Application of backwashing with demineralized water for UF fouling control in UF-RO desalination
Sheng Li, S. G. J. Heijman and J. C. van Dijk

ABSTRACT
The effectiveness of demineralized water backwash on ultrafiltration (UF) fouling control of seawater is investigated in this study. Fouling experiments for two different backwashes (UF permeate and demineralized water) were conducted at three fluxes: 120, 180 and 240 L/(h m²) to compare their fouling control efficiency on UF membranes. Results show that backwashing with demineralized water improved the fouling control of UF membranes. When the UF membranes were backwashed with demineralized water, probably because more foulants were flushed away from the UF membrane than UF permeate backwashes, the increase in trans membrane pressure (TMP) for backwashing with demineralized water was less than that with UF permeate. Furthermore, the fluxes of experiments also played a role on the fouling control. When the flux was 120 L/(h m²), the difference between two different backwashes was small. However, at the flux of 240 L/(h m²), the TMP for backwashing with UF permeate increased faster than that with demineralized water, although the TMP for backwashing with demineralized water increased as well.

Key words | ultrafiltration, backwash, demineralized water, desalination

INTRODUCTION
Ultrafiltration as an pretreatment of desalination
Ultrafiltration (UF) has been applied for water treatments for two decades due to its good removal on the particles and microorganisms (Laine et al. 2000). With the development of membrane technology, the cost of low pressure membranes (microfiltration and UF) decreases to an acceptable level for application. That is the reason why the use of low pressure membranes for water purification has substantially grown in the past decades. Not only in the drinking water treatment, but also in the desalination field, UF as a pretreatment for the reverse osmosis (RO) currently appeared.

Several studies have investigated using hollow fiber UF membranes as a pretreatment for desalination with reverse osmosis (SWRO). Ahmad & Aleem (1993) showed that comparing to conventional pretreatments, the inside-out hollow fiber UF process is an easy-to-use and robust alternative. Hoof et al. (1999) carried out a pilot test in Addur using X-Flow hollow fiber UF membranes as a pretreatment for six months, and results showed that the UF permeate had a stable SDI as low as 1.5. Merrilee & James (2004) successfully supplied a UF-SWRO system to the government of the United Arab Emirates that treats about 11.4 million litres (3 million gallons) of seawater a day with UF to supply 3.8 million litres (1 million gallons) to the SWRO system.

Application of the DEMIFLUSH concept
Same as the UF in drinking water treatment, the main challenge of UF in the seawater treatment is still fouling. Since all industrial plants produce water at a constant flux, the trans membrane pressure (TMP) has to be increased to overcome the increased resistance caused by fouling. In order to control fouling, normally the membrane is hydraulically backwashed to recover the membrane permeability. The part of TMP reduced after a hydraulic backwash is related
to the hydraulically reversible fouling, while the part still higher than the initial TMP indicates the hydraulically irreversible fouling. However, the hydraulically irreversible fouling probably can be removed by enhanced chemical backwashes.

Although the UF fouling in desalination is less serious than the natural surface water treatment (due to a low organic concentration, etc.), a coagulation pretreatment is still required in some cases to control the UF fouling (Yang & Kim 2009). Coagulation has been proven to be a good method to control the UF fouling, however, it creates a certain amount of waste sludge containing a high concentration of metal (Al$^{3+}$ or Fe$^{3+}$) during the hydraulic backwashes. It is not environmentally friendly to discharge this waste sludge in the surface water body, so it has to be treated and consequently increases the cost of treatment plant. In a previous study, the authors have shown that backwashing with demineralized water can substantially improve the UF fouling control in surface water treatment (the DEMIFLUSH concept) (Li et al. 2009). That is probably because both the organic matter in surface water and the tested UF membranes are negatively charged, the repulsion between them was reduced due to the cations in feed water (including calcium and sodium, etc.) via charge screening effect. Consequently, the organic matters easily deposited on the membrane surface and formed a fouling layer. When the membrane backwashed with demineralized water, the cation concentration was diluted and thus the charge screening effect was reduced. Therefore, the repulsion force between membrane and organic matter was restored. In addition with the shearing force of hydraulic backwashes, the fouling layer can be better removed. However, when the membrane was backwashed with UF permeate, the repulsion force can not be restored because the UF membranes do not reject cations causing UF fouling. Therefore, the cations concentration near the membranes during a backwash was not diluted in this case, and thus charge screening effect was maintained.

In theory, there is much more sodium in the seawater for charge screening, so it is possible to apply the DEMIFLUSH concept on the seawater UF. However, there is no study investigating the feasibility of backwashing with demineralized water to control UF fouling of seawater. Since the RO permeate is available in desalination plants, it is convenient to make use some of them for this purpose. In this paper, the UF fouling control of seawater with the DEMIFLUSH concept at conditions closely resembling industrial circumstances was investigated.

**MATERIALS AND METHODS**

**Feed and backwash water**

Raw seawater was taken from the Scheveningen beach in the Hague, the Netherlands. The seawater was stored in a refrigerator at a temperature of 4 °C without a prefiltration. Two types of backwash water were used in this study: (1) UF permeate and (2) demineralized water. The water qualities of both feed and backwash water are shown in Table 1.

**Chemical cleaning**

Because each experiment was conducted with a new self-prepared membrane module, no chemical cleaning was carried out in this study (Figure 1).

**Membrane module**

Self-prepared membrane modules containing UFC M5 0.8 mm hollow fibers (X-FLOW Company) were prepared. Five

<table>
<thead>
<tr>
<th>Water quality of feed water and backwash water</th>
</tr>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Feed water</td>
</tr>
<tr>
<td>UF permeate</td>
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<tr>
<td>Demineralized water</td>
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</table>

**Figure 1** | Layout of homemade membrane module.
30 cm fibers were potted in an 8 mm PVC pipe (using a polyurethane potting resin) to represent one module with a surface area of 0.00375 m². The characteristics of UFC M5 fibers are shown in Table 2.

**UF setup**

The UF setup was designed for constant flux experiments, as shown in Figure 2. The constant feed and backwash flow were maintained during the experiment with a DUAL syringe pumps system and one single syringe pump (New Era Pump Systems, Inc.), respectively. All these syringe pumps are programmable. Four operation phases have been developed for this setup: forward flush of inside of membrane fibers, filtration, forward flush of outside of membrane fibers and backwash. The ‘on’ and ‘off’ situation of different components for each operation phase are shown in Table 3. Two digital pressure meters were used to measure the pressure of filtration feed flow and backwash feed flow. Since the pressure of UF permeate and backwash waste stream was equal to atmosphere, the pressure on those two pressure meters were the TMP. The TMP values were uploaded to the computer every 8 s.

**Filtration protocol**

All experiments were carried out in a dead-end operation mode. Before each experiment (and after each chemical cleaning), the setup was thoroughly flushed with demineralized water in filtration mode and backwash mode to remove the chemical residues and air in the system. Afterwards, the setup was operated at a flux of 120 L/(h m²) for half an hour to determine the initial permeability of the membrane. Each fouling experiment consisted of more than 10 operational cycles. Each cycle was composed of three phases: (1) filtration for 15 min; (2) one minute forward flush of outside of membrane fibers to clean the tubes before backwashing; (3) backwash at a double filtration flux for 1 or 2 min (exact duration for each experiment is clarified in Table 4). All pressure data was logged on a computer every 8 s.

Two group comparison experiments were conducted as follow:

The fluxes used in this study were much higher than the real situations (normally around 60 L/(h m²)). This is because experiments were conducted at a low fouling period. If the fouling loading is not sufficient, the difference between two backwashes on fouling control is difficult to observe. To increase the fouling loading, either extending filtration time or increasing fluxes can be applied. In order to do experiments in a shorter period, high fluxes were applied.

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**Table 2** Characteristics of UFC M5 fibers provided by manufacturer

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular weight cut-off</td>
<td>100K Da</td>
</tr>
<tr>
<td>Filtration mode</td>
<td>Inside-out</td>
</tr>
<tr>
<td>Internal fiber diameter (mm)</td>
<td>0.8</td>
</tr>
<tr>
<td>Membrane composition</td>
<td>(1) Hydrophilic membrane composed of a blend of polyvinylpyrrolidone and polyethersulfone; (2) Containing glycerine for pore protection and bisulfite for prevention of microbiological growth</td>
</tr>
</tbody>
</table>

**Table 3** Operational phases of UF setup

<table>
<thead>
<tr>
<th>Valve 1</th>
<th>Valve 2</th>
<th>Filtration pumps</th>
<th>Backwash pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward flush of inside of membrane fibers</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Filtration</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Forward flush of outside of membrane fibers</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Backwash</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*0*: off; *1*: on.
RESULTS AND DISCUSSION

Improvement of demineralized water backwash

The TMP as a function of time for Experiments 1 and 2 was shown in Figure 3. These two experiments were conducted at a constant flux of 180 L/(h m²) and with 2-min backwash. The reason for conducting 2-min backwash was to ensure that the membrane was thoroughly backwashed with demineralized water and reach a really low salinity situation after backwashes comparing with UF permeate backwash. Figure 3 shows that the TMP of the first cycle for both backwashes were increased rather fast, however, a hydraulic backwash recovered most of the membrane permeability. Furthermore, the maximal TMP of the second cycle was much lower than the first cycle. That is probably because there was air in the filtration system which was not flushed away in the air removing step. From the second cycle on, filtration worked properly and the TMP steadily increased afterwards. When the membrane was backwashed with UF permeate, the TMP within each cycle increased dramatically with the increase of filtration cycle. The hydraulically irreversible fouling (related with the TMP at the start point of each cycle) increased from 0.16 bar up to around 0.32 bar. On the other hand, backwashing with demineralized water showed a better control on the membrane fouling, especially on converting the hydraulically irreversible fouling to reversible fouling. Although there was still a certain amount of TMP increase after each backwash for demineralized water backwash, from 0.16 bar up to 0.2 bar, it was lower than UF permeate backwash. Therefore, backwashing with demineralized water can substantially improve the UF fouling control for seawater filtration as well, similar with the previous finding in canal water treatment (Li et al. 2009).

The mechanisms behind the DEMIFLUSH concept probably involve charge screening effect and calcium-bridging effect. During filtration of seawater, due to the high salinity, the negatively charged natural organic matter (NOM) in seawater can easily deposit on the negatively charged UF membrane by reducing the repulsion force between them. Consequently, the fouling of UF membranes developed over time. On the other hand, the presence of calcium in seawater can bind the negatively charged NOM and UF membranes. When the UF membranes are backwashed with UF permeate, since the UF permeate remain almost all the cations in feed water, the concentration of cations on the membrane surface is not changed during backwash. The charge screening effect and calcium bridging effect are probably maintained, against the hydraulic force of backwashing. Therefore, some of the foulants are not flushed away. However, when the UF membrane is backwashed with demineralized water, the cation concentration on the membrane surface can be substantially reduced, and consequently the repulsion

Table 4 | Operational conditions of experiments

<table>
<thead>
<tr>
<th>Filtration flux (L/(h m²))</th>
<th>Filtration time (minute)</th>
<th>Backwash media</th>
<th>Backwash flux (L/(h m²))</th>
<th>Backwash time (minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 1</td>
<td>180</td>
<td>15</td>
<td>Demineralized water</td>
<td>360</td>
</tr>
<tr>
<td>Experiment 2</td>
<td>180</td>
<td>15</td>
<td>UF permeate</td>
<td>360</td>
</tr>
<tr>
<td>Experiment 3</td>
<td>120</td>
<td>15</td>
<td>Demineralized water</td>
<td>240</td>
</tr>
<tr>
<td>Experiment 4</td>
<td>120</td>
<td>15</td>
<td>UF permeate</td>
<td>240</td>
</tr>
<tr>
<td>Experiment 5</td>
<td>240</td>
<td>15</td>
<td>Demineralized water</td>
<td>480</td>
</tr>
<tr>
<td>Experiment 6</td>
<td>240</td>
<td>15</td>
<td>UF permeate</td>
<td>480</td>
</tr>
</tbody>
</table>

Figure 3 | TMP as a function of time for backwashing with UF permeate and demineralized water at a filtration flux of 180 L/(h m²), feed water from the Scheveningen beach (the Hague), the Netherlands.
force between NOM and UF membranes can be restored. It is useful for the hydraulic backwashes.

More foulants removal by demineralized water backwash has been reported by the authors in a study of surface water via a mass balance calculation on DOC (Li 2010a). It is probably the case for seawater application as well. Backwashing with demineralized water probably flushed away more foulants. Therefore, more permeability of the UF membranes was restored after a backwash, contributing for a more steady filtration for the next cycle. However, there were more foulants remaining on the membrane after a UF permeate backwash, so some of the membrane pores were blocked over time leading to less effective membrane area. Because all experiments were constant flow experiments, the same amount of feed water passed through less effective area, increasing the real effective flux. Therefore, as shown in Figure 3, the increase in TMP within each filtration cycle for backwashing with UF permeate was faster than its previous cycle (except the first two cycles which might be influenced by the air).

Effect of filtration flux

The results of Experiments 3–6 are displayed in Figure 4. It is a graph showing TMP as a function of time for backwashing with UF permeate and demineralized water at two fluxes: 120 and 240 L/(h m²). At the beginning, both experiments with different backwashes were operated at a flux of 120 L/(h m²). As shown in this Figure, the increase in TMP for both cases is very small, and the difference between these two different backwashes is hardly noticeable. Considering the different initial conditions of two membranes, the TMP of each experiment was normalized to its corresponding clean water TMP, and depicted in Figure 5. In Figure 5, the difference between backwashing with UF permeate and demineralized water for filtration at a 120 L/(h m²) flux is clearer than Figure 4. It indicates that backwashing with demineralized water contributed to a better fouling control in a 2.5-h filtration under a flux of 120 L/(h m²). The difference is not very obvious, but it is probably because the filtration time is relatively short for this specific feed water to show a clear difference.

However, when the flux of filtration increased up to 240 L/(h m²), the increase in TMP for both cases was much faster than before. That is because more foulants were brought to the membrane surface per unit time due to the increase of filtration flux. Some other studies reported the impact of initial permeation drag on the formation of RO membrane fouling (Zhu & Elimelech 1997; Subramani & Hoek 2008). However, the difference on fouling control for two different backwashes was pretty clear at 240 L/(h m²) filtration flux. The increase of reversible and irreversible fouling for backwashing with UF permeate was much higher than backwashing with demineralized water. The explanation in details behind DEMIFLUSH can be found in the previous publication of the authors (Li et al. 2010). Furthermore, similar results of seawater were observed at another location in the Netherlands (Li et al. 2010b).

CONCLUSIONS

Backwashing with demineralized has been proven to be a good method to control the UF fouling when surface canal
water is treated. That is probably because of the charge screening effect and Ca-bridging effect. Since seawater contains a lot of cations, backwashing with demineralized water should be applicable on seawater treatment as well. Results indicated that backwashing with demineralized water indeed can improve the fouling control of UF in desalination. Furthermore, flux plays an important role on fouling. At a low flux (120 L/(h m²)), the difference of two different backwashings (UF permeate and demineralized water) on fouling control was small within 3 h. That is probably due to the low fouling potential of the seawater. However, the improvement of backwashing with demineralized water is much clear when the fouling experiment was conducted at a high flux (240 L/(h m²)).

ACKNOWLEDGEMENT

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