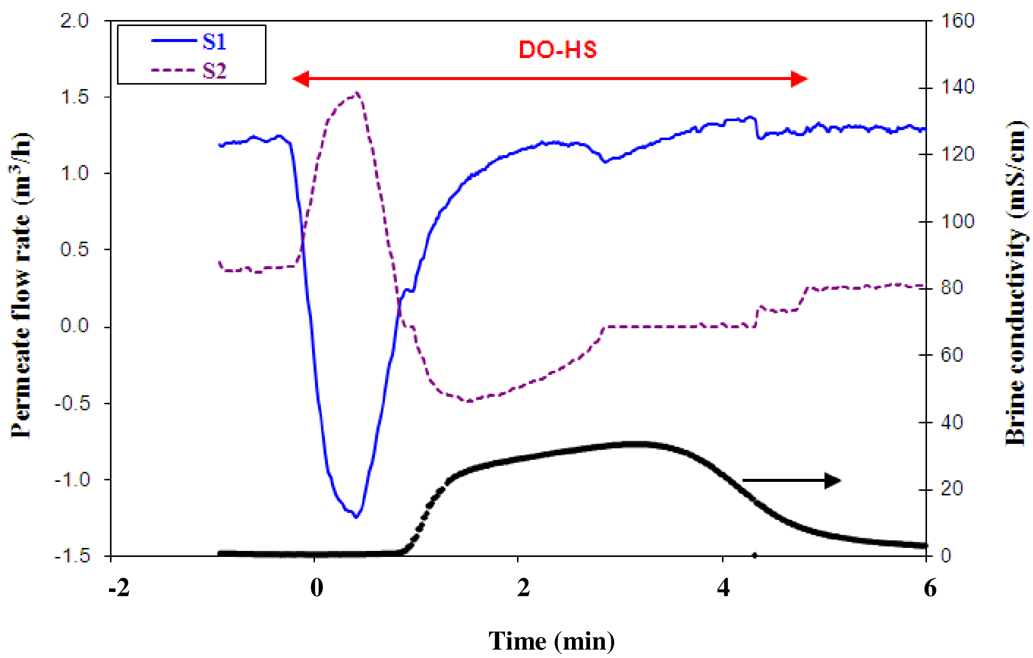

Figure 4 RO permeate flow rate of Stage 1 and Stage 2 vs. time during DO-HS treatment

Step 3 - Demonstration on removal of foulants with DO-HS treatment

Figure 5 illustrates measured turbidity of the RO brine stream as a function of time. The maximum turbidity of the brine stream during DO-HS treatment (3 NTU) was 10 times higher than that (0.3 NTU) before (the first sample) and after (the last sample) DO-HS treatment and majority of the foulants were carried over by HS solution at the time of 1 minute plus right after the HS solution came out from the RO outlet (referring to Figure 4). Furthermore, the analysis on RO brine samples before (the first sample) and during DO-HS (the third sample with the maximum turbidity) in Table 2 shows that concentrations of the potential scalants and organics in the brine steam with DO-HS treatment were higher than that before DO-HS. The results demonstrated that the DO backwash induced by HS injection indeed could dislodge the foulants from the membrane surface which would be carried over to the brine.

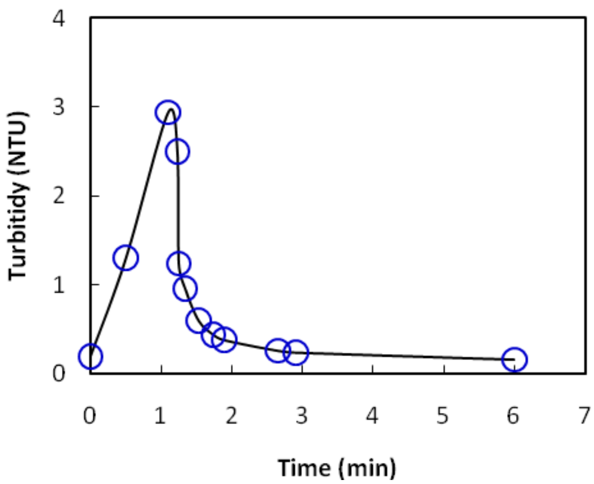

Figure 5 Turbidity of the RO brine stream vs. time during DO-HS treatment

Table 2 Analysis on RO brine samples before and during DO-HS treatment

Parameter	Unit	Before DO-HS	During DO-HS*
Conductivity	mS /cm	1.19	10.88
Turbidity	NTU	0.3	3.05
Barium (as Ba)	mg/L	0.02	0.07
Calcium (as Ca)	mg/L	38	133
Magnesium (as Mg)	mg/L	5.9	21
Total phosphate (as PO_4)	mg/L	15	16
Silica (as SiO_2)	mg/L	19	21
Strontium (as Sr)	mg/L	0.10	0.39
Sulphate (as SO_4)	mg/L	125	129
Fluoride (as F)	mg/L	5.8	6.3
DOC	mg/L	12	14

* Adjusted pH to 2 with HCl before analysis except for conductivity and turbidity

Step 4 - Demonstration on lower RO fouling rate with DO-HS method

The first test in Table 1 involved the daily injection of 25 seconds of NaCl solution at 12% over two months compared to that without DO-HS treatment as the control experiment. The results in Figure 6 demonstrated that the RO fouling rate was reduced by 2.5 times. In addition, no interruption on the continuous RO operation was observed during the DO-HS treatment. All the results demonstrated that the DO-HS concept was proven in water reuse. However, the salt consumption was much higher and there was a need to reduce for ease of operation.

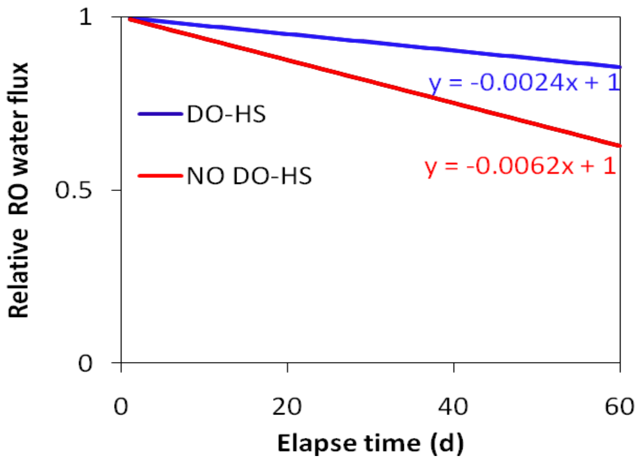

Figure 6 Comparison of RO fouling rate without & with DO-HS method

OPTIMIZATION FOR MINIMIZATION OF SALT CONSUMPTION

Step 1 – Reduction of salt injection frequency

In Test 2 the salt injection frequency was reduced to every alternate day. The results in Figure 7 indicate that RO membrane fouling rate was much faster when compared with daily DO-HS treatment although it was slightly better than that without DO-HS treatment. It meant Test 2 was not successful.

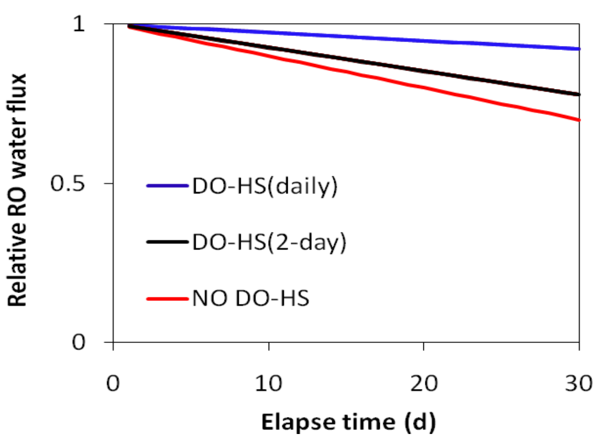

Figure 7 Effect of salt injection frequency on RO membrane fouling rate

Step 2 – Demonstration on reduction in CIP frequency of the RO train

In Test 3, salt injection duration was cut down to 15s while concentration of HS solution and salt injection frequency remained as same as in Test 1. For better comparison, the pilot plant operation was in parallel to a full scale RO train. Our observation over a period of 6 months as shown in Figure 8 further demonstrated that five CIPs were required at Stage 2 of RO for the current full scale operation without DO-HS while only one CIP was conducted for the pilot RO train with the DO-HS method. This means CIP frequency at Stage 2 of the RO train could be significantly reduced with the DO-HS method. The salt consumption was reduced by 40% during this trial. In addition, there was no impact of DO-HS treatments on RO product quality in terms of TOC and conductivity.

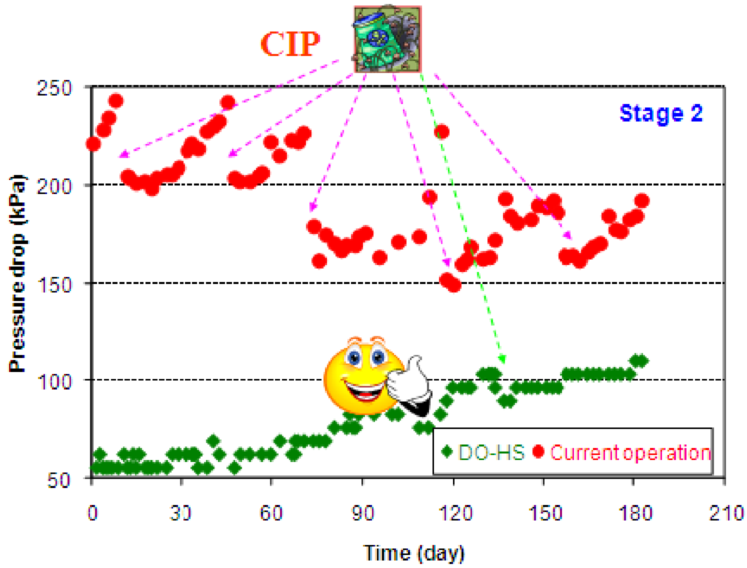

Figure 8 Effect of DO-HS on Delta P of RO operation & CIP frequency

Step 3 – Further cut down of salt injection duration
Our On-going Test 4 with a daily injection of 8 seconds of 12% salt solution also has showed good results over two moths so far and the salt consumption has been reduced by 68% to 0.16 ton for 10,000 m^3/day production, which is manageable.

MOVING FORWARD
The current study Test 4 will last for 4 more months to look into the sustainability. If successful, the DO-HS method can be adopted in full-scale NEWater plants. The target set is to achieve a salt consumption of 0.05 ton per 10,000 m3/day flow capacity.

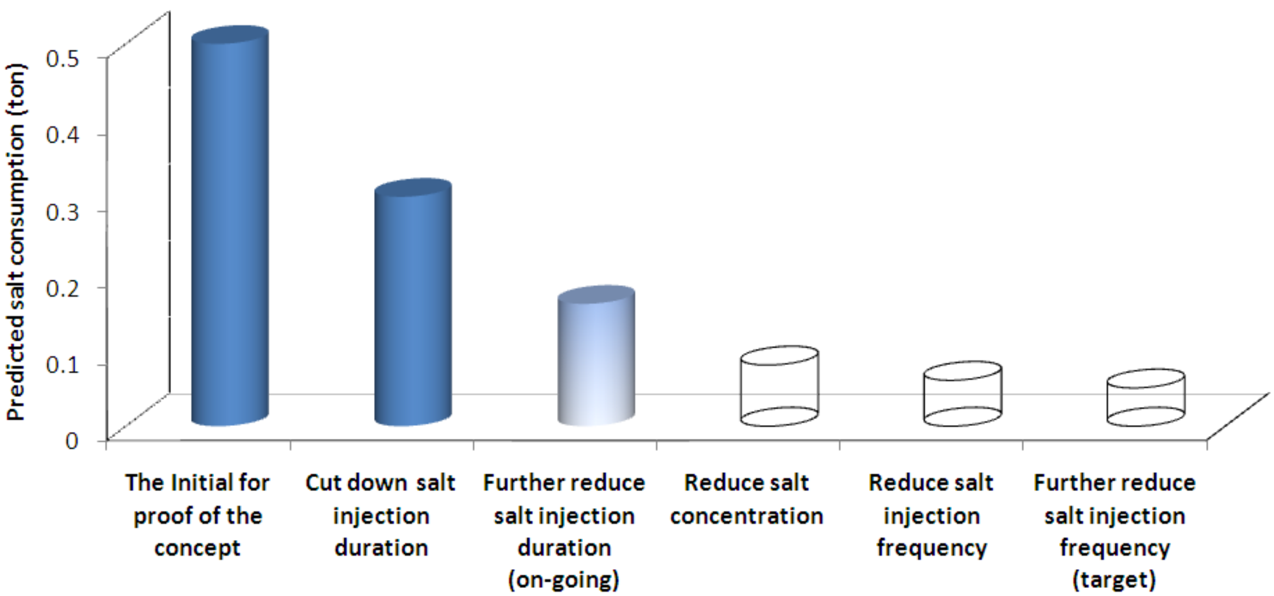

Figure 9 Steps for reduction of salt consumption for 10,000 m^3/day production

In summary, Figure 9 shows the steps taken to reduce the salt consumption from the proof of the DO-HS concept at 0.5 ton for 10,000 m^3/day production to the current consumption at 0.16 ton and to the target at 0.05 ton in the future.

CONCLUSIONS

Following conclusions can be drawn:

1) The concept of DO-HS cleaning works in RO operation for water reuse.
2) The DO-HS method does not require RO train shut down
3) There was no impact on the salt rejection performance of RO membranes during the trials.
4) The DO-HS method demonstrated a benefit to lower the downtime of the RO train for CIPs significantly.
5) The salt consumption was reduced by 68% from the initial at 0.5 ton to the current at 0.16 ton for 10,000 m^3/day production.

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