

A pilot-scale study of backwashing ultrafiltration membrane with demineralized water

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ABSTRACT

This study investigates the effectiveness of different backwash waters on ultrafiltration (UF) fouling control on a pilot-scale setup. Surface water and ion exchange (IEX) pretreated surface water were used as feed water. Three backwash waters were tested: demineralized water, UF permeate and nanofiltration (NF) permeate. Results show that backwashing with demineralized water substantially improves fouling control efficiency. It is supposed that both the reduction of charge screening and Ca-bridging effect cause this improvement on fouling control. Furthermore, backwashing with NF permeate also negatively influences the fouling control efficiency, indicating the impact of monovalent ions in backwash water on the ultrafiltration fouling. Findings from such a pilot scale setup also show that it is possible to apply backwashing with demineralized water on the operation of UF plants.

Key words | backwash, demineralized water, fouling, ultrafiltration

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INTRODUCTION

In recent decades, membrane filtration (especially low pressure membrane: microfiltration and ultrafiltration) has become increasingly popular in drinking water treatment. That is because membrane filtration is a promising process as a first step in surface water treatment. For example, ultrafiltration (UF) can achieve a better removal of particles and microorganisms than conventional treatments (Laine *et al.* 2000). However, fouling is a main constraint to the application of UF membranes.

Fouling results in the increase of energy consumption, in water loss due to hydraulic backwash, in the use of chemicals for cleaning, and eventually in the too early replacement of membranes. Therefore, many studies have been conducted to control the fouling of UF membranes with pretreatment such as in-line coagulation (Kabsch-Korbutowicz 2006; Panglish *et al.* 2008). In this study, a new method (backwashing with demineralized water) was investigated on a pilot scale in terms of fouling control. Natural organic matter (NOM) is thought to be the main fouling contributor (Fan *et al.* 2001; Dong *et al.* 2007). Furthermore, many researchers

have reported that NOM fouling is influenced by some external factors, such as pH and ionic strength (Hong & Elimelech 1997; Song & Singh 2005; Katsoufidou *et al.* 2007). Hong & Elimelech systematically investigated the impact of pH, ionic strength and concentration of divalent ions on NOM fouling of nanofiltration (NF) with humic acid model compounds, and reported that the NOM fouling of NF increases when the pH of feed water is low (4 in their study), when ionic strength increases and when the concentration of calcium increases (Hong & Elimelech 1997). They argued that the negatively charged NOM compounds are protonated at low pH values, so they become less negatively charged which can reduce the repulsion force between them and negatively charged NF membranes. When the feed water contains a high ionic strength, the negative charge of NOM compounds and the NF membrane is screened by monovalent cations in water, which is known as the 'charge-screening effect'. When the concentration of calcium in the feed water is high, the NF fouling becomes severe. This is due not only to the charge-screening effect, but also to the

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Ca-bridging effect. Some recent studies also indicate the impact of these factors on the fouling of UF membranes.

However, all these studies focus on the influence of these factors on formation of fouling. Only limited studies considering their corresponding effect on UF membrane fouling control are available. Abrahamse *et al.* (2008) investigated the effectiveness of backwashing with Milli-Q water on UF membrane fouling control with small scale membrane modules (with a surface area of 0.0125 m²), and found that backwashing with Milli-Q water is much better than with normal UF permeate (the normal operation procedure in UF plants) in terms of the recovery of membrane permeability. They attributed this to the reduction of ionic strength and Ca-bridging effect due to the absence of mono- and divalent cations and NOM compounds in Milli-Q water. However, this study was carried out at a very small scale. It is not clear whether the same case would be observed in a UF membrane with a higher surface area.

The objective of this study is to investigate the effectiveness of backwashing with demineralized water on a pilot scale. Backwashing with demineralized water is likely to dilute the ion concentration on the membrane surface which will increase the repulsion force between NOM and the membrane. Compared with normal backwashing with UF permeate (containing the same amount of cations as UF feed water), it can remove the fouling layer from the membrane surface more efficiently. Furthermore, the influence of monovalent cations is also investigated by backwashing with NF permeate.

METHODS

Feed water

In this pilot scale study, two types of feed water were used: untreated Schie canal water and ion exchange pretreated Schie canal water. The Schie canal water was continuously pumped from the canal and no pre-filtration was used. The concentrations of metal ions were checked using flame atomic absorption spectroscopy (AAS) and the dissolved organic carbon (DOC) was determined with a Shimadzu TOC-V series TOC analyser. The water quality of two types of feed water is shown in Table 1. The IEX effluent showed a

Table 1 | Water quality of Schie water and Schie water pretreated by IEX

Water quality parameter	Raw water	Effluent of IEX
Ortho phosphate (mg l ⁻¹)	0.65	0.56
Silicate (mg l ⁻¹)	7.5	6
Sulphate (mg l ⁻¹)	154	176
Aluminium (µg l ⁻¹)	5.9	10
Barium (µg l ⁻¹)	16	1.3
Calcium (mg l ⁻¹)	150	<0.5
Potassium (mg l ⁻¹)	18	9.4
Magnesium (mg l ⁻¹)	26	<0.01
Manganese (µg l ⁻¹)	0.99	13
Sodium (mg l ⁻¹)	92	290
Iron (mg l ⁻¹)	<0.05	0.1
DOC (mg l ⁻¹)	15	16

very high sodium concentration, probably because the sample was taken at the early stage of the study when the dosage of NaHCO₃ for pH adjustment after the IEX column 1 had not been optimized (too much NaHCO₃ in column 2). When the dosage was optimized, the sodium concentration in the IEX effluent should have been about 100 mg l⁻¹, based on the theoretical calculation (4 mmol l⁻¹ NaHCO₃ dosed). There is no clear explanation regarding the increase in aluminium, manganese and iron. This may have been due to impurities in the columns or the pipes.

Backwash water

Three different types of backwash water were prepared: 1) demineralized water, 2) UF permeate and 3) NF permeate. The water quality of these backwash waters is shown in Table 2.

Chemical solution

Because enhanced chemical backwash was incorporated in long-term experiments, a chemical solution with a pH of 12 was prepared by dosing NaOH in demineralized water.

Table 2 | Composition of backwash water

	DOC (mg l ⁻¹)	Ca (mg l ⁻¹)	Conductivity (µS cm ⁻¹)
Demineralized water	<0.5	<0.1	1
UF permeate	16	126	980
NF permeate	N/A	<0.1	600

Table 3 | Characteristics of membrane modules

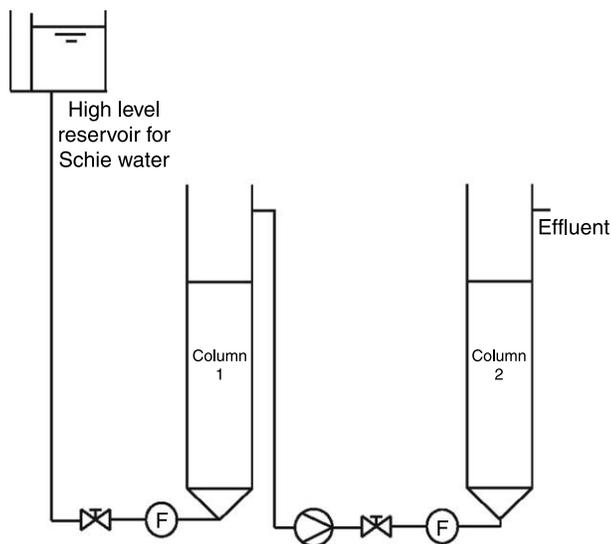
Membrane material	PES/PVP
Molecular weight cut-off	100 kDa
Filtration mode	Inside-out
Internal fibre diameter (mm)	0.8
Length of module (cm)	100
Surface area (m ²)	2.4

Membrane

Two similar polymeric hollow fibre ultrafiltration membrane modules were used in this study. The characteristics of the modules are shown in Table 3. These membranes are made of a mixture of polyethersulfone (PES) with a small amount of polyvinylpyrrolidone (PVP).

Ion exchange (IEX) setup

In order to investigate the impact of monovalent ions on the fouling control efficiency of ultrafiltration, a fluidized pseudo-moving ion exchange system, consisting of two columns, was used as a pretreatment for ultrafiltration (as shown in Figure 1). In this system, two columns are placed in series. After breakthrough occurs in the first column, the second column takes care of the polishing. Therefore, the

**Figure 1** | Scheme of ion exchange setup.

effluent of this system is free from divalent cations. When the first column is saturated with divalent cations, it is regenerated and connected after the second column after regeneration. Each column is 2.5 m high and its inner diameter is 19 cm, the flow rate of this system is 3.6 m h⁻¹. Weak acid cation resin, Amberlite IRC86 from Rohm & Haas Company, was used in this study. Its capacity is 4.1 eq l⁻¹. Because hydrogen ions were released from the resin, the pH of the effluent from IEX column 1 decreased from 8.1 (raw surface water) to about 4. The reduction of pH hindered the process in column 2 (resin works properly at a pH >4.8), so 4 mmol l⁻¹ NaHCO₃ was dosed in the effluent of column 1 as a buffer.

Some studies indicated that fouling of the nanofiltration membrane becomes more serious when the pH of feed water is low (e.g. Hong & Elimelech 1997). That is because the carboxyl functional groups of the NOM molecules can be protonated with hydrogen ions in water. Consequently, the NOM molecules become less negatively charged and easier to deposit on the negatively charged membrane. Therefore, when the ion-exchange pretreated water was used as the feed water for ultrafiltration, 1.8 mmol l⁻¹ NaOH was dosed in it to increase its pH to around 7, which was about 4 after the ion exchange pretreatment.

Ultrafiltration setup and filtration protocol

An ultrafiltration setup from Kiwa Water Research was used in this study for dead-end fouling experiments. This setup consists of two parallel centrifugal feed pumps, two centrifugal backwashing pumps and two chemical dosing pumps, enabling parallel experiments (as shown in Figure 2). There are two sieves (0.5 mm) before the feed pumps to retain large suspended solids that can block membrane fibres (Heijman *et al.* 2007). Permeate was collected in a storage vessel. Transmembrane pressure (TMP) and flow rates of feed and permeate were measured with precision manometers (Endress and Hauser) and logged every 8 s. Afterwards, the respective graphs as a function of time were automatically plotted on computer.

This setup works automatically based on the following program settings: 1) 15 min filtration at a constant flux of 65 l/h m²; 2) one-minute backwashing at a constant flux of 130 l/h m²; and 3) enhanced chemical backwashing with

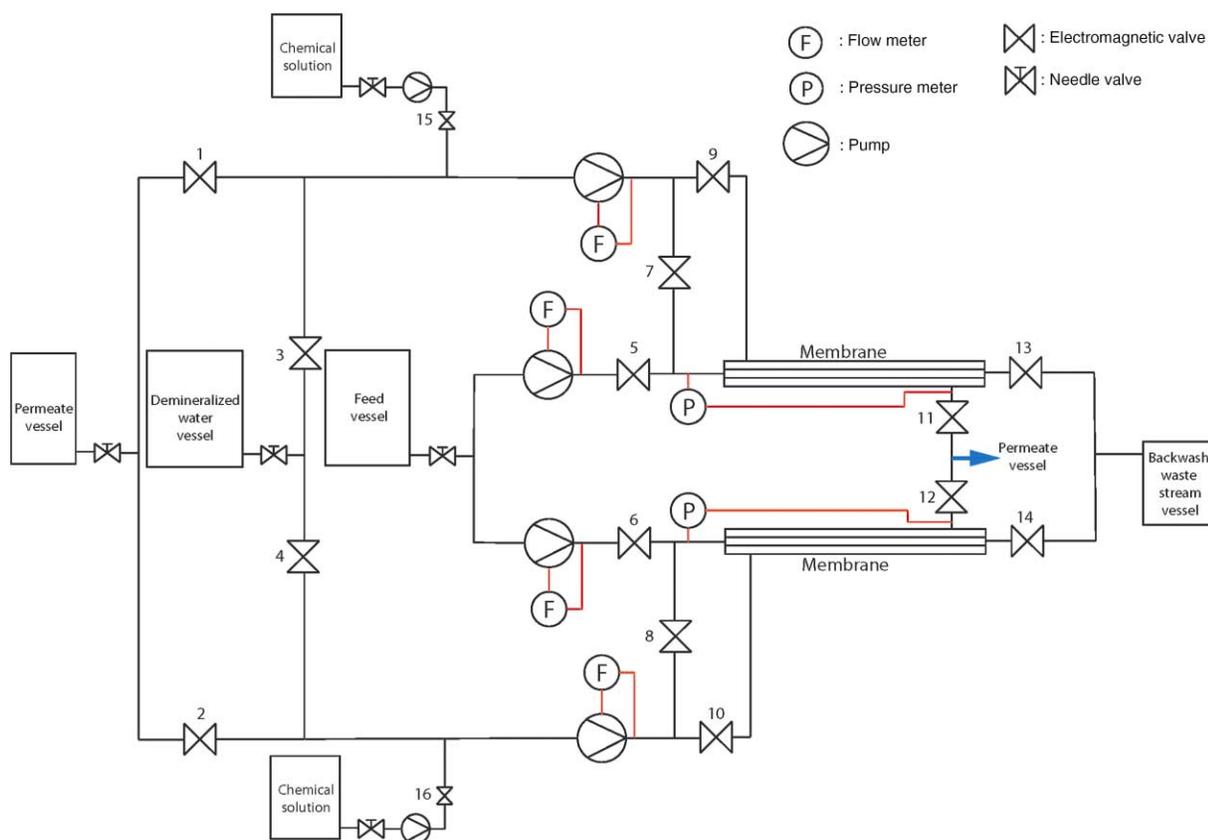


Figure 2 | Scheme of ultrafiltration pilot setup.

NaOH at a pH of 12. Enhanced chemical backwash is composed of 30-second backwashing with chemical solution, 15-min soaking and 20-second normal backwashing.

RESULTS AND DISCUSSION

Influence of backwashing with demineralized water

Figure 3 shows the TMP as a function of time in the short term for four conditions (as shown in Table 4). For condition 1 (Schie water is feed water and UF permeate is backwash), increase in TMP is the fastest, from 0.4 bar to almost 1.4 bar within 2.3 h. On the other hand, either removing divalent cations from feed water or backwashing with demineralized water can substantially reduce the speed of increase in TMP (the speed of fouling). Furthermore, when both removing divalent cations and backwashing with demineralized water were applied

(condition 4), the lowest increase in TMP occurred. Based on this figure, backwashing with demineralized water is as good as removal of divalent cations from the feed with respect to fouling control.

Figure 4 shows the TMP as a function of time in the long term for backwashing with two types of water: demineralized water and normal UF permeate. Raw Schie water was used in this experiment as feed water. From the beginning of the experiment until the 48th hour, the membrane was backwashed with demineralized water. After the 48th hour, the membrane was backwashed with normal permeate. The improvement of backwash (BW) with demineralized water can be seen. For BW with demineralized water, TMP increased to 0.5 bar within 48 h. Given the benefit of chemical cleaning, the increment of TMP was only 0.2 bar. In contrast, for BW with permeate, the TMP increased by 0.6 bar within 4 h. This corresponds to the short-term results.

Backwash with demineralized water was able to remove the fouling more efficiently than backwash with permeate.

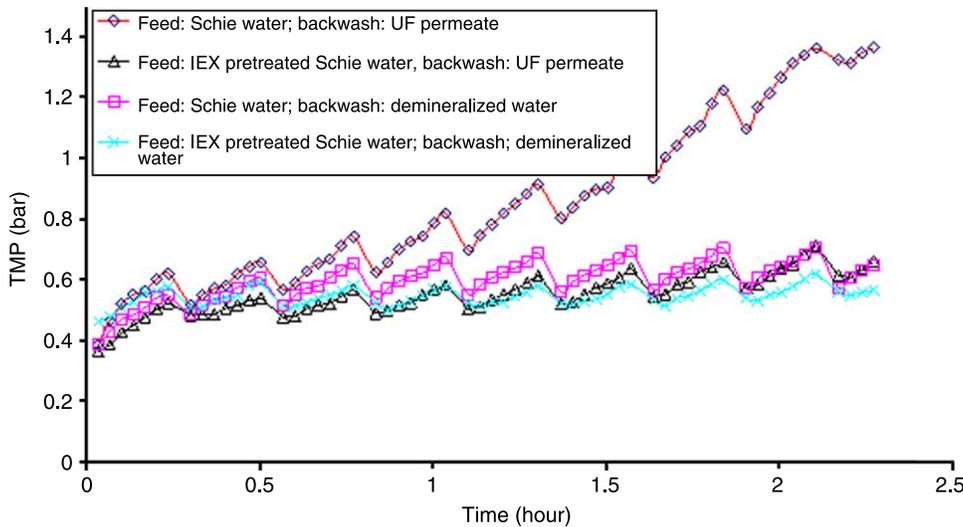


Figure 3 | TMP as a function of time in the short term for four conditions.

This is probably due to the absence of multivalent cations (Ca^{2+} , Mg^{2+} , Ba^{2+}), monovalent cations (Na^+ , K^+) and organic substances in demineralized water. Multivalent cations can bridge negatively charged membranes and negatively charged natural organic matter (NOM), compacting the fouling layer on the surface of the membranes.

Multivalent cations on the membrane surface are the most important factors in fouling, because they are the bridge between the membrane and NOM. The concentration of multivalent cations is lower during the BW with demineralized water; therefore, it is easier to remove the fouling layer with the same backwash velocity. During the BW with permeate the concentration of multivalent ions is the same as the feed water; the UF cannot reject multivalent ions therefore fouling was more significant.

Influence of backwash with NF permeate

Backwashing with demineralized water and nanofiltration permeate were compared in the experiment with a constant

Table 4 | Different filtration conditions applied in this study

	Feed water	Backwash water
Condition 1	Schie water	UF permeate
Condition 2	IEX pretreated water	UF permeate
Condition 3	Schie water	Demineralized water
Condition 4	IEX pretreated water	Demineralized water

flux of $421/\text{h m}^2$. In this experiment ion exchange was used as pretreatment. **Figure 5** shows the results and it should be considered in three parts: 1) 0–10 h; 2) 10–32 h; and 3) 32–52 h. The membrane is backwashed with

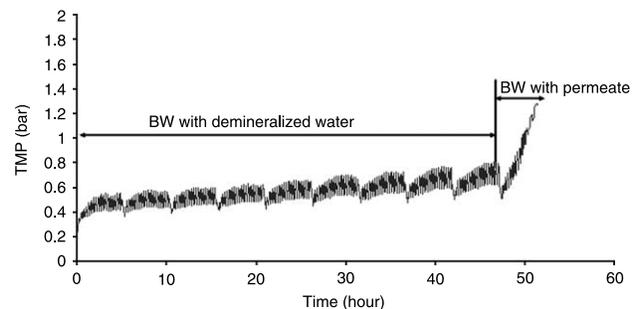


Figure 4 | TMP as a function of time at $651/\text{h m}^2$ for untreated Schie water, with two different backwash periods: demineralized water 0–48 h and permeate 48–52 h (no in-line coagulation was used).

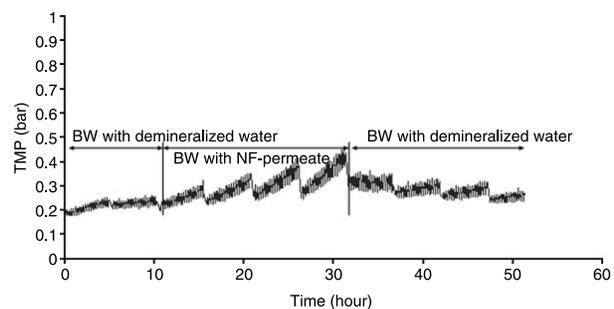


Figure 5 | TMP as a function of time at $421/\text{h m}^2$ for IEX pretreated Schie water, with three different backwash periods: demineralized water 0–10 h and 32–52 h, NF permeate 10–32 h.

demineralized water in parts one and three, and it is backwashed with nanofiltration permeate in part two.

In part one, TMP remained stable, which suggests that the BW with demineralized water successfully prevented the formation of fouling. However, the TMP started to increase when nanofiltration permeate was used for the backwash. When demineralized water was used again for the backwash in part three, the TMP of the system decreased and became stable again.

As most of the multivalent cations and organic matter were rejected in the NF, the possible fouling factor in the NF permeate was monovalent cations, such as Na^+ and K^+ . Although monovalent cations cannot bridge NOM and membrane material, they can reduce the electrostatic repulsion force by decreasing the zeta potential around NOM and the membrane. The zeta potential is an important factor in the formation of a fouling layer, and Hong & Elimelech (1997) reported for nanofiltration that the higher the ionic strength of the solution, the more serious membrane fouling becomes.

CONCLUSIONS

The impact of different backwash waters on UF fouling control has been investigated at a pilot scale in this study. Two types of feed water (raw canal water and ion-exchange pretreated canal water) and three types of backwash water (demineralized water, UF permeate and NF permeate) were tested in this study. Results show that ion-exchange pretreatment can substantially prevent UF fouling. Furthermore, regarding the three types of backwashing, demineralized water is the best option for backwashing of UF. That is partly due to the absence of multivalent cations and

monovalent cations, reducing the charge screening effect and Ca-bridging effect between the negatively charged membrane and NOM, leading to a restoration of repulsion force and consequently an easy removal of the fouling layer.

REFERENCES

- Abrahamse, A. J., Lipreau, C., Li, S. & Heijman, S. G. J. 2008 Removal of divalent cations reduces fouling of ultrafiltration membranes. *J. Memb. Sci.* **323**, 153–158.
- Dong, B.-Z., Chen, Y., Gao, N.-Y. & Fan, J.-C. 2007 Effect of coagulation pretreatment on the fouling of ultrafiltration membrane. *J. Environ. Sci.* **19**, 278–283.
- Fan, L., Harris, J. L., Roddick, F. A. & Booker, N. A. 2001 Influence of the characteristics of natural organic matter on the fouling of microfiltration membranes. *Water Res.* **35**, 4455–4463.
- Heijman, S. G. J., Vantieghem, M., Raktoe, S., Verberk, J. Q. J. C. & van Dijk, J. C. 2007 Blocking of capillaries as fouling mechanism for dead-end ultrafiltration. *J. Memb. Sci.* **287**, 119–125.
- Hong, S. & Elimelech, M. 1997 Chemical and physical aspects of natural organic matter (NOM) fouling of nanofiltration membranes. *J. Memb. Sci.* **132**, 159–181.
- Kabsch-Korbutowicz, M. 2006 Removal of natural organic matter from water by in-line coagulation/ultrafiltration process. *Desalination* **200**, 421–423.
- Katsoufidou, K., Yiantsios, S. G. & Karabelas, A. J. 2007 Experimental study of ultrafiltration membrane fouling by sodium alginate and flux recovery by backwashing. *J. Memb. Sci.* **300**(1–2), 137–146.
- Laine, J. -M., Vial, D. & Moulart, P. 2000 Status after 10 years of operation: overview of UF technology today. *Desalination* **131**(1–3), 17–25.
- Panglish, S., Dautzenberg, W. & Holy, A. 2008 Drinking water treatment with combined coagulation ultrafiltration: long term experience with Germany's largest plant. *Water Supply* **8**(4), 363–375.
- Song, L. & Singh, G. 2005 Influence of various monovalent cations and calcium ion on the colloidal fouling potential. *J. Colloids Interf. Sci.* **289**, 479–487.

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