Preliminary study on novel backwash cleaning for RO fouling control in reclamation of municipal wastewater

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Abstract

The objective of the study was to validate a novel backwash cleaning technique of direct osmosis (DO)-high salinity solution (HS) for reverse osmosis fouling control in reclamation of municipal secondary effluent after it was developed in the previous study. In this study, a UF-RO pilot system was continuously (24-h) operated on site with the secondary effluent as the feed over 4 months and the RO plant was run at 75% recovery and at the membrane flux of 10 gfd to simulate the NEWater production process 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 without interruption on RO operation and impact on RO product quality.

Keywords: Reverse osmosis; backwash cleaning; direct osmosis; fouling control; high salinity; water reclamation.

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 and the common fouling factors, typical preventive strategies and their efficiency have been well documented [1]. Cleaning-in-place (CIP) with chemicals is most widely used to remove foulants and maintain the membrane performance [2] although physical cleaning such as forward/revise flushing and air sparging is effective for specific fouling [3]. However, CIP needs a down time of frequent RO operation stoppage resulting in low effectiveness of production and creates environmental issues related to the waste chemical disposal.

In recent years, forward osmosis (FO) or direct osmosis (DO) backwash cleaning technique of RO has become increasingly attractive as it is highly efficient and environmentally friendly technique [4-13], which has been extensively reviewed [14]. A down time of RO operation was still engaged in the DO backwash investigations [4-10] while there was no interruption of RO operation in a new DO cleaning technology development where a high salinity solution (HS) was injected into the feed water over a few seconds that could induce multiple cleaning mechanisms composed of fouling lifting and sweeping (as shown in Figure 1) as well as bio-osmotic shock and salt dissolve shock, thus could provide high cleaning efficiency [11-13]. The DO-HS cleaning method had been applied in four brackish water RO trains at Dshanim Factory in Israel [12].

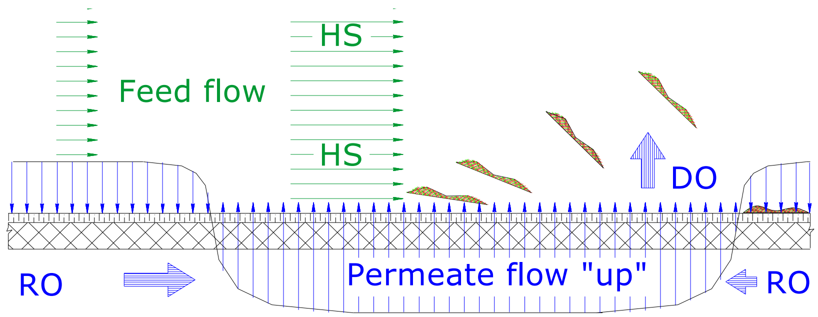


Figure 1 Schematic of foulants lifting & sweeping during DO-HS cleaning [12]

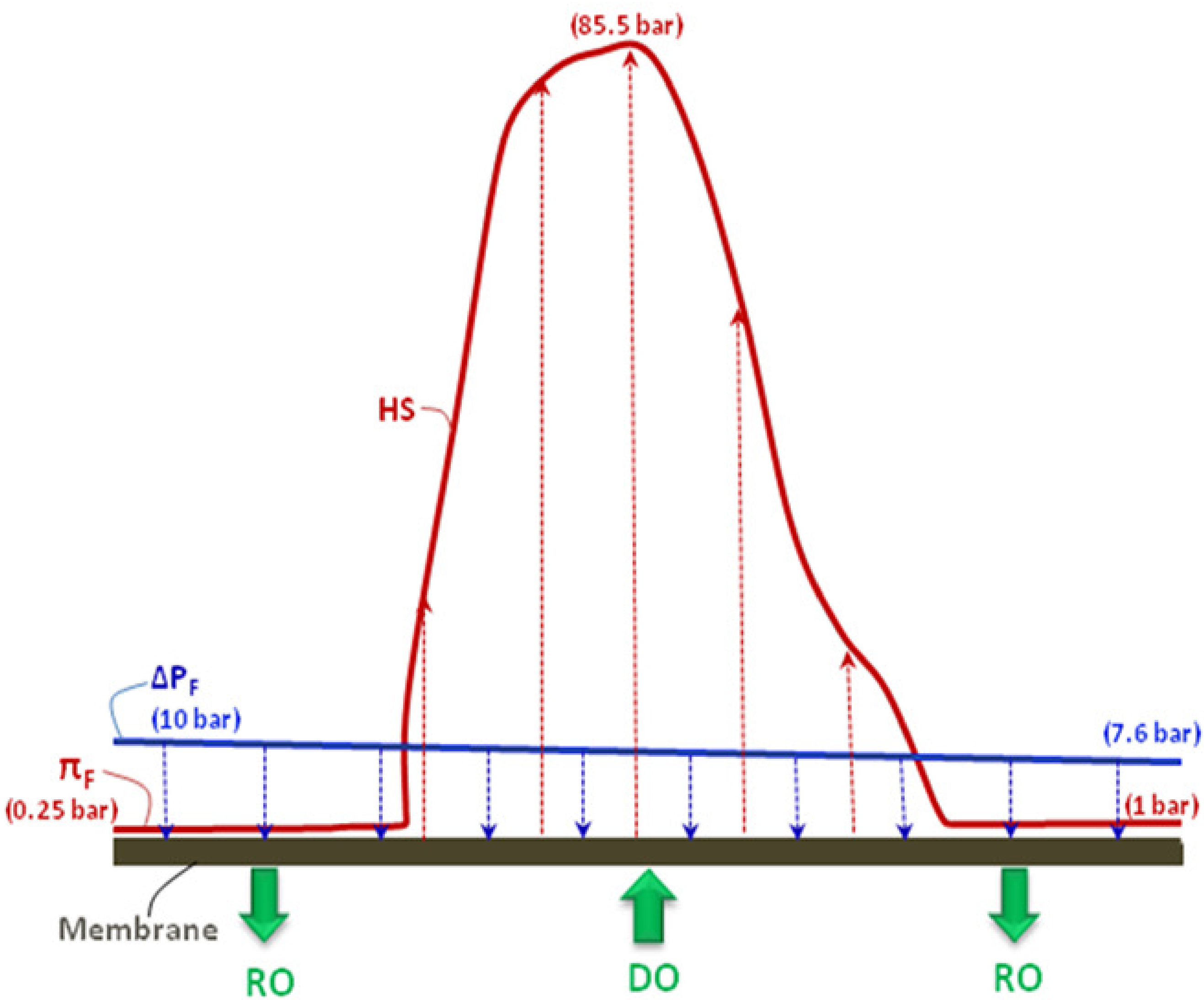


Figure 2 Schematic of RO and DO with HS injection and driving force profile for DO backwash

To date, few studies on the DO-HS method have been reported. In our previous study, the DO-HS backwash cleaning technique for RO was further developed in reclamation of the municipal secondary effluent and the effects of major parameters and operating conditions were systematically investigated [15]. Figure 2 shows a schematic of RO and DO with HS injection and driving force profile for DO backwash in RO membranes [15]. The solid blue and red lines indicate profiles of the gauge pressure and osmotic pressure in the feed channel, respectively. It can be seen that HS caused very high osmotic pressure π_F at the locations in RO membranes where HS reached and the maximum π_F could be 85.5 bar. The objective of this study aimed at validating DO-HS backwash cleaning technique for reverse osmosis fouling control in reclamation of municipal secondary effluent for NEWater production via a continuous pilot plant operation for future practical implementation.

PILOT PLANT STUDY

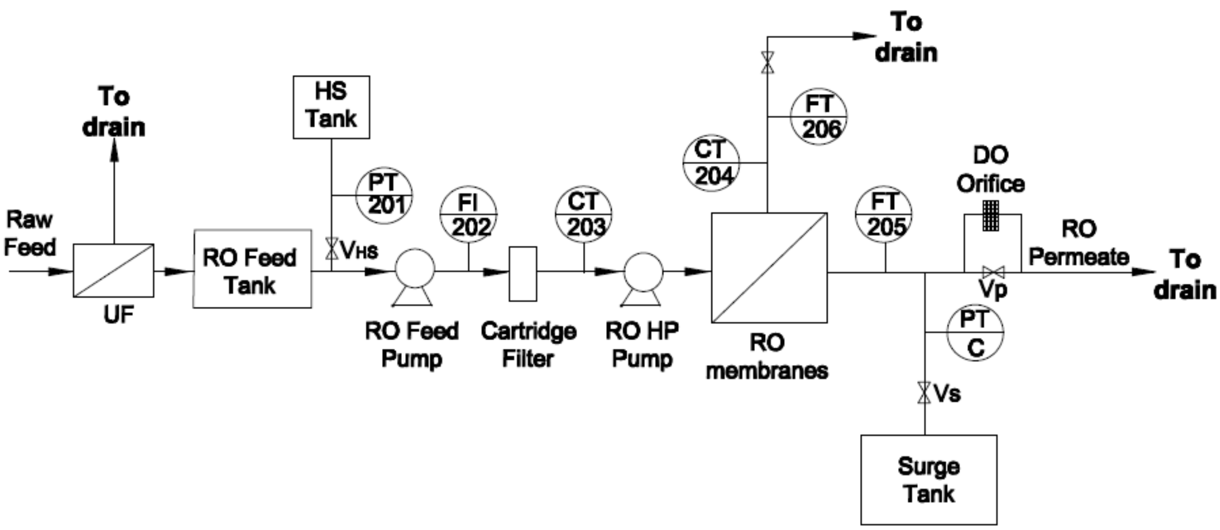


Figure 3 Schematic of the pilot system with DO-HS treatment facility

In this study, a UF-RO pilot system was continuously (24-h) operated on site at Changi Water Reclamation Plant (CWRP), Singapore over 4 months. Schematic diagram of the pilot system with DO-HS treatment facility is shown in Figure 3. The G3 secondary effluent at CWRP was used as the raw feed. The RO plant with 3 pressure vessels and six LFC1-4040 elements in each vessel was in 2:1 configuration with two stages. Major upgrading of the existing RO plant for this study includes the newly installed HS tank, digital pressure gauge to monitor HS consumption, conductivity meters (brand: Flow X3) at the RO feed inlet and brine outlet, pressure gauge of permeate line, surge tank, orifice line, flow meters (brand: GLI Model 53) of permeate backwash and brine. Concentration of the HS at the RO inlet and outlet, flow rates of RO permeate backwash and brine streams as well as pressure of RO permeate line during DO-HS treatment were on-line monitored and recorded in a datalogger. The pilot system description was given in details in previous study [15]. In the first two months, the pilot system was operated without DO-HS treatment as a baseline study. Then the used RO membranes were replaced with new ones and the pilot system was operated with DO-HS treatment over another two months. DO-HS treatment was carried out once per day except weekends and 5 times per week. HS was prepared with industrial grade NaCl and RO permeate on site.

Table 1 Typical conditions of DO-HS treatment

Parameter	**Unit**	**Value**
Diameter of orifice	cm	4.3
Concentration of HS (NaCl)	kg/m^3	110
pH of HS	-	6.5
Injection time of HS	s	25
Volume of HS consumption per treatment	L	15
Maximum conductivity at the RO inlet	mS/cm	60
Maximum conductivity at the RO outlet	mS/cm	158
Maximum brine flow rate	m3/h	2.0
Maximum compensated permeate backwash flow rate	m3/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**	
		Before DO-HS	During DO-HS
RO feed flow	(m3/h)	3.2	3.2
RO product flow	(m3/h)	2.4	1.7
RO feed pressure	(psi)	92	150
Pressure between S1&S2	(psi)	73	130
RO brine pressure	(psi)	62	110
RO permeate stable pressure	(bar)	-0.11	5.6
RO feed conductivity	(uS/cm)	690	690
RO product conductivity	(uS/cm)	23	24

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, which are based on the recommendations for DO-HS treatment in future continuous pilot operation in the previous study [15]. Before DO-HS treatment, the RO plant was operated at membrane flux of 10 gfd and water recovery of 75% to simulate the NEWater production process. Three simple steps were added to the plant operation for DO-HS treatment: 1) Close the permeate valve Vp to create permeate pressure with a desired orifice, meanwhile permeate for backwash was stored in the surge tank; 2) Open valve V_{HS} over the desired time to inject HS into the RO feed line by gravity; 3) Resume the normal RO operation via opening Vp after completion of a DO-HS treatment.

Membrane performance refers to the permeability as defined in equation (1):

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

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

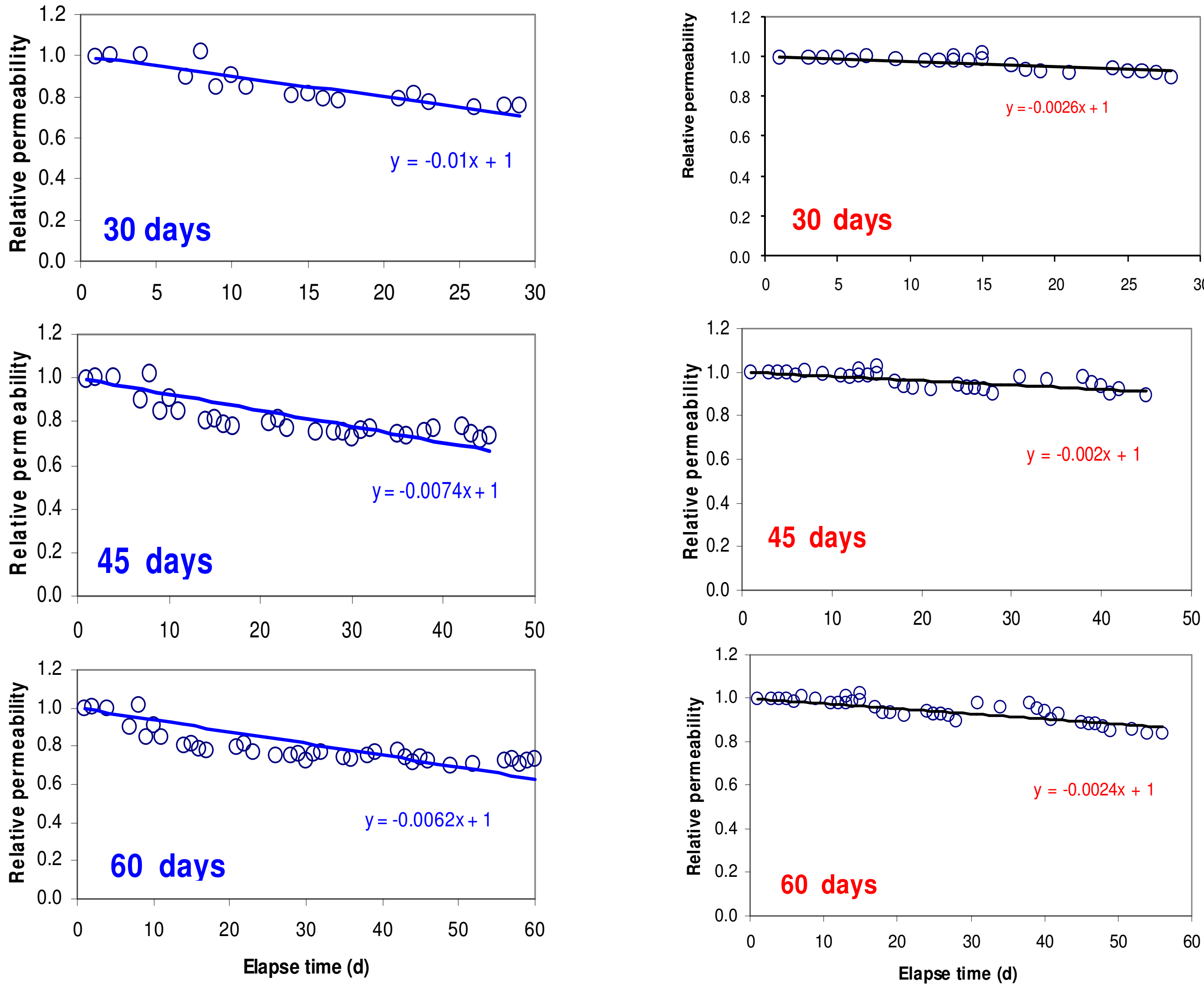
$$\Delta P_{driving} = \Delta P - \Delta \Pi = (P_F - P_P) - (\Pi_F - \Pi_P) \quad (2)$$

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

RESULTS AND DISCUSSION

Effect of DO-HS treatment on RO membrane fouling tendency

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 pilot plant operation. The left set is the baseline of RO performance without DO-HS treatment and the right set is RO performance with DO-HS treatment. It can be seen that the RO fouling rate with the DO-HS treatment was 26%, and 27% 39% of that without DO-HS treatment in 30 days, 45 days and 60 days, respectively. The preliminary results indicated that DO-HS treatment indeed demonstrated a benefit to low RO fouling tendency. In addition, 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.



a. Baseline **b. DO-HS**

Figure 4 Comparison of baseline and DO-HS treatment on RO membrane fouling tendency

Impact of DO-HS on RO permeate TOC

In Figure 5, the purple line indicates the flow rate of RO permeate before, during and after DO-HS treatment as explained in the previous study [15] while the red line shows the RO permeate TOC, which is the most concerned parameter for NEWater quality. It can be seen that there was no much change of RO permeate TOC before, during and after DO-HS treatment, even the on-line TOC was slightly lower after DO-HS treatment due to a higher permeate flow rate than that before DO-HS treatment. The results indicated no impact of DO-HS treatment on RO permeate TOC.

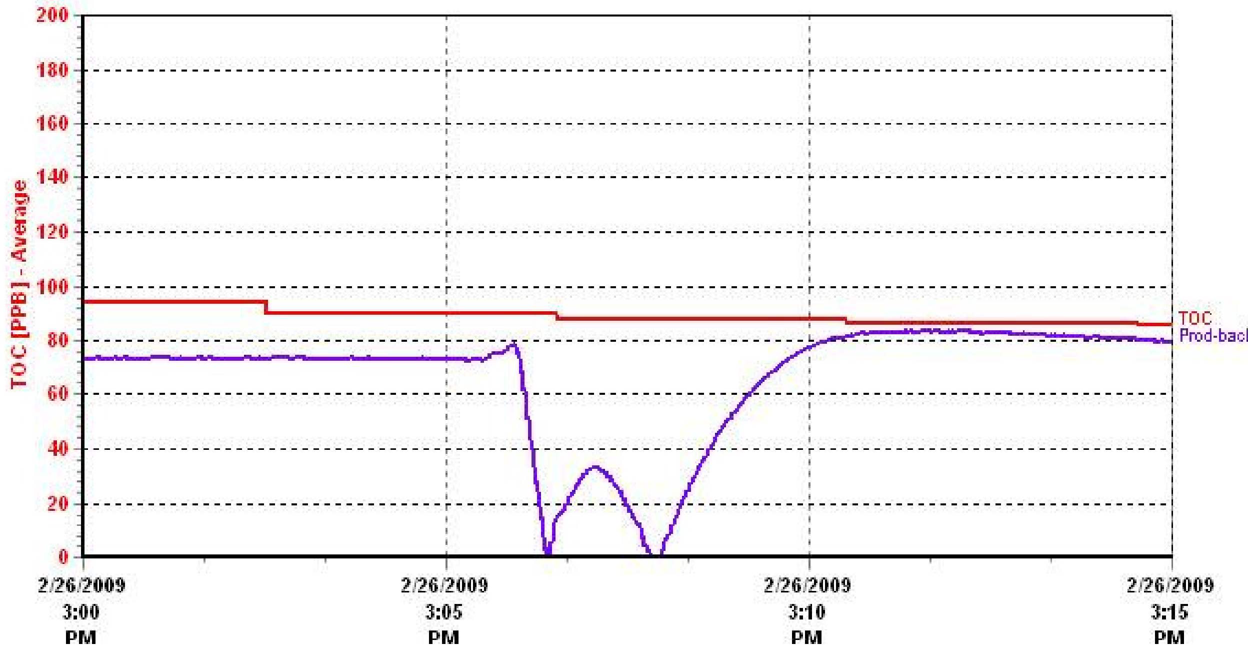


Figure 5 RO permeate TOC during DO-HS

Impact of DO-HS on permeate conductivity

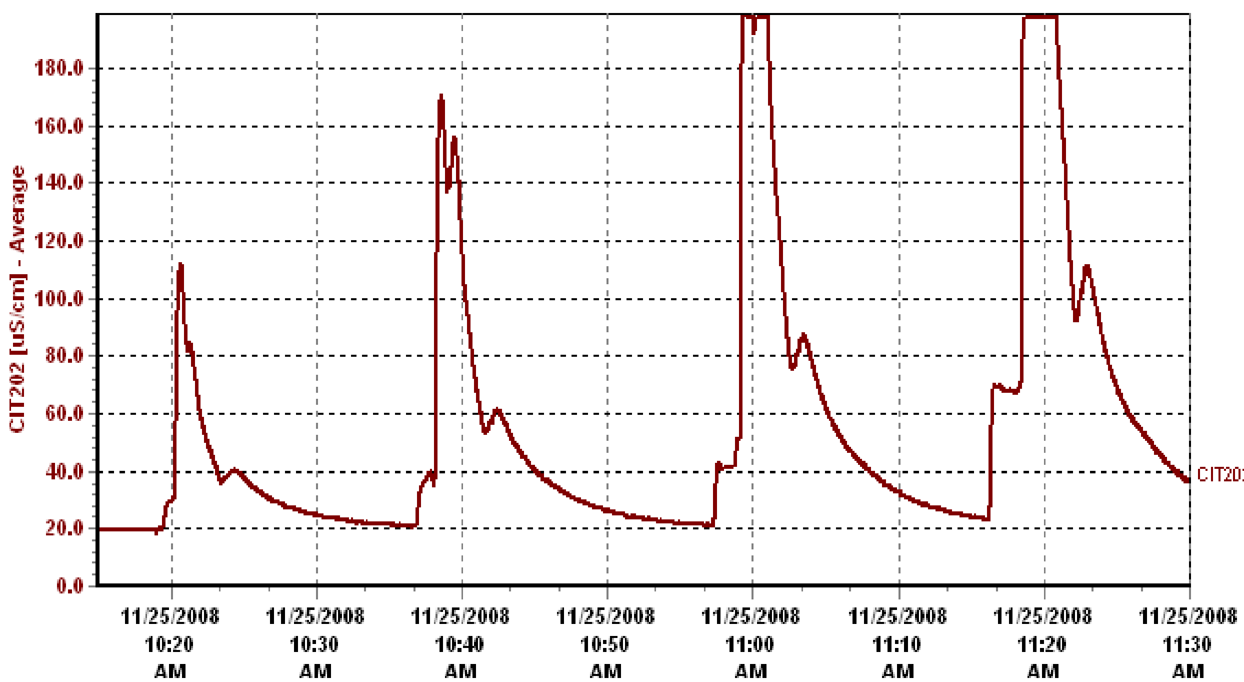


Figure 6 Effect of HS injection time on permeate conductivity

Figure 6 shows permeate conductivity during 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 μS/cm and the duration last about 2 minutes. There will not be an issue for the overall permeate quality because the impact of permeate conductivity during DO-HS treatment on the overall product conductivity can be negligible comparing 2 minutes of the DO-HS treatment to 24 hours of normal production.

Analysis of RO feed and permeate

Table 3 shows the typical analysis of RO feed and permeate during the study. RO feed quality was well within the standard limits. RO permeate quality met the requirement of NEWater.

Table 3 Typical analysis of RO feed and permeate (G3 effluent as the raw feed)

Parameter	**ROF**	**ROP**	**NEWater**
Aluminium (as Al)	0.09	0.04	<0.1
Ammonium-N (as N)	0.3	<0.1	<1.0
Barium (as Ba)	0.007	0.005	<0.1
Boron (as B)	0.08	0.07	<0.5
Calcium (as Ca)	19	0.42	4 – 20
Chloride (as Cl)	100	3.8	<20
Conductivity (uS/cm)	600	35.7	<250
Copper (as Cu)	0.005	0.004	<0.05
Fluoride (as F)	3.0	0.36	<0.5
Manganese (as Mn)	0.03	<0.002	<0.05
Magnesium (as Mg)	2.8	0.06	-
Nitrate-N (as N)	0.39	0.08	<15
pH Value	7.0	6.5	7.0 – 8.5
Phosphate (as PO_4)	7.9	<0.02	-
Silica (as SiO_2)	10	0.7	<3.0
Sodium (as Na)	80	11	<20
Strontium (as Sr)	0.05	<0.01	<0.1
Sulphate (as SO_4)	66	0.3	<5
Total Dissolved Solid (TDS)	349	25	<150
Total Organic Carbon (TOC)	7.5	0.090**	<0.5
Turbidity (NTU)	-	<0.1	<5
Zinc (as Zn)	-	0.08	<0.1

Remarks: **All units are in mg/L unless specified; ** On-line data.*

Relationship between TDS and conductivity in RO feed is shown in Figure 7. The osmotic pressure of RO feed (Π_F) and brine (Π_B) during the plant operation was estimated based to the correction factor of 0.52 obtained from the relationship as well as Π = 1 psi per 100 mg/L TDS. Π_F and Π_B were used in equation (1) to calculate the permeability and relative permeability of RO membranes shown in Figure 4.

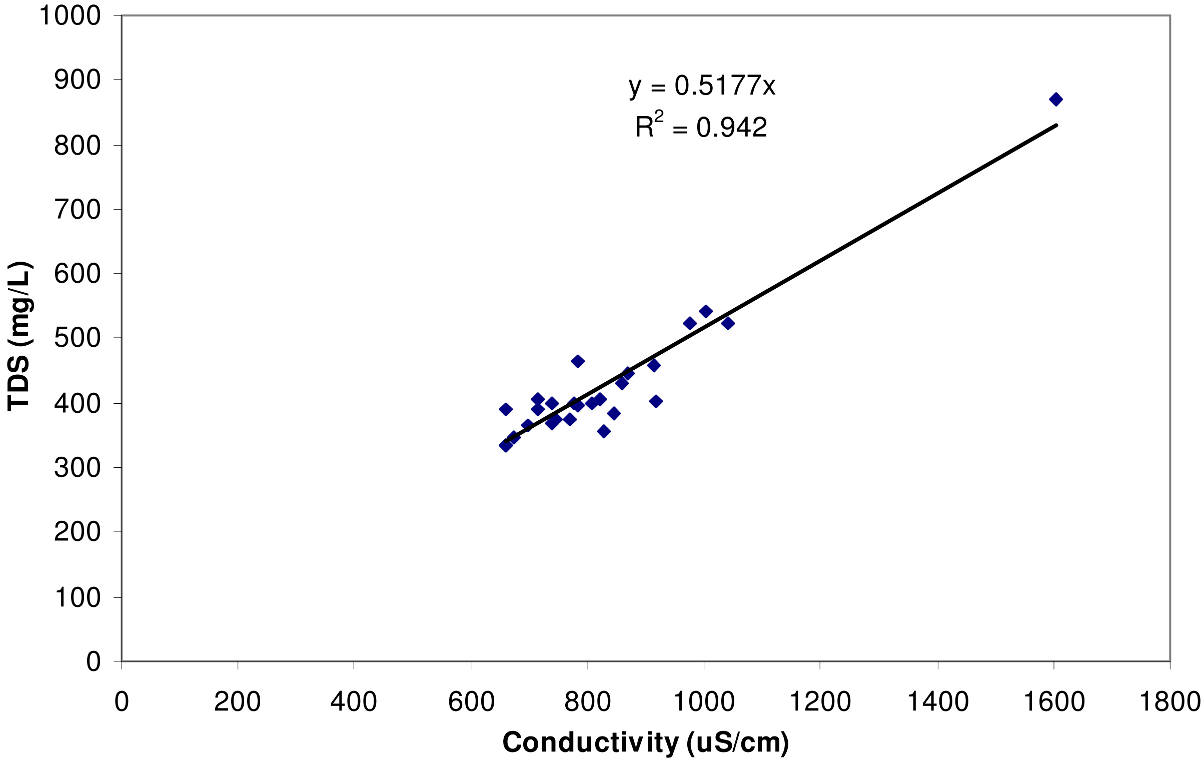


Figure 7 Relationship between TDS and conductivity in RO feed

Future work

The frequency of DO-HS treatment, HS injection time and HS concentration will be optimized in order to cut down the 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 low RO fouling tendency
2) There was no impact of DO-HS treatment on RO product quality
3) The DO-HS method is easy to implement in NEWater production without interruption of RO operation

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