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# Experiences from the Adelaide Desalination project: ultrafiltration cleaning optimisation—from pilot to full-scale operation

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ABSTRACT

Membrane fouling remains a major concern for ultrafiltration (UF) pretreatment for seawater reverse osmosis (RO). The focus of this study was the optimisation of the chemical cleaning regime and any associated impact on the downstream cartridge filters (pre-RO). Different shock acidification/chlorination and maintenance wash (MW) regimes for the pilot UF were tested. The results of the study at the Adelaide Desalination Pilot Plant (ADPP) are summarised as follows:

- Sulphuric acid shock dose alone at pH 4 was ineffective for prevention of UF biogrowth, when performed for one hour per week or less.
- Shock chlorination provided an effective tool for limiting biogrowth in UF systems.
- Relocating the sodium metabisulphite dechlorination dosing point downstream of the cartridge filters was essential for controlling biogrowth and to ensure stable operation of the filters.
- Chlorine MWs provided better UF permeability and transmembrane pressure (TMP) recovery than sulphuric acid MWs.
- A chlorine MW frequency once in every 4 days and sulphuric acid MW frequency more than once in every 2 weeks was chosen for the full-scale plant.
- Addition of ferric sulphate into the UF feed significantly impaired operational performance with respect to TMP and permeability decay rate. This is most likely due to the low seawater turbidity and dissolved organic carbon levels.

Data from the ADPP were used to optimise operation conditions for the full-scale plant during commissioning. The Operator of the Adelaide Desalination Plant, AdelaideAqua Pty. Ltd. used the pilot plant findings to assist with optimisation of the dose/frequency regime for chlorine and sulphuric MWs. A comparison of pilot operation and full-scale plant commissioning performance is discussed.

*Keywords:* Ultrafiltration; Fouling; Biofouling

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## 1. Introduction

Membrane fouling remains a major concern for ultrafiltration (UF) pretreatment for seawater reverse osmosis (RO). The four key fouling types are: suspended solids, salts precipitation, organic and biological fouling [1]. Optimisation of cleaning regime with respect to UF membrane performance may result in reduced energy and chemical consumption.

At the Adelaide Desalination Plant (ADP), optimisation of the Siemens Memcor submerged UF system cleaning regime (maintenance washes [MWs] and clean-in-place [CIP]) for organic fouling control, as well as the intake tunnel disinfection process for marine growth control (shock dosing) should result in reduced chemical and energy consumption, without compromising the performance of the downstream RO treatment system. The Adelaide Desalination Pilot Plant (ADPP) was developed to simulate key aspects of the full-scale facility design. One of the main objectives was the installation of a UF membrane to verify its performance with seawater. To control fouling on the UF membrane two types of routine activities were undertaken: (1) shock acidification and chlorination, in which low-dose chlorine (<15 mg/L) and pH adjustment to either 4.0 (acid alone) or 7.2 (with hypochlorite) were used, in order to simulate the effect of shock dosing the inlet pipe to control marine growth on the UF and (2) MWs, in which much higher concentrations of chlorine (typically 300 mg/L) and/or acid (typically pH 2) were used. These cleaning processes have been undertaken frequently at other desalination plants [2]. Sodium metabisulphite was used to neutralise free chlorine residual prior to the RO to prevent membrane oxidation [3]. Fig. 1 shows the pilot plant flow diagram.

The focus of this study was the optimisation of the pretreatment for the Memcor UF. Cleaning of the Norit UF system was not considered as the Memcor system was chosen for installation in the full-scale plant. For these purposes, different shock dosing and MW regimes on the UF were tested. Sodium hypochlorite and sulphuric acid in different concentrations were used to determine effectiveness of the cleaning processes.

Data from the ADPP were used to optimise operating conditions at the full-scale plant during commissioning start-up. The AdelaideAqua D&C Consortium used the pilot plant findings to assist with optimisation of the dose/frequency regime for chlorine and sulphuric MWs. For the conditions of the pilot plant, the optimal MW conditions were: every 4 days for sodium hypochlorite; and less than once in every 14 days for sulphuric acid. A comparison of pilot operation and full-scale plant commissioning performance is discussed.

## 2. Methodology

Trials were undertaken in two-week periods. Seawater quality was relatively stable throughout the testing period, with variations observed during periods of heavy rainfall off-shore. Turbidity was recorded with a range of 0.2–3.8 NTU (average 0.7 NTU), dissolved organic carbon (DOC) 0.9–1.4 mg/L (average 1.1 mg/L) and total suspended solids of 1–8 mg/L (average 2.2). Shock dosing tests were carried out using two chemicals at various dose rates; sodium hypochlorite (0–15 mg/L as chlorine) and sulphuric acid (to achieve pH between 4 and 7). Table 1 summarises the test conditions.

In trials 1–6, chlorine and sulphuric acid dosing were carried out independently. For the remaining trials, chlorine and sulphuric acid were dosed simultaneously. Trial 9 and 9a conditions were identical, with exception of ferric sulphate dosing of the UF feed during trial 9a, due to the potential for elevated seawater turbidity (>10 NTU) in the full-scale plant.

Various control parameters were monitored to assess the efficiency of the operating conditions:

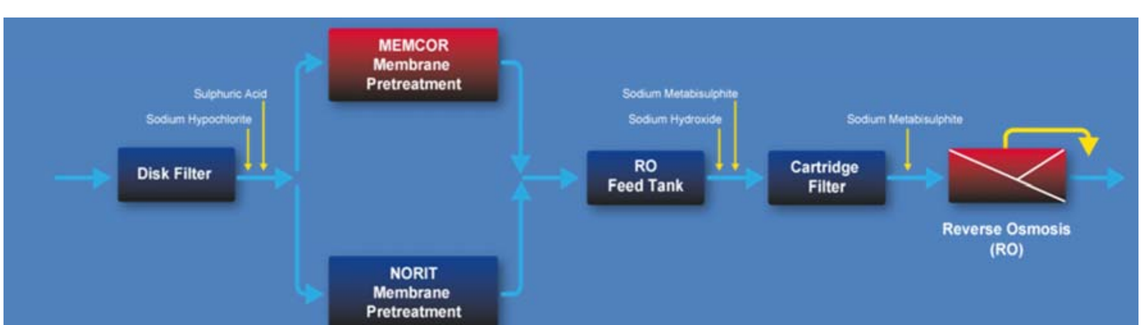


Fig. 1. Block diagram of the ADPP after modifications.

Table 1
Shock dosing test conditions

| Trial | Chlorine | Sulphuric acid |
|---|---|---|
| 1 | 15 mg/L<br>20 min/d | N/A |
| 2 | N/A | pH = 4<br>1 h per week |
| 3 | 15 mg/L<br>20 min/d | pH = 4<br>1 h/ per week |
| 4 | 5 mg/L<br>20 min/d | pH = 4<br>1 h per week |
| 5 | 5 mg/L<br>20 min/d | N/A |
| 6 | 5 mg/L<br>20 min/2d | pH = 4<br>1 h per week |
| 7 | 5 mg/L;<br>20 min | pH = 7<br>2 days per week |
| 8 | 5 mg/L<br>20 min | pH = 7<br>1 day per week |
| 9 & 9a | 5 mg/L<br>20 min | pH = 7<br>2 days per week |

bacterial counts and biogrowth control. Aerobes, *Escherichia coli*, Coliforms and *Clostridium* sp. microbiological analyses were carried out in different sampling locations through the process in order to monitor biogrowth:

- seawater (intake)
- UF filtrate
- cartridge filtrate

Biopolymers such as polysaccharides were monitored using stainless steel biocoupons [4]. This provides an indication of bacteria present, as when bacteria attach to surfaces exposed to water, they begin to excrete a sticky substance that are mostly polysaccharides [5]. These biocoupons were installed in the UF feed, UF filtrate and downstream of the cartridge filters.

To understand how biological growth affected the performance of the cartridge filters, two different chlorine neutralisation locations (using sodium metabisulphite) were tested; before and after the cartridge filters.

UF was operated at a constant flux of 53 $L/m^2/h$ (LMH), with a normal backwash interval of 90 min (higher than the full-scale plant design of 30 min). MWs were undertaken regularly to recover the permeability and transmembrane pressure (TMP) after filtration cycles. MWs involved the addition of 300 mg/L of chlorine (using sodium hypochlorite) or sulphuric acid (to achieve a pH of 2). MW frequencies varied during the testing period in order to establish the minimum cleaning frequency, without compromising UF performance. Table 2 summarises the test conditions.

Table 2
Test conditions for UF MWs

| Trial | MW interval (days) | |
|---|---|---|
| | Hypochlorite | Sulphuric acid |
| 1 | 2 | 4 |
| 2 | 2 | 7 |
| 3 | 2 | 14 |
| 4 | 4 | 7 |
| 5 | 3 | 14 |
| 6 | 4 | 14 |
| 7 | 7 | 7 |
| 8 | 7 | 7 |
| 9 & 9a | 7 | 7 |

CIPs were performed after every second trial, in two stages; the first using sodium hypochlorite at 500 mg/L free chlorine residual; and, the second with 0.25% citric acid, adjusted to pH 2.0 using sulphuric acid.

UF TMP and normalised permeability were studied to assess the performance of each set of operating conditions.

## 3. Results

### 3.1. Shock dosing

Only aerobic bacteria counts were reduced from seawater to UF filtrate, suggesting bioaccumulation on the UF membranes. Fig. 2 shows the reduction in aerobic counts when seawater passes through the UF membranes. All other bacteria analysed have almost consistently been zero after the disc filters, due to very low seawater concentrations (data not shown).

Images of the biocoupons were taken after each main trial. Red areas indicate the presence of polysaccharides, which shows inadequate disinfection to control the biogrowth. Table 3 shows biocoupon images from the UF feed and filtrate from trials 2 and 9. Red areas were only observed on coupons from trial 2, indicating that pH 4 sulphuric acid shock dosing alone was ineffective to control biogrowth.

The sodium metabisulphite dosing point (chlorine neutralisation before RO membranes) was relocated before to after the cartridge filter between trials 4 and 5. Before starting trial 5, the cartridge filter was also

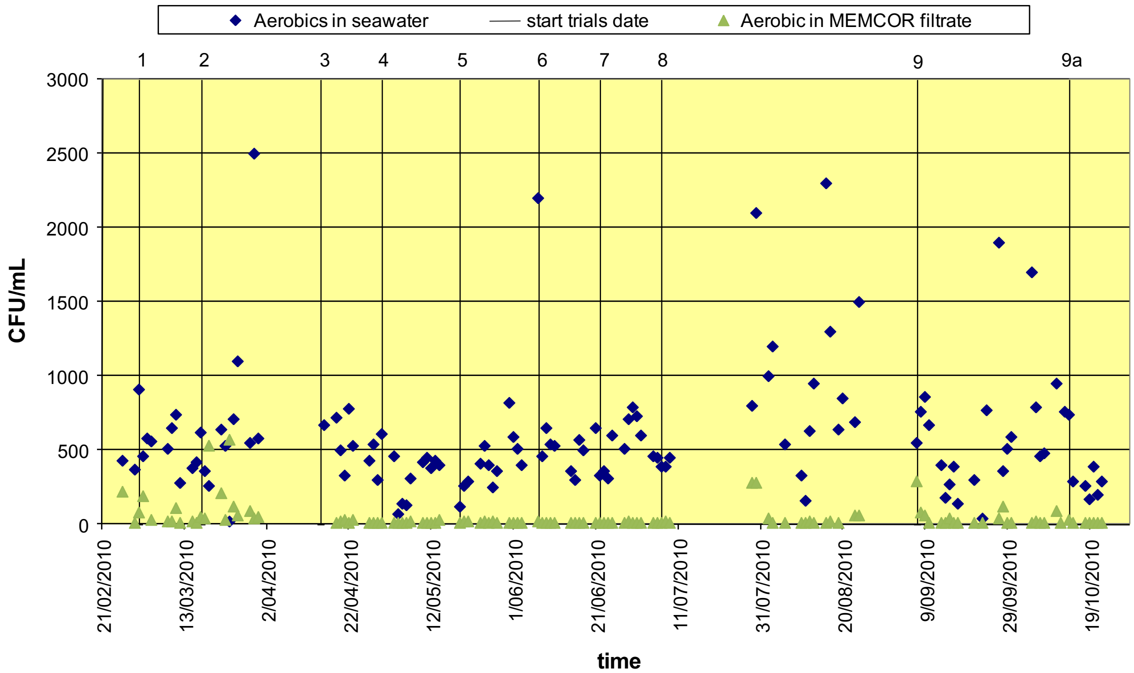


Fig. 2. Aerobes in seawater and in UF filtrate for the entire operating period.

disinfected with chlorine to a Ct value of 2,800 (mg/L×h). These two actions yielded an immediate reduction in differential pressure across the cartridge filter (Fig. 3). The differential pressure remained low for the remaining trials. This confirmed the benefit of including cartridge filtration in the shock chlorination pathway.

### 3.2. UF maintenance backwashes

Bioaccumulation within the UF membrane was controlled by MWs (Fig. 4). Different frequencies and chemicals were used for UF MWs (Table 2). Biofouling was reflected not only by the microbiological results (above) but also from the measured recovery in UF performance following hypochlorite MWs, compared with sulphuric acid.

As shown in Fig. 4 (trial 4 data), a clear increase in normalised permeability was observed following a chlorine MW. For all trials, hypochlorite MWs resulted in better TMP recovery, compared to sulphuric acid.

Table 4 shows results of the following parameters for the trials:

- *a*: average normalised permeability decay rate between MWs
- *b*: average normalised permeability increase after chlorine MW
- *c*: average normalised permeability increase after sulphuric acid MW
- *d*: average TMP increase rate between MWs
- *e*: average TMP decrease after chlorine MW
- *f*: average TMP decrease after sulphuric acid MW.

During the initial hours of filtration after a MW, the highest TMP increase or permeability decrease was observed (refer to Fig. 4). The *a* and *d* values were calculated also taking into account this part of the curve. For this reason, values *a* and *d* for trials 1–3 (Table 4) are higher than, for example, trial 4, even when the MW frequency is higher.

Permeability after MWs were close to 200 LMH/bar, with initial TMP values ranging from 27 to 30 kPa (Fig. 5). After trial 4, the TMP increased with each subsequent trial, indicating that more frequent MWs were effective at controlling biogrowth. This trend was also reflected in the permeability decay data. Several process interruptions occurred during trial 8, which are evident in Fig. 5.

As TMP and permeability were not normalised for temperature variability of the seawater feed, membrane resistance was calculated to assess UF system performance. Resistance is defined by the following equation:

$$R = (\mathrm{TMP} \times N \times A \times 10^{-3})/(\eta \times Q)$$

Table 3
Biocoupons images

| Trial | Coupon location/view | Picture |
|---|---|---|
| 2 | UF feed (face1) |  |
| 2 | UF feed (face2) |  |
| 2 | UF filtrate (face1) |  |
| 2 | UF filtrate (face2) |  |
| 9 | UF feed (face1) |  |
| 9 | UF feed (face2) |  |
| 9 | UF filtrate (face1) |  |
| 9 | UF filtrate (face2) |  |

where $R$ = Resistance ($m^{-1} \times 10^{12}$), TMP = Average Trans Membrane Pressure (kPa), $N$ = Number of modules filtering, $A$ = Surface area of , each sub-module ($m^2$), $\eta$ = Viscosity of water at the feed temperature (centipoise) and $Q$ = Average filtration flow rate (L/s).

Resistance between each MW was similar within each trial ranging between 1.6 and $2.2 \times 10^{-12}\,m^{-1}$. The rate of resistance increase between MW within each trial was similar (Fig. 6). However, a measurable increase in resistance slope was observed for trial 9a. This is most likely due to the dosing of ferric coagulant to the seawater feed. The absence of significant turbidity and DOC did not result in effective coagulation, with unreacted dissolved iron adsorbed onto the UF membrane fibres. Based on the observed results, UF system operation with hypochlorite MW intervals of 2–7 days should yield consistent performance with respect to TMP and permeability.

Fig. 7 illustrates the average irreversible fouling resistance data for each trial. Here, irreversible fouling is defined as the average rate of increase of resistance for each trial, and represents the material that could not be removed using physical backwash and chemical MW regimes. No significant differences were observed across trials 1–9. However, the result for trial 9a was measurably higher, consistent with the dosing of ferric coagulant. Despite increasing the MW interval to 7 days, this did not appear to increase the rate of irreversible fouling. More chemically intensive CIP activities were performed after trials 2, 4, 6 and 8. Membrane performance recovery appeared to be similar, except after trial 8. Resistance dropped from 2.2 to $1.6 \times 10^{-12}\,m^{-1}$. However, the CIP after trial 8 only reduced the resistance to $2.0 \times 10^{-12}\,m^{-1}$. This is likely due to the fact that CIP solutions were not heated and the coldest water temperature was experienced after trial 8. It is well known that CIP cleaning efficiency can be strongly, negatively affected by cold water temperatures, via a significant reduction in the kinetics of foulant dissolution from the membrane surface. The D&C Consortium decided, in consultation with the membrane system supplier (Siemens Memcor) that the full-scale plant would include a UF CIP heating system to ensure a cleaning recirculation temperature range of 20–25˚C.

As piloting across variable MW conditions showed little difference when using an interval of 2–7 days for hypochlorite MWs, this verified the deci-

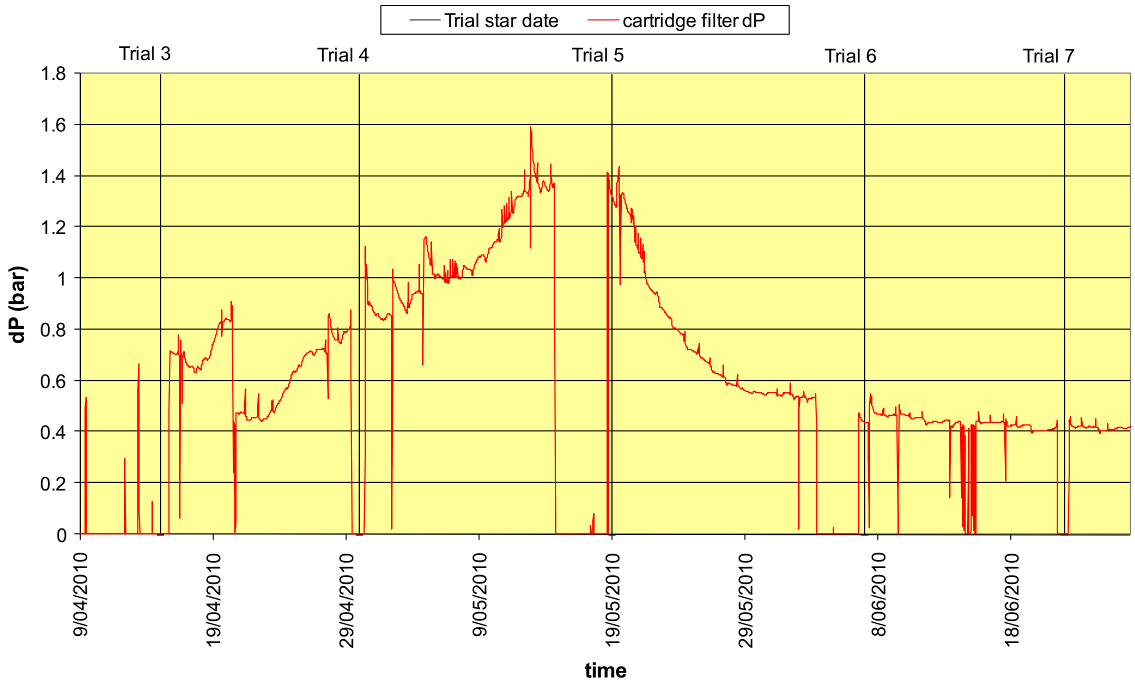


Fig. 3. Differential pressure in cartridge filter.

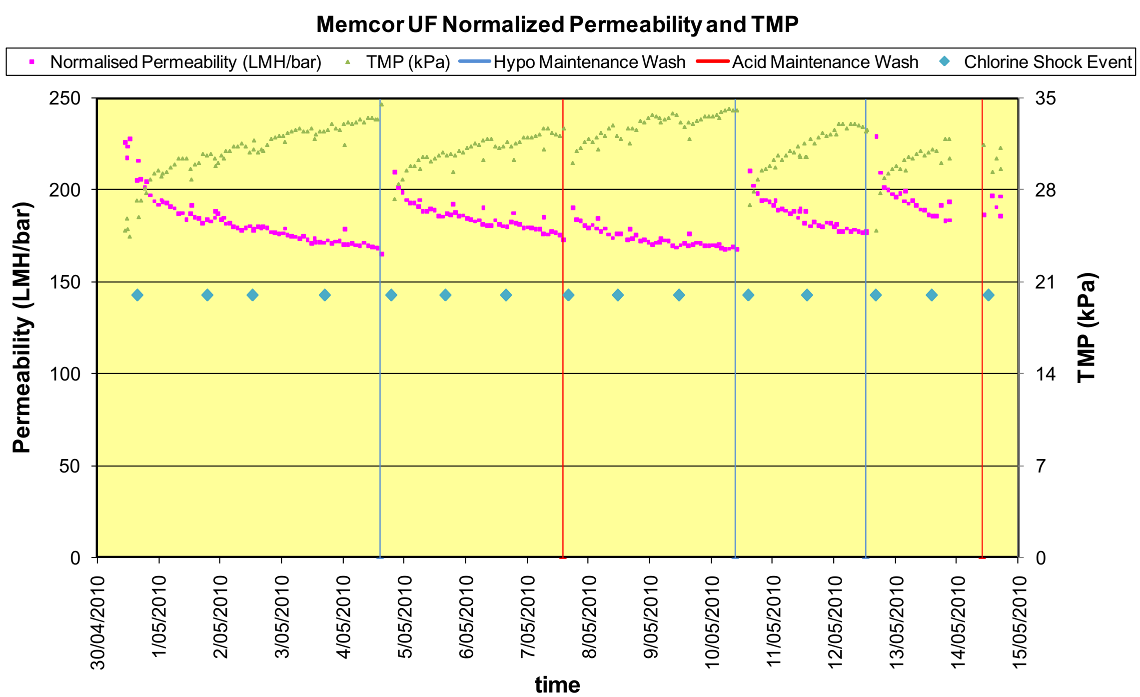


Fig. 4. MWs comparison during trial 4.

sion made by the D&C Consortium in consultation with Siemens Memcor to adopt a relatively conservative hypochlorite MW interval of 4 days for the full-scale plant. In order to achieve acceptable TMP rise rates, the hypochlorite MW frequency needed to be >1 per week.

Table 4
Trial results

| Trial | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9a |
|---|---|---|---|---|---|---|---|---|---|---|
| *a*-LMH/bar/d | 11.8 | 14.8 | 13.1 | 9.3 | 11.9 | 7.5 | 11.5 | 12.2 | 6.5 | 44.7 |
| *b*-LMH/bar | 33.5 | 28.9 | 44.1 | 46.9 | 37.8 | 40.0 | 38.8 | 9.3 | 36.7 | 13.5 |
| *c*-LMH/bar | N/A | 30.7 | 1.2 | 13.6 | 13.7 | 1.0 | 14.4 | 40.1 | 7.6 | 12.4 |
| *d*-kPa/h | 3.5 | 3.7 | 2.7 | 1.5 | 2.5 | 0.9 | 2.4 | 2.5 | 3.0 | 16.8 |
| *e*-kPa | 5.4 | 4.6 | 7.1 | 7.4 | 6.8 | 7.4 | 7.1 | 2.1 | 7.5 | 4.6 |
| *f*-kPa | N/A | 4.0 | 0.2 | 2.1 | 2.4 | 0.1 | 2.7 | 7.9 | 1.7 | 5.0 |

The final trial at the pilot plant (9a) was carried out with ferric sulphate coagulant dosing of the UF feed. From 14 October, iron residual concentration was 0.25 mg/L and was increased to 0.50 mg/L on 18 October. Fig. 8 shows permeability and TMP results, with blue and red vertical lines indicating hypochlorite and acid MWs, respectively.

One difference with the main plant is that ferric sulphate will be dosed before disc filters and during trial 9a the ferric was dosed before UF membranes. The different location may cause a partial filtration of coagulated iron by the disc filter, resulting in a lower concentration in the UF feed. Addition of coagulant at the ADPP did not take place before the disc filter as there was no provision. However, the absence of significant concentrations of organic and particulate matter (<1.5 NTU) to assist in formation of iron hydroxide floc resulted in poor flocculation and the UF was exposed to iron residual which can absorb rapidly to membranes. Commencement of ferric sulphate dosing on 14 October resulted in significantly increased permeability decay rate and elevated TMP. Hypochlorite MWs were relatively ineffective in restoring normalised permeability and TMP, indicating accumulation of inorganic mineral foulants on the membrane surface which is in agreement with previous studies [6]. In the full-scale plant, coagulant dosing will be considered when seawater turbidity is greater than 10 NTU.

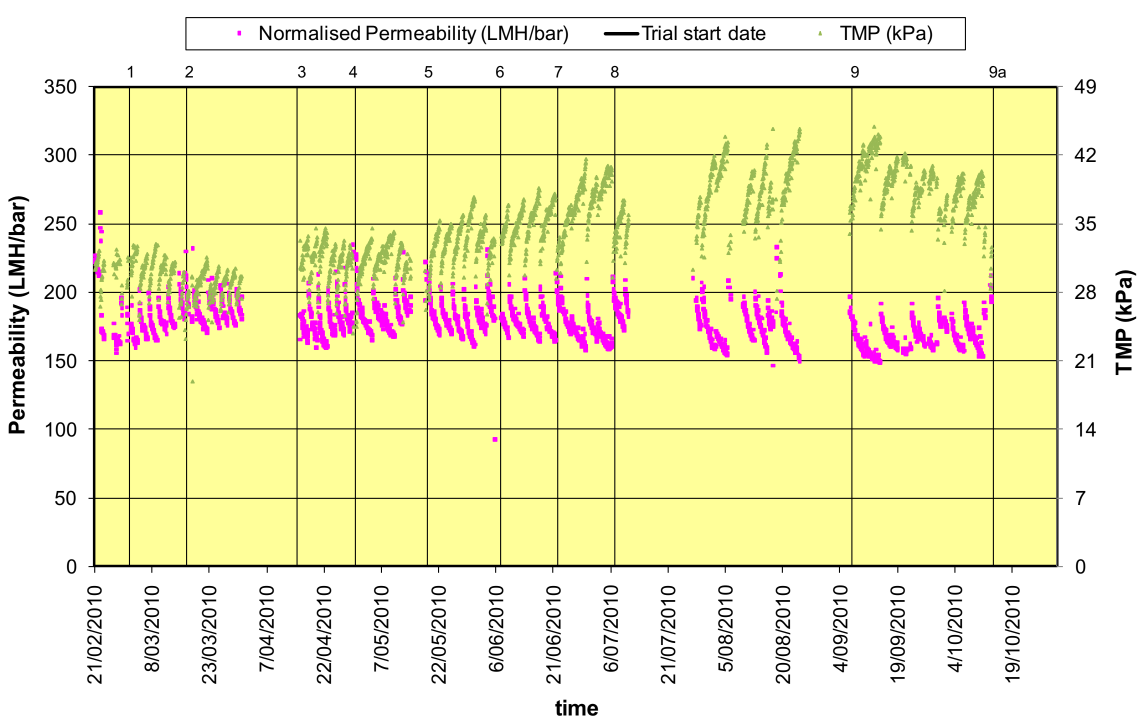


Fig. 5. Normalised permeability and TMP in all trials.

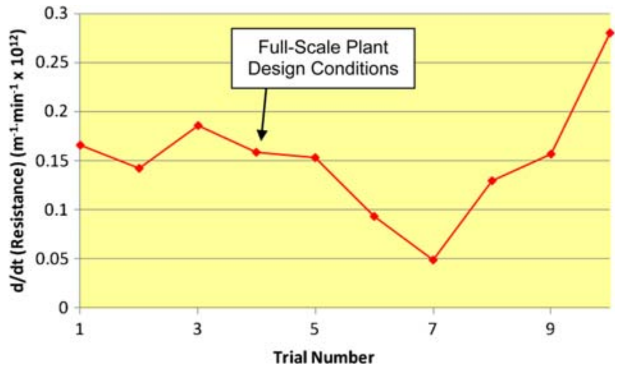


Fig. 6. Change in resistance between MWs.

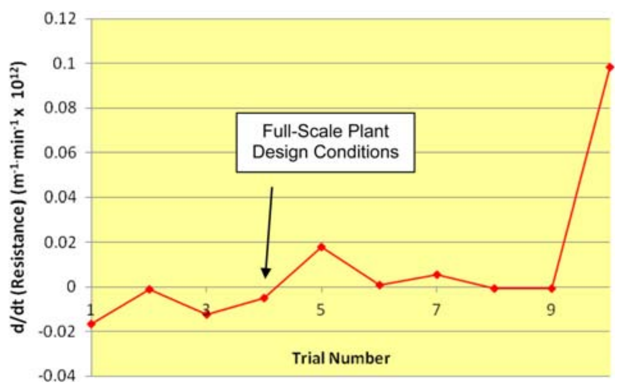


Fig. 7. Irreversible fouling rate based on resistance.

### 3.3. Full-scale plant data

Results from the pilot plant cleaning trials were used to gain confidence with acid and chlorine MW frequency in the full-scale plant. During commissioning, four UF cells (14 in total) were initially made operational, with three cells in filtration mode and one in backwash mode. The backwash interval was set at 70 min, based on the stable performance observed in the pilot plant trial (90 min) and consultation with the membrane system supplier. The ADP was operated at 1/10 of its drinking water production capacity, 30,000 $m^3$/day. As the UF filtrate required for commissioning was far less than the design specification for three operating UF cells, the actual operating flux was low, 44 LMH (flow per cell = 1,100 $m^3$/h), rather than 53 LMH (design conditions). Fig. 9 shows flow and resistance data from a single UF cell.

It is likely that the UF was operating below the critical flux for this membrane in this feedwater [7] as the increase in resistance is minimal once the cell's flow was stabilised. MWs have occurred infrequently, as the resistance values have not yet triggered regular MWs. A CIP was undertaken in order to commission the CIP system, which consisted of soak and filtration cycles (4 h) using 500 mg/L sodium hypochlorite. CIP using sulphuric acid was not available during this time as this dosing system was not yet commissioned.

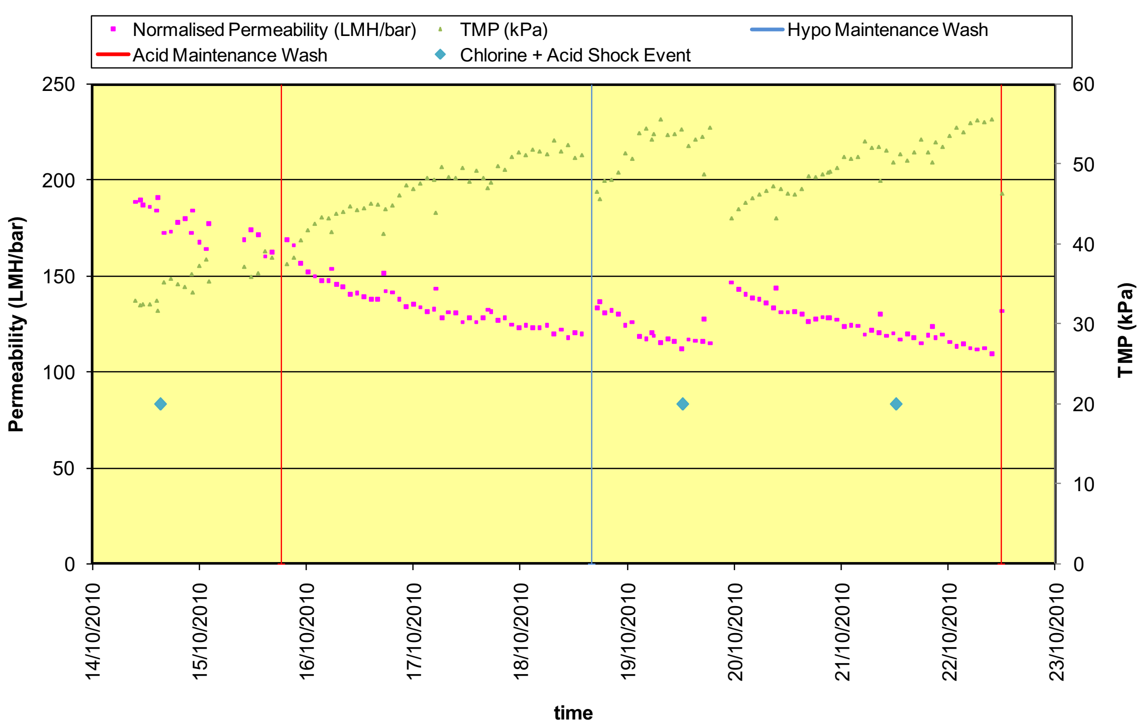


Fig. 8. Normalised permeability and TMP trial 9a.

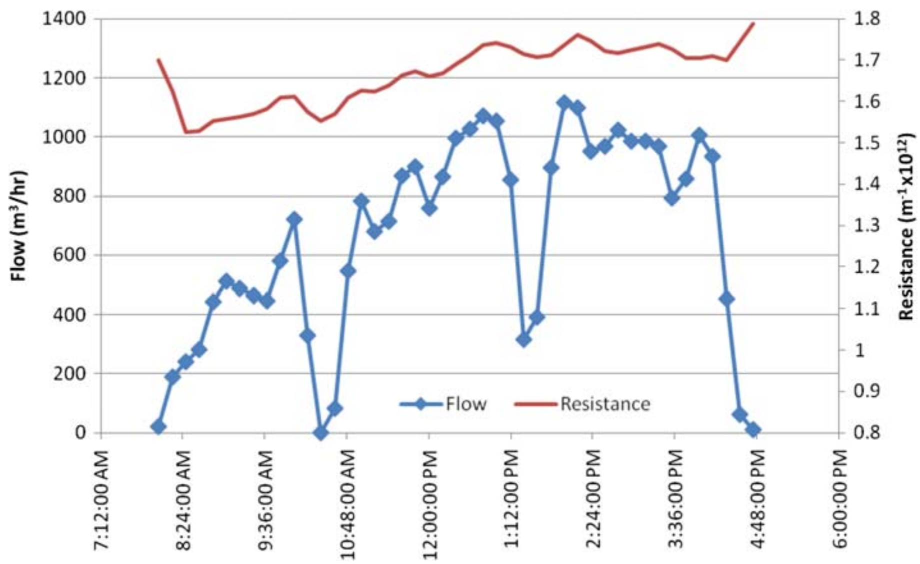


Fig. 9. Resistance and flow data for a single UF cell at the full-scale plant prior to hypochlorite CIP (7 February 2012).

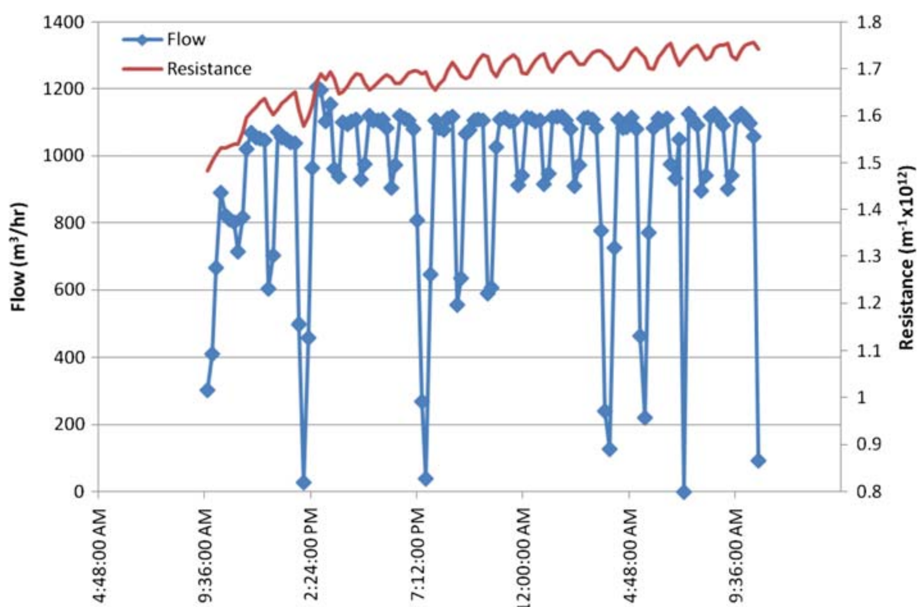


Fig. 10. Resistance and flow data for a single UF cell at the full-scale plant after hypochlorite CIP (15 February 2012).

However, the hypochlorite CIP did not appear to provide a significant performance recovery benefit, with respect to TMP or resistance (Figs. 10 and 11).

At a flux of 53 LMH in the pilot plant, TMP increased 5–10 kPa over a 24 h period (Fig. 4) and this increase rate was large directly after a MW. At 44 LMH in the full-scale plant, TMP increased by 1 kPa over a 24 h period. While there is a rise in resistance shown in Fig. 8, this is not significant when compared to the pilot plant data.

Despite not undertaking MWs at the full-scale plant during commissioning, UF modules were stored in 10 mg/L hypochlorite solution between operational periods. As per Dixon et al. [8], where the same Memcor PVDF membranes were stored in 50 mg/L hypochlorite in a week-on/week-off rotation, storage in hypochlorite is also a viable method for maintaining low resistance. Dixon et al. [8] showed very little increase in resistance over a 12 month period, with resistance values never exceeding $2.0 \times 10^{12}\,m^{-1}$.

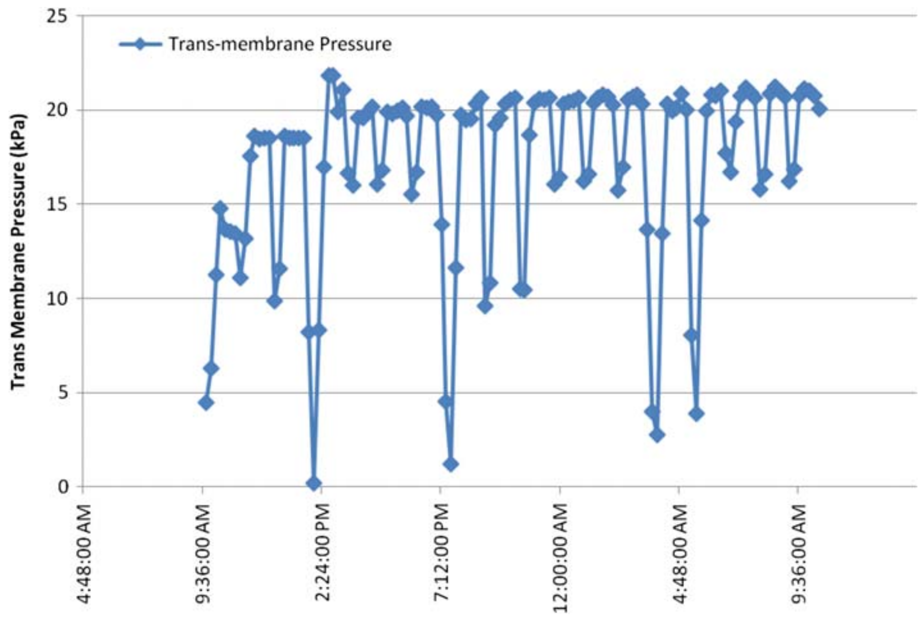


Fig. 11. TMP data for a single UF cell at the full-scale plant after hypochlorite CIP (15 February 2012).

## 4. Conclusions

The optimisation of pretreatment for UF was investigated. Different shock dosing and MW regimes on the UF membranes were tested. Sodium hypochlorite and sulphuric acid in different concentrations were used to determine effectiveness of the cleaning processes. The following specific conclusions were made:

- Sulphuric acid shock dose alone at pH 4 was ineffective for prevention of UF biogrowth, when performed for one hour per week or less.
- Shock chlorination provided an effective tool for limiting biogrowth in UF systems.
- Relocating the sodium metabisulphite dechlorination dosing point downstream of the cartridge filters was essential for controlling biogrowth and to ensure stable operation of the filters.
- Chlorine MWs provided better UF permeability and TMP recovery than sulphuric acid MWs.
- A chlorine MW frequency of once every 4 days and sulphuric acid MW frequency greater than once every 2 weeks was chosen for the full-scale plant.
- Addition of ferric sulphate into the UF feed significantly impaired operational performance with respect to TMP and permeability decay rate at very low turbidity. This is most likely due to the low seawater turbidity and DOC levels.

Operational findings of the pilot plant became less relevant during commissioning of the full-scale plant, due to operation below critical flux and extended periods of soaking membranes in hypochlorite solution. Further analysis of the full-scale plant operation at its design flux of 53 LMH is necessary to assess whether the established MW conditions will be suitable or require modification.


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