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Monitoring and controlling biofouling in an integrated membrane system

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ABSTRACT

An integrated membrane system, producing high-quality industrial water from canal water, suffered severely from membrane biofouling. The full-scale plant (comprising: coagulation, moving bed filtration, ultrafiltration and reverse osmosis) has a capacity of 1750 m^3/d. It is equipped with three reverse osmosis units and is located in Klazienaveen, the Netherlands. Fouling of the reverse osmosis membranes manifested as a frequent and rapid increase in pressure drop across the feed-brine channel of the first stage. Frequent chemical cleaning (CIP; cleaning in place) was therefore needed to prevent damage to the membranes. To reduce the cleaning frequency, a research project was conducted with the following objectives: controlling biofouling by dosing peracetic acid (PAA) and DBNPA and evaluating a newly developed in-line biofouling monitor, which monitors biofouling in an early stage. This in-line monitor continuously measures the increase in pressure drop across the feed-concentrate channel of the first element of the first stage in a unit. The in-line biofouling monitor demonstrated that the increase in head loss occurred almost exclusively in the first element and could be accurately measured. Biofouling was controlled by intermittently dosing PAA and DBNPA to two different units. The third unit was used as reference. The results of these efforts were: Intermittent dosing of PAA and DBNPA successfully controlled biofouling. It led to a reduction in the cleaning frequency from 12 times per year (and almost weekly in the summer) to once every three to four months; No increase in salt passage was observed, which could be attributed to the use of PAA or DBNPA.

Keywords: Biofouling; In-line biofouling monitor; Biofouling control; Peracetic acid; DBNPA; Reverse osmosis; Operational experience

1. Introduction

Reverse osmosis is applied worldwide in the production of drinking and industrial water. This paper presents the results of a study conducted at a full-scale plant that processes canal water for the production of high-quality water used for industrial purposes. The plant is owned by Beta-Water, a subsidiary of Waterleidingmaatschappij Drenthe, and has been operational since 2000.

It abstracts water from a canal in Klazienaveen in the North-east of the Netherlands, which is fed in the winter by agriculture run-off water (with a high level of organic substances), treated domestic and industrial wastewater and, during the summer, water from Lake IJssel (with a

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high conductivity). Ever since the plant started operating, the three reverse osmosis units have suffered from biofouling, especially during the summer when there are elevated water temperatures. Initially frequent membrane cleanings, up to 25 times per unit per year, were required to keep the plant running. Membranes were replaced once every three years. Optimization of pretreatment, which consists of moving bed filtration with polyaluminium chloride dose, followed by ultrafiltration and flushing the reverse osmosis units with RO permeate, improved the situation substantially. However, cleaning frequencies were still rather high, about 12 times per year. During the summer, weekly cleaning was sometimes necessary.

To further reduce the cleaning frequency, a study was conducted with the aim of controlling biofouling by making use of two different biocides, namely peracetic acid (PAA) and 2,2-dibromo-3-nitrilopropionamide (DBNPA). PAA has biocidal properties and might be a useful tool in controlling biofouling [1]. No applications of intermittent on-line treatment are known. In the literature, a limited number of successful applications of DBNPA have been reported [2] PAA has the advantage of being less expensive than DBNPA and might decrease the amount of fouling, which already exists on the membrane. Furthermore, it is broken down relatively quickly into harmless substances. PAA combined with iron and/or manganese on the membrane surface might, however, damage the membranes. No membrane damage by DBNPA in combination with iron and/or manganese deposits on membrane surface has been reported. DBNPA can easily be neutralized with sodium bisulfite [3].

Measuring biofouling potential of RO feed waters is an ongoing challenge. AOC and BDOC are parameters that have been developed for this purpose. Measuring these parameters, however, is costly, and time consuming and requires specialized staff. Moreover, the predictive value of these parameters for the occurrence of biofouling in full-scale plants is limited. To overcome these disadvantages, the biofouling monitor and, later on, biofouling simulator have been developed [4–6]. These instruments are strong research tools. In full-scale plants, however, there is a need for a robust in-line monitoring system. The ''in-line biofouling monitor'' has therefore been developed and tested. This device monitors the development of the pressure loss across the first element in the first stage, since biofouling tends to occur mainly in this element [7].

2. Installations, materials and methods

2.1. Plant and operation

The full-scale plant treating canal water has a capacity of 1750 m^3/d. Pretreatment consists of 2 moving bed filters, followed by 4 ultrafiltration units. Three reverse osmosis units, each with two stages and equipped with spiral-wound elements, achieve 75% recovery. The reverse osmosis units were operated at a constant flux (of 22.5 L/m^2.h) by adapting the feed pressure to compensate for temperature changes and fouling. Permeability was normalized for temperature, pressure and osmotic pressure. The feed-concentrate pressure drop (NPD) was monitored and normalized for flow (MTC) and temperature [8]. The term ''biofouling'' refers to a feed-channel pressure drop (feed-concentrate pressure drop).

Polyaluminium chloride was dosed in front of the moving bed filters to improve the removal of suspended and colloidal particles and reduce the organic matter content of the raw water. Ultrafiltration is acting as a polishing step to ensure MFI values below 3 s/L^2.

Over the course of time, automatic flushing was incorporated in the operation procedures. These flushes were performed with product water after each shut down of the unit. Together with improved cleaning procedures it resulted in a reduction in cleaning frequencies. However, during the summer in particular, the cleaning frequency remained high.

Cleaning frequencies were governed by the development of the pressure drop across the feed-concentrate channel in the first stages. Decrease in permeability (MTC) played a minor role.

2.2. In-line biofouling monitor

Studies on biofouling in RO systems indicated that this phenomenon mainly arises due to an increase in the pressure drop in the feed-concentrate channel of spiral-wound elements. In the majority of cases, most of the fouling occurs in the first element in the first stages. It assumed that the fouling in this plant is due to biofouling because:

- pressure drop increase is much higher during the summer than the winter;
- membrane cleaning at high pH is the most effective method;
- particulate fouling is unlikely because of the use of ultrafiltration as pretreatment;
- organic fouling due to presence of natural organic material (NOM) is unlikely since it will not result in development of pressure drop across the feed-concentrate channel.

An in-line biofouling monitor was installed to verify the assumption that biofouling will mainly occur in the first element of the first stage. It also allowed the development of biofouling at an early stage to be monitored. The monitor measures the normalized pressure drop across the feed-concentrate channel of the first element (Figs. 1–3).

2.3. Biocides

Two different biocides were intermittently applied: PAA and DBNPA. PAA was dosed during flushing with

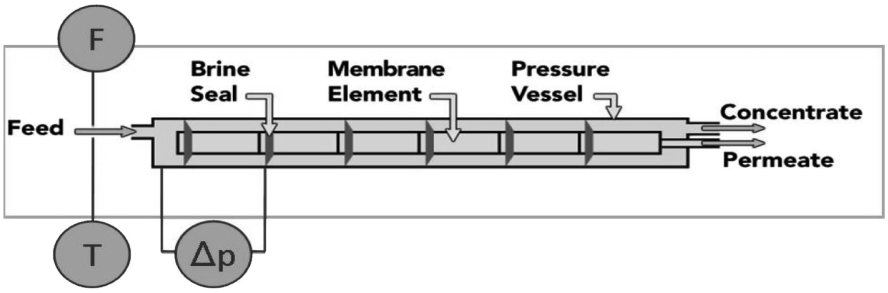

Fig. 1. Principle of the in-line biofouling monitor.

Fig. 2. Pressure sensors placed in pressure vessel. Left: In existing pressure vessel. Right: In new vessel.

permeate RO and DBNPA during full production. Full details about this are provided in Table 1.

DBNPA was applied in RO unit 3, initially equipped with two-year-old Trisep 8040 X201 UWA spiral-wound elements. In March 2009 the test was continued with newly installed ESPA 2 (Hydranautics) membranes.

PAA was applied in RO unit 1, till March 2009 equipped with old ESPA 2 membranes (placed in 2004) and after that filled with the old Trisep 8040 X201 UWA spiral-wound elements from RO unit 3. These elements had already been in use for 2 years, and were tested in 2009 with DBNPA.

RO unit 2 was used as a reference and was equipped with ESPA 2 which had been put into operation 2 years previously.

To minimize the risk of damaging the membranes exposed to PAA, due to presence of iron and/or manganese, the PAA was dosed during a flush with permeate RO and a special cleaning of the membranes was performed to remove these metal oxides.

DBNPA was neutralized prior to discharge in the wastewater pond and subsequent discharge into the surface water. Sodium bisulfite was applied for neutralization and ORP was used to monitor adequate neutralization.

Table 1
Dosing PAA and DBNPA

	PAA	DBNPA
Dosing interval, h	6–24	20
Concentration on the membrane, mg/L	10	20
Added to:	Permeate during flush	Feed water during production

3. Results and discussion

3.1. In-line biofouling monitor

Fig. 3 illustrates the development of the normalized pressure drop in RO-3 (unit with addition of DBNPA) across the:

- first stage
- last 5 elements of first stage (average)
- first element

A pronounced increase across the first element and the first stage is clearly shown in September and December

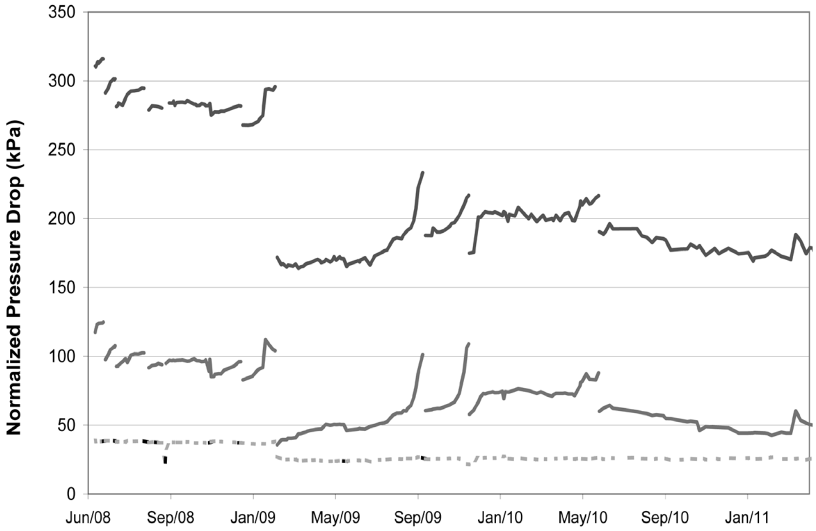

Fig. 3. Normalized pressure in RO-3 across first stage (black), first element (thick striped gray) and average last 5 elements (dotted light gray).

and is attributed to biofouling. The observed increase across the entire first stage is entirely caused by the pressure drop across the first element of the first stage.

Biofouling in an early stage was monitored by both a pressure increase in the first element and the first stage. The readings of the in-line biofouling monitor are somewhat more accurate and pronounced than readings across the entire first stage.

3.2. *Effect of PAA on biofouling*

Fig. 4 depicts the development of the normalized pressure drop in RO-1 and RO-2 (reference). RO-1 was exposed to regular intermittent flushing with PAA and shows a very stable pressure drop. This resulted in a much lower cleaning frequency than required in RO-2 (See triangles and circles at the bottom). Almost all cleanings of RO-1 were done to remove iron and/or manganese or to further reduce the pressure drop (prevention). The rather high pressure drop had been built up in the period prior to the application of PAA.

The frequency of CIP was reduced to 4 per year, while the reference RO units were cleaned more than 12 times per year.

Since dosing PAA on RO-2 was started in August 2009, the NPD of this RO unit decreased rapidly. This was

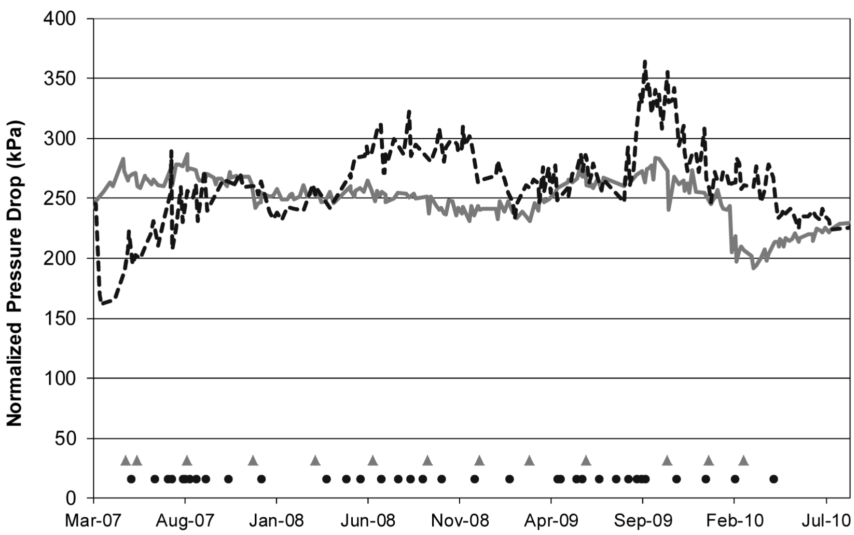

Fig. 4. Normalized pressure drop RO-1 with dosing PAA (gray) and RO-2 (dotted black) without any biocide (reference). At the bottom, triangles and circles indicate CIP of both RO units.

most probably caused by the oxidization of old fouling components from the RO-element spacers.

3.3. *Effect of DBNPA on biofouling*

Fig. 5 shows the development of the pressure drop in RO-2 and RO-3. Until June 2008, no biocides were applied in these units. Since June 2008, tests with DBNPA on fouled and old membranes have been performed on RO-3. In March 2009, RO-3 was equipped with new ESPA 2 membranes. Cleanings are indicated as triangles at the bottom of the graph. A remarkably low cleaning frequency can be observed right from the moment that DBNPA was introduced. The cleaning frequency has been reduced to 3 times per year. Moreover, one of these cleanings was done for preventive reasons only. In the same period, RO-2 was cleaned more than 12 times.

3.4. *Mass transfer coefficient (MTC)*

Fig. 6 depicts the development of the normalized flux/mass transfer coefficient (MTC) of the first stage for the three RO units.

The MTC in RO-1 exhibits some variations during the reported period, but is basically quite stable. The MTC of the membranes in this unit is lower than in RO-2 and RO-3, which is attributed to a different type of membrane (TriSep) and a longer period of operation. The MTC in RO-2 (reference; without any biocide) exhibits more variations due to biofouling and chemical cleanings. RO-3, where DBNPA was directly dosed on new membranes, has a very stable MTC during the entire period. None of the membranes from the three units needed to be cleaned due to decrease in MTC.

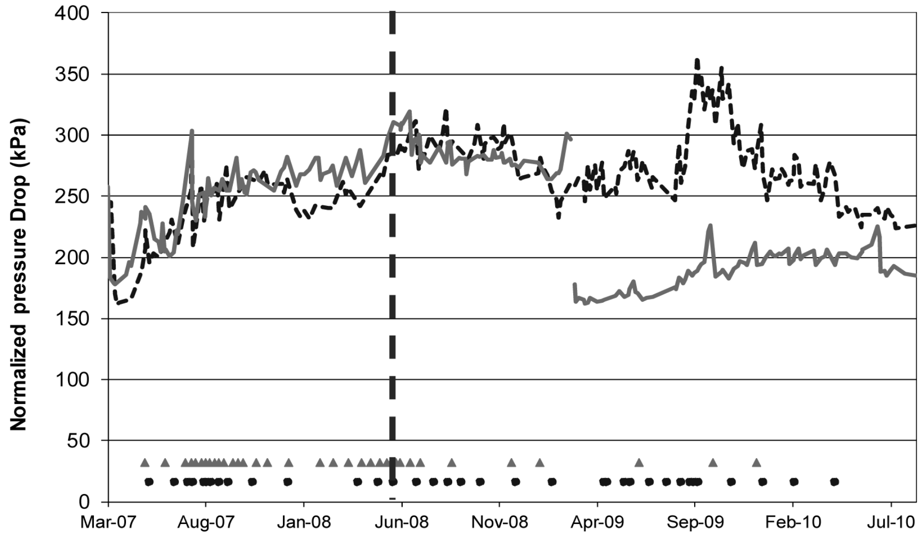

Fig. 5. Normalized pressure drop in RO-3 with DBNPA (gray) and RO-2 as reference, without any biocide (dotted black). At the bottom, triangles and circles indicate CIP of both RO units.

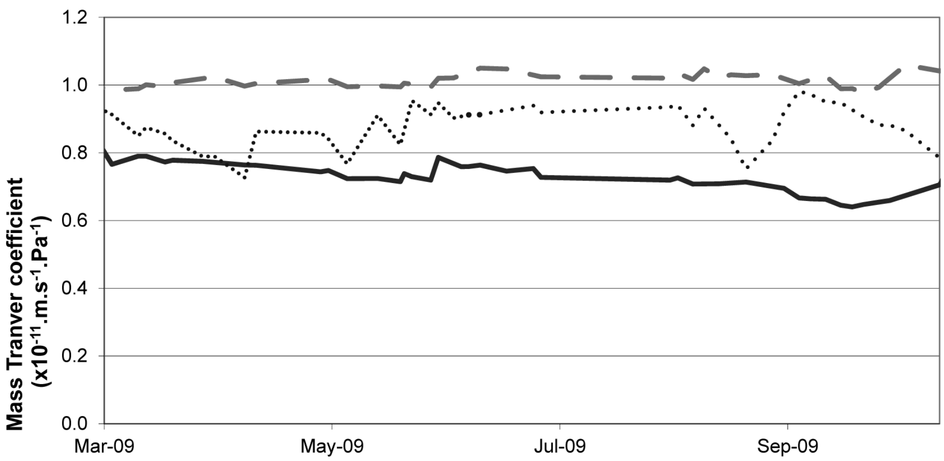

Fig. 6. Mass transfer coefficient: RO-1 (black), RO-2 (reference; dotted black) and RO-3 (striped gray).

3.5. Effect on salt rejection

Application of PAA and DBNPA had no negative effect on the salt rejection of the membranes. This is shown in Fig. 7 where no difference in development of the normalized salt passage (based on conductivity) in RO-1 (PAA), RO-2 (ref.) and RO-3 (DBNPA) is observed.

3.6. Neutralization of DBNPA

The effectiveness of DBNPA neutralization with sodium bisulfite was measured in samples and by continuous monitoring of oxidation-reduction potential (ORP) in both the concentrate of RO-3, (before and after addition of sodium bisulfite) and in the wastewater pond. Fig. 8 shows that this treatment was highly effective. Note: Peaks in ORP in the concentrate of RO-3 during no addition of DBNPA were due to flushing with permeate RO. Peaks in ORP in the wastewater pond during no addition of DBNPA were due to chemical enhanced backwash (CEB) of the ultrafiltration with sodium hypochlorite.

3.7. Effect on operation and maintenance

Application of PAA and DBNPA in RO-1 and RO-3 respectively resulted in much lower cleaning frequencies, especially during the summer. Without biocides, CIP was necessary on an almost weekly basis. With biocide, this frequency dropped to once every three to four months. Table 2 shows the development of the cleaning frequencies per unit during the period 2001–2009.

Due to this result, the entire process was far more stable and the operation and maintenance costs could be reduced by approximately € 0.05/m^3.

Expected longer life time of the membranes will result in an additional saving of € 0.08/m^3.

4. Conclusions

1. Intermittent flushing with PAA and dosing DBNPA were effective in controlling biofouling in reverse osmosis units. Cleaning frequencies could be reduced from about 12 times per year (during the summer

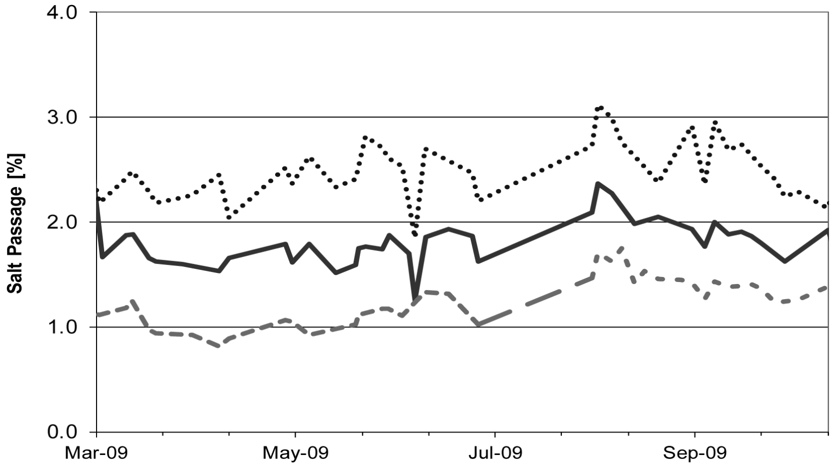

Fig. 7. Normalized salt passage (based on conductivity); RO-1 (black), RO-2 (dotted black) and RO-3 (striped gray).

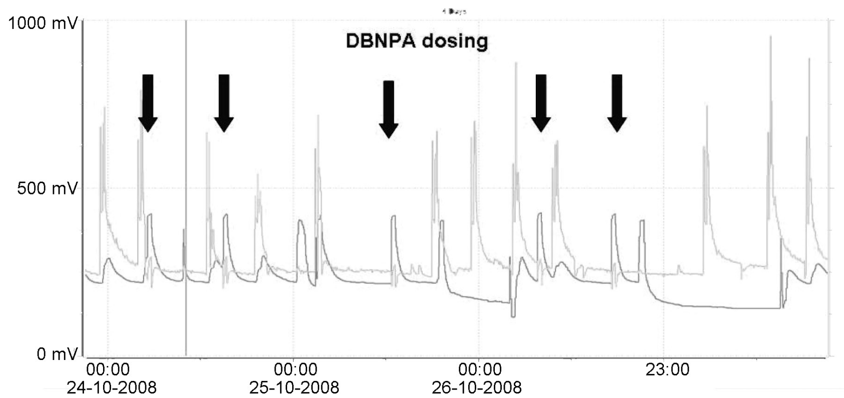

Fig. 8. ORP potential concentrate of RO-3 with intermittent DBNPA dosing (dark gray) and after neutralization with sodium bisulphite (light gray).

Table 2
Frequency of CIP per RO unit from 2001 to 2009

Number of CIP	RO1 (PAA)	RO2 (Ref.)	RO3 (DBNPA)
2001	19	22	18
2002	26	27	19
2003	27	26	22
2004	10	15	13
2005	10	9	8
2006	14	10	10
2007	5[1)]	12	18
2008	4	9	14
2009	4	13	4[2)]

[1)] Year started testing with PAA
[2)] Year started testing with DBNPA

weekly cleaning was sometimes necessary) to three times per year.

2. During the test period, the MTC of the three units was fairly stable. The membranes did not need to be cleaned due to a decrease in MTC.
3. No loss of salt rejection, which might be attributed to the application of the biocides, has been observed during a period of more than one year.
4. Neutralization of DBNPA has been effectively achieved by dosing sodium bisulfite and monitoring oxidation-reduction potential (ORP).
5. The In-line biofouling monitor demonstrated that the pressure drop increase in the feed-concentrate channel occurred in the first element of the first stage. This increase in pressure drop could be accurately monitored in an early stage.

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