Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.940216

55 (2015) 3358–3366
September

Taylor & Francis
Taylor & Francis Group

RO membrane cleaning using microbubbles at 6,800 m^3/d wastewater RO plant in UAE

Maqsood Fazel*, S. Chesters

Genesys International Ltd., 3A Aston Way, Middlewich CW10 0HS, UK, Tel. +44 1606 837 605; email: mfazel@genesysro.com

Received 1 April 2014; Accepted 16 June 2014

ABSTRACT

It is well known that any fouling of the membrane surface has a dramatic effect on energy consumption and plant efficiency; this is particularly true for waste water reverse osmosis (RO) plants due to the higher fouling rate. Such fouling can be very difficult to clean using commodity chemicals or even speciality chemicals. This paper explores the use of a novel cleaning process designed to increase the efficiency of membrane cleaning using microbubbles. The microbubbles were created by both a physical and chemical process, which circulate in the cleaning solution increasing turbulence at the membrane surface. These bubbles create shear forces which agitate and dislodge the foulant giving greater removal in a reduced time period. In order to demonstrate that there was no damage to the membrane surface or element using this cleaning method with microbubbles, we selected a number of 8´´ membranes from the major membrane manufacturers and performed repeat cleans over a 12 month period. Membranes were autopsied to analyse presence of damage, flux and salt rejection performance, results showed that no damage was caused by using this method. These compatibility results were presented in papers at IDA Tianjin 2013. This paper explains how the multiple cleaning mechanisms (both physical and chemical) help remove foulants and restore performance at a tertiary treated sewage effluent treatment plant producing high quality water for reuse. The 6,800 m^3/d plant treats conventional activated sludge with microfiltration and RO. Cleans were conducted every 2 or 3 months due to reduced flows and high differential pressures. The new cleaning method using microbubbles with specially formulated cleaning compound cleaners demonstrated that the plant could be cleaned more efficiently and in a shorter timescale than using conventional cleaners.

Keywords: Microbubbles; Physical and chemical cleaning; Reverse osmosis

1. Introduction

Foulants on membrane surfaces are rarely of one type but comprise composite layers of different foulants, consisting of primary, secondary and even tertiary layers [1]. The use of formulated cleaning products with multiple cleaning mechanisms offers enhanced cleaning performance by targeting these composite layers [2]. The authors have formulated membrane Cleaners A (alkaline) and B (acidic) which

---

*Corresponding author.

Presented at the Conference on Desalination for the Environment: Clean Water and Energy
11–15 May 2014, Limassol, Cyprus

incorporate effervescent reagents that produce a range of microbubble sizes (5–500 m) which agitate deposits at the membrane surface assisting their removal. The new cleaners also use additional cleaning mechanisms such as high ionic strength compounds causing normal osmosis to occur during periods of soaking, from permeate to the feed side breaking up layered deposits; surfactants and chelants to help solubilise the deposits and effervescents to create microbubbles. The amount of generated microbubbles is further increased physically by using a specially designed microbubble generator which inducts air into the cleaning solution being circulated through the reverse osmosis (RO) plant. The authors discovered that by using specially formulated cleaning agents (Cleaner A or B) the coalescing of micro, mini and midi bubbles into larger bubbles can be minimised. The cleaning reagents create a suspension of bubbles and cleaning solution which distributes evenly over the membrane giving an enhanced cleaning effect. Extensive lab scale experiments with Cleaners A and B with air have been carried out over 18 months using a flat sheet test rig with polycarbonate viewing window. Cleans were then carried out on full 8´´ spiral wound polyamide membrane elements in a single and triple element pressure vessel RO pilot plant. These lab and pilot plant results indicated promising results for foulant removal. Flux rates were improved when compared with using conventional and commodity cleaners and subsequent autopsies confirmed improved cleanliness. The microbubble cleaners were then trialed to help remove foulants and restore performance at a tertiary treated sewage effluent treatment plant producing high quality water for reuse. The 6,800 m^3/d plant treats conventional activated sludge with microfiltration (MF) and RO. Cleans were conducted every 9–10 weeks due to reduced flows and high differential pressures. The new cleaning method using microbubbles with specially formulated cleaning compound cleaners demonstrated that the plant could be cleaned more efficiently and in a shorter timescale than using conventional cleaners.

2. Cleaning with microbubbles

The use of microbubbles, effervescent and high ionic strength cleaners tested in our research facility has resulted in enhanced cleaning of membranes. This is due to increased agitation of deposits on the membrane surface by the combined effect of different chemical and physical mechanisms.

Agitation of deposits at the membrane surface using a wide distribution of bubble sizes are well known for cleaning a variety of deposits in different industries. The cleaning effect occurs "when bubbles expand and collapse close to boundaries, a shear flow is generated which is able to remove particles from the surface, thus locally cleaning it" [3]. Compressed, injected air [4], is used in cleaning and backwashing membrane bioreactors, MF and ultrafiltration membranes but has not been applied successfully to RO membrane elements. The 2 μm polyamide surface of an RO membrane is at a molecular level and very easily damaged by scouring and use of compressed air and so air scouring has traditionally not been used on RO or NF membranes. Research by Willems into using a single source compressed air as a possible method of increasing RO membrane efficiency noted considerable drawbacks due to problems associated with velocity of the introduced bubbles, too low and resultant stagnant bubbles blocked flow through the membrane, too high and the bubbles passed straight from inlet to outlet. Both effects reduce the area coverage of the bubbles [5]. Experiments have shown that when cleaning tests are performed using only air and water with the microbubble generator, the bubbles produced are large (Fig. 1) and inconsistent. The use of commodity chemicals did not reduce the bubble size. Using specially formulated Cleaners A and B in combination with the microbubble generator produced much smaller bubbles (Fig. 2).

When pictured on the membrane flat sheet test rig the air bubbles with water and commodity caustic chemicals tend to become lodged into the feed spacer diamond shape around 1–2 mm in size. This reduces contact between the cleaning solution and the membrane and spacer surfaces thus reducing the chemical affect the cleaning solution could have. The bubble size

Fig. 1. Large bubbles created with air and water.

Fig. 2. Small refined bubbles with Cleaner A + air.

was measured using an endoscope and is shown in Fig. 3. Using the specially formulated cleaning reagents A or B created a suspension of very small bubbles and cleaning solution which distributed evenly over the membrane surface in a pulsed fashion. This phenomenon alleviated the problems discovered by Willems et al. who could not get even distribution of bubbles across the membrane surface [5]. This created a more turbulent cleaning solution, agitating the foulant on the membrane surface for ease of removal. The bubble sizes measured with the endoscope pictured on a flat sheet test rig were between 5 and 500 μm. In order to demonstrate that there was no damage to the membrane surface or element using this cleaning method with microbubbles , we selected a number of 8″ membranes from the major membrane manufacturers and performed repeat cleans over a 12 month period. Membranes were autopsied to analyse presence of damage, flux and salt rejection (SR) performance, results showed that no damage was caused by using this method.

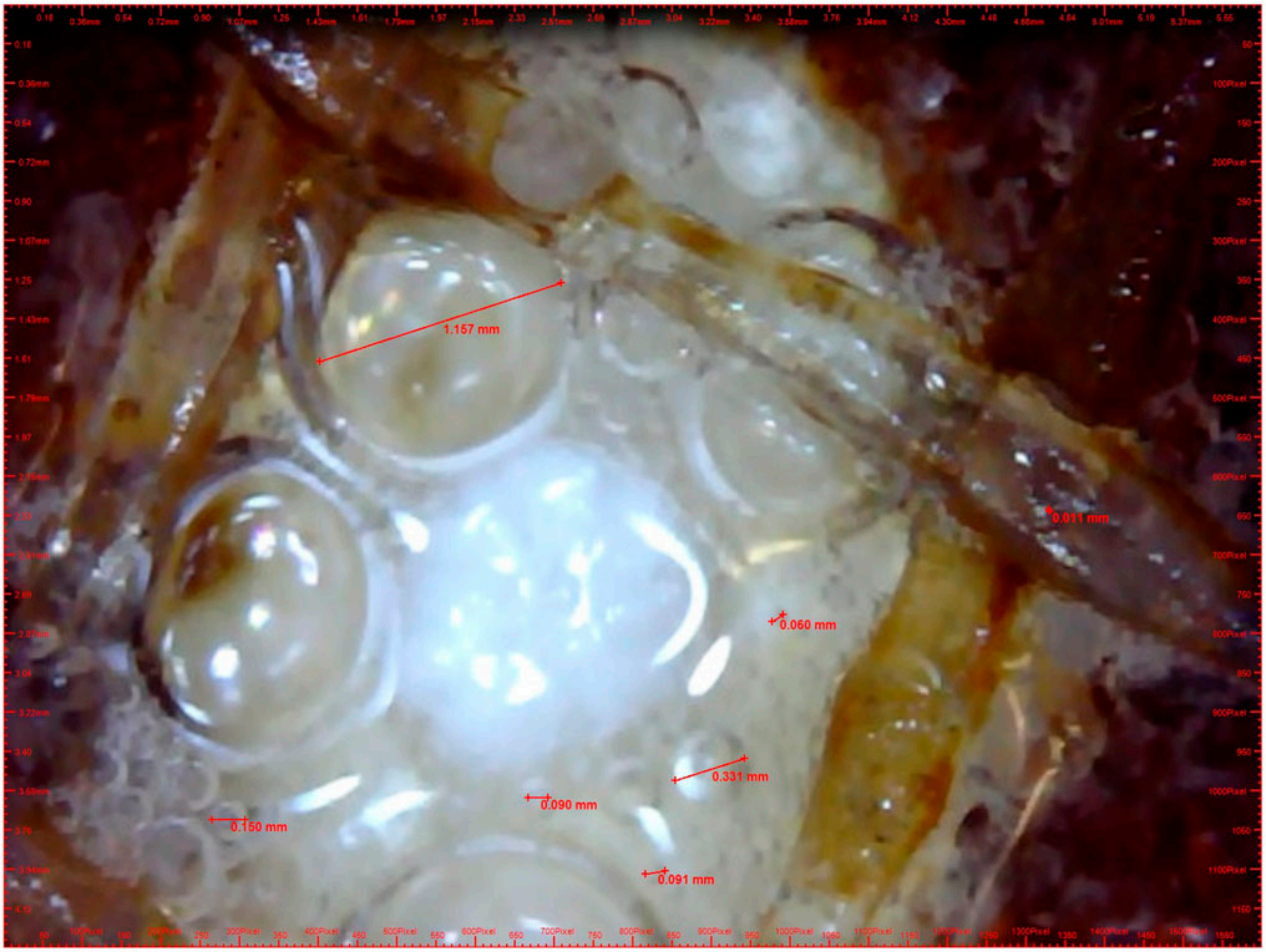

Fig. 3. Small refined bubbles with effervescent Cleaner A (5–500 m).

These compatibility results were presented in papers at IDA Tianjin 2013 [6–8].

2.1. Osmotic effect

During periods of soaking in the cleaning protocol the high ionic strength of the cleaning solution causes movement of permeate across the membrane surface through natural osmosis. This low flow of permeate is sufficient to agitate and dislodge difficult to remove foulants; in particular layers of biofilm or colloidal clay. This then enables the cleaning compounds to further break up, disrupt and remove fouling particles. This in turn would allow greater access to the surfactant cleaning chemicals to remove deposits. The removal of deposits away from the membrane into the concentrate stream is likely to help minimise membrane abrasion.

2.2. Effervescent reagents

When a powder based formulated cleaner including an effervescent reagent is dissolved in permeate water to make up the cleaning solution the effervescent reagents evolve gas as bubbles which physically agitate the foulant during cleaning circulation. This has a dual effect of physically removing the foulant and increasing surface area of the cleaning reagents to the foulant surface. The effervescent creates a wide distribution of mini, midi and microbubbles sizes from 5 to 500 μm (Fig. 3).

2.3. Chemical

Cleaning agents can remove deposits from the membrane surface through a number of reactions notably: hydrolysis, saponification, solubilisation, dispersion (suspension) and chelation. Cleaners A and B are specially formulated high and low pH powdered cleaning reagents containing detergents, chelants, effervescent, surfactants and ionic strength builder. The high pH Cleaner B is used to remove clay, biofilm and organics. Cleaner B mode of action can be described as follows: the first stage of attack occurs at the water/surface inter-phase of the clay deposit and is due to the synergistic mode of operation of the combined speciality chemicals. This process works by reducing the surface tension of the deposit allowing the surfactant to become more effective in overcoming the impermeability of the material; this allows the cleaning solution to penetrate to the inter-layer space of the clay structure. The clay then becomes more porous increasing the permeability to water and consequently increasing the surface area of the deposit allowing more active chemical to penetrate and disrupt the "body" of the deposit. Cleaner B provides a secondary physical action which increases cleaning efficiency at the membrane surface allowing a "double edged" approach to deposit removal. This action removes blockages from the membrane pores caused by the swelling effect of the hydrated clay particles. Low pH is used to remove some mineral scales and metal deposits. The ratio of these reagents in the products is vital to the cleaning process as they incorporate multiple cleaning mechanisms. During our experiments we found that the cleaning reagents A and B when used at a 1–2% solution in conjunction with the microbubble generator had a profound effect on the bubble size distribution and also imparted a pulsing phenomenon on the cleaning solution after exit from the physical generator device. The even distribution of the cleaning and bubble suspension can be seen in Fig. 5.

3. Case study

An RO plant having a history of organic and biofouling was chosen to trial the new microbubble multi-mechanism cleaning approach. The site is a tertiary treated sewage effluent Besix Safi RO plant in the UAE producing high quality water for reuse. The 6,800 m^3/d plant treats conventional activated sludge with MF and RO. Cleans were conducted every 9–10 weeks due to reduced flows and high differential pressures (Fig. 4).

3.1. System description

- Two RO Trains: RO1 and RO2 to treat tertiary treated sewage effluent to quality water for reuse (irrigation, cement mixing, cooling and cleaning).
- Design cap. 6,800 m^3/d plant treats conventional activated sludge with MF and then RO.
- Fouling is suspected to be organics and biofouling.

Feed water source	Tertiary treated municipal effluent (Ajman WWTP)
Pre-treatment	MF
Design feed water TDS	4,000 mg/l
Design RO capacity	694 GMP (3,785 m^3/d) per RO train
Number of RO trains	2
RO array configuration	Stage 1–24 pressure vessels × 6 elements Stage 2–12 pressure vessels × 6 elements

Fig. 4. RO plant.

Design RO average flux	10.9 GFD (18.6 l/m^2 h)
Design water temp.	25℃
Design RO recovery	75%
Element type	Hydranautics LFC3-LD and ESPA2-LD

3.2. System operation

The RO plant was commissioned in 2010 and has been prone to fouling under periods of peak production. The results of autopsies on membrane elements and cartridge filters indicated that foulant is mainly organic and microbiological in origin and some inorganics. A three stage clean was conducted using a Cleaner C and Cleaner D. The biocide and Cleaner C, an alkaline blend of detergent, chelant and surfactant, was used to remove biofilm and organics. Cleaner D is a mild acidic cleaner which when used at a pH of 3.0–4 is very effective at removing calcium phosphate scale and iron. A basic programme of cleaning using Cleaner C and D has been implemented for the past few years. In 2013, two new effervescing products with high ionic strength were introduced, Cleaner A (alkaline) and Cleaner B (acidic). The last two cleans in 2014 have been conducted using these new cleaners and inducted air.

3.3. Cleaning products

The following cleaning products have been used to clean the RO plant.

Product	Description	Mode of use
Cleaner A	Powder alkaline high ionic strength detergent chelant surfactant cleaner with effervescents	1–2% solution, 35–40℃, pH 11–13
Cleaner B	Powder acidic high ionic strength detergent chelant surfactant cleaner with effervescents	1–2% solution, 20–25℃, pH 2.5–4
Cleaner C	Powder alkaline cleaner with high ionic strength	1–2% solution, 35–40℃, pH 11–13
Cleaner D	Liquid mild acid cleaner	2–3% solution, 20–25℃, pH 2.5–4

3.4. Methodology

The cleaning process using conventional Cleaners C and D is outlined below followed by cleaning process using new Cleaners A and B with the installation of the air induction system and methodology for microbubble cleaning.

- *Conventional cleaning*: an alkaline using Cleaner C is conducted first to remove organics and biofilm. This is then followed by a biocide step followed by an acidic clean using Cleaner D to remove calcium carbonate and phosphate scale and metal oxides. The total CIP volume recommended by membrane manufacturers is 40 l/8′′ membrane element for each individual skid being cleaned. In order to prepare membranes for most efficient cleaning heat CIP tank with just permeate to 30–35˚C.
- 2% Cleaner C, pH 12 at 28–30˚C with following times: (20 min circulation/20 min soak/20 min circ) × 3 h.
- 400 ppm Biocide for 1 h circ followed by.
- 2% Cleaner D, pH 2.4 at 27–29˚C for (20 min circ/20 min soak/20 min circ) × 3 h.
- The feed pressure sure just before RO for CIP was 45 psi.
- *Microbubbles*: in order to further enhance the cleaning effect, speed up the process and increase the periods between cleans an air induction device is installed which in combination with Cleaner A produces a suspension of very small mini, midi and microbubbles between 5 and 500 μm in size. The microbubble generator device is installed on a bypass loop of the CIP system after the recirculating pump and cartridge filters on the inlet to the pressure vessels as shown in Fig. 5. The procedure has been fine tuned to a 20 min warm water flush, 20 min recirculation of 2% cleaning solution warmed to 35–40˚C followed by a 20 min soaking period during which permeate flows back across the membrane due to normal osmosis lifting deposits from the feed side membrane surface. The microbubble generator is then put on line by partially opening valves 2, 3 and 4 and partially opening valve 1. The cleaning solution is then circulated for 20 min with microbubbles to dislodge the cake layer on the membrane surface. The recirculation, soaking and microbubble stages are repeated twice maintaining the cleaning solution temperature at 35–40˚C and pH between 11.5 and 12.0 followed by flushing with permeate.
- 2% Cleaner A, pH 12 at 28–30˚C with following times: (20 min circ + Air/20 min soak/20 min circ without air) × 3 h.
- Followed by 6 h soak.
- 400 ppm Biocide for 1 h circ (no air) followed by.
- 2% Cleaner B, pH 2.4 at 27–29˚C for (20 min circ + Air/20 min soak/20 min circ without air) × 3 h followed by 6 h soak.

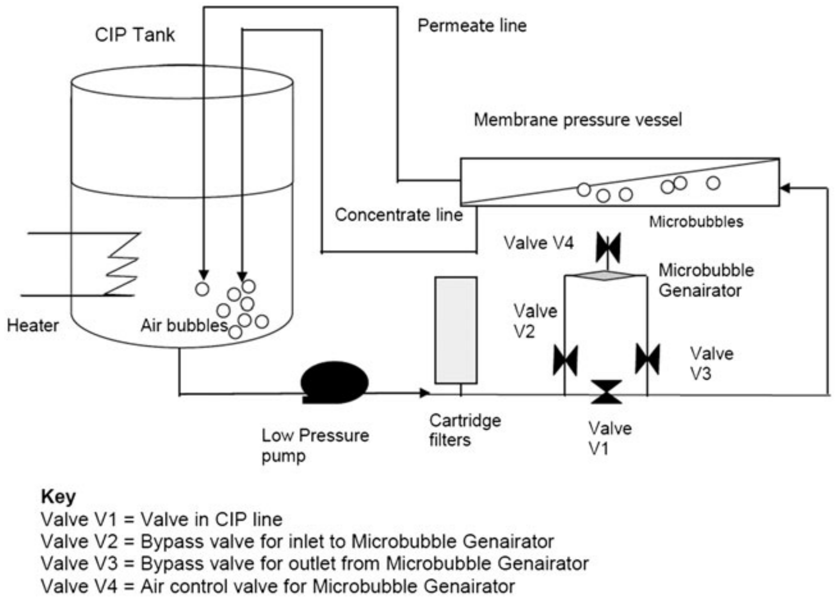

Fig. 5. Installation schematic for the CIP microbubble generator.

NB: It would have been preferable to clean at 35–40˚C, however, due to limitations of heating the CIP solution, the cleans could only be performed at ~30˚C.

3.5. Results

The starting point for reference was taken as August 2013 as this was the last time the RO2 Train was cleaned using Cleaners C and D—Fig. 6 shows the loss in flux before the microbubble Genairclean clean was carried out in March 2014. The benchmark flux in August 2013 was 544 GPM and before the clean was down to 484 GPM, after the Genairclean the flux was increased to 530 GPM. That is within 3% of benchmark flux—see Figs. 5(a) and 5(b).

Fig. 6 shows the differential pressure (dP) during this period and recovery after the microbubble Genairclean. The benchmark dP in August 2013 was 36 psi and before the clean was up to 40 psi after the Genairclean the dP was reduced to 37 psi.

Fig. 7 shows the % salt passage during this period and recovery after the microbubble Genairclean. That is no increased salt passage after the clean.

The initial results are very encouraging showing a distinct improvement in flux recovery and reducing

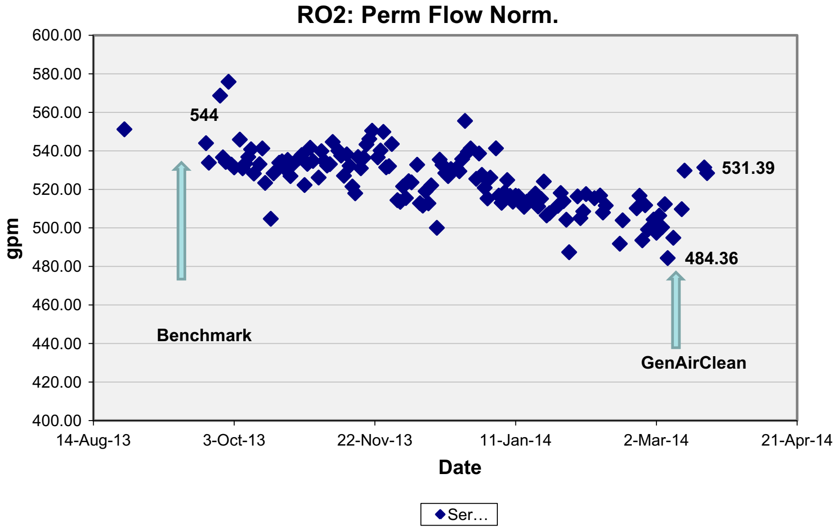

Fig. 5(a). Graph of normalised permeate flow over time and after Genairclean.

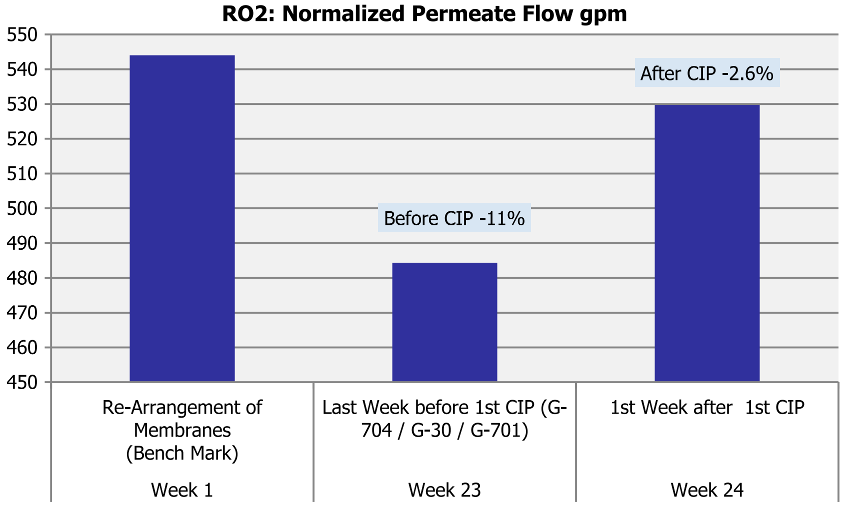

Fig. 5(b). Graph of normalised permeate flow before and after Genairclean.

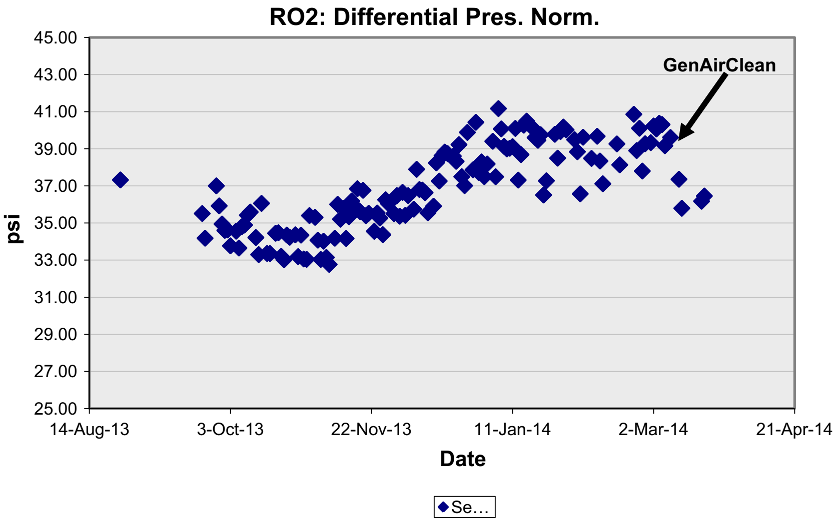

Fig. 6. Graph of differential pressure over time and Genairclean.

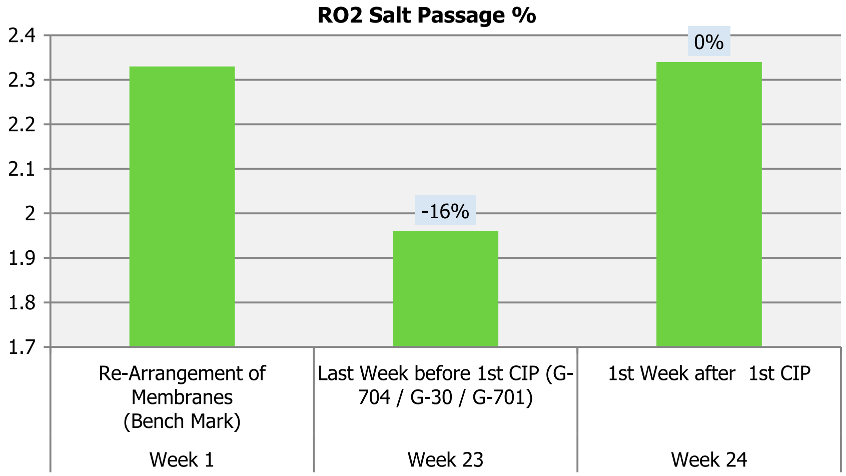

Fig. 7. Graph of salt passage before and after Genairclean.

dP after Genairclean with microbubbles with no increased salt passage.

4. Conclusions

The results of this trial show improved RO performance with use of Genairclean and combined cleaning mechanisms, thus prolonging membrane life and improving operational efficiency. A summary of our findings are:

- Cleaning is improved in the first stage of a rapidly fouling RO plant using a high ionic strength formulated cleaners with an effervescent reagent.
- Cleaning is further improved using microbubbles generated by a venturi air injector.
- The combined effect of cleaning with microbubbles and effervescent cleaning reagents can improve cleaning performance over conventional methods.
- This concept can be easily and cost effectively applied to any RO/NF cleaning system.

References

[1] N. Pena, F. del Vigo, Evaluating impact of fouling on reverse osmosis membrane performance, in: EDS Barcelona, April 2012, Spain.

[2] W.S. Ang, N.Y. Yip, A. Tiraferri, M. Elimelech, Chemical cleaning of RO membranes fouled by wastewater effluent: Achieving higher efficiency with dual-step cleaning, J. Membr. Sci. 382 (2011) 100–106.

[3] N. Al-Bastaki, A. Abbas, Use of fluid instabilities to enhance membrane performance: A review, Desalination 136 (2001) 255–262.

[4] M.J. Um, S.H. Yoon, C.H. Lee, K.Y. Chung, J.J. Kim, Flux enhancement with gas injection in crossflow ultrafiltration of oily wastewater, Water Res. 35(17) (2001) 4095–4101.

[5] P. Willems, A.J.B. Kemperman, R.G.H. Lammertink, M. Wessling, M. van Sint Annaland, N.G. Deen, J.A.M. Kuipers, W.G.J. van der Meer, Bubbles in spacers: Direct observation of bubble behavior in spacer filled membrane channels, J. Membr. Sci. 333 (2009) 38–44.

[6] R. Wilson, M. Fazel, S. Chesters, Air bubbles enhance membrane cleaning: A future perspective, in: The International Desalination Association (IDA) World Congress on Desalination and Water Reuse, Tianjin, REF: IDAWC/TIAN13-225.

[7] M. Fazel, S. Chesters, R. Wilson, Autopsy results confirm safe and effective use of microbubbles for removal of RO membrane scaling and fouling, in: The International Desalination Association (IDA) World Congress on Desalination and Water Reuse, Tianjin, REF: IDAWC/TIAN13-140.

[8] S. Chesters, M. Fazel, M. Armstrong, RO membrane cleaning, past, present, future—Innovations for improving RO plant operating efficiency, in: The International Desalination Association (IDA) World Congress on Desalination and Water Reuse, Tianjin, REF: IDAWC/TIAN13-204.