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Using SDI, SDI$^+$ and MFI to evaluate fouling in a UF/RO desalination pilot plant

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ABSTRACT

This paper assesses the performance of a UF/RO demonstration plant located in the Oosterschelde estuary in the south-western part of the Netherlands. Spring blooms in the seawater pose a challenge to the plant because of the resulting increased fouling potential of the water. Determinations of the fouling indices SDI, SDI$^+$ and MFI0.45 were carried out at the plant with different operational conditions, such as of coagulant addition and pH correction. Eight different membranes were used in the tests. In general, the UF performance was found to be good as the SDI values were around 1, provided standard membranes were used, and the MFI0.45 values lower than 1 s/L^2. The MFI0.45 showed the same tendency as the SDI in most cases. As expected, whereas the SDI showed marked sensitivity to used membrane type and operational conditions, the SDI$^+$ did not display this dependency and hence appear to be a more reliable fouling index than the SDI. Storing the RO feed overnight in the feed tank increased the fouling potential of the RO feed, likely caused by continued coagulation.

1. Introduction

An alternative to established desalination methods like vacuum distillation and multi-stage flash distillation is reverse osmosis (RO). It can be used to separate dissolved solutes from brackish water and seawater in the preparation of drinking water. RO is more energetically favorable as no phase transformation is required, only electrical energy to drive the pumps to overcome the osmotic pressure, but is hampered by membrane fouling. Several types of fouling can occur in RO membrane systems, e.g. inorganic fouling or scaling, particulate and colloidal fouling, organic fouling, and biofouling. This results in a decline of the permeate flux and loss of product quality. To predict the colloidal fouling behavior of RO feed water, fouling indexes can be used. The Silt Density Index (SDI) and the Modified Fouling Index (MFI0.45) are the two most popular fouling indexes.

The ASTM established a standard protocol for measuring the SDI [1]. From a practical point of view and the membrane manufacturers' specifications, the SDI of fine hollow fiber membrane RO feed water preferably should be lower than 3 [2]. The SDI has been routinely applied worldwide for many decades, and is currently considered the ultimate test for measuring the fouling potential of feed water for reverse osmosis and nanofiltration membranes. Main advantage of the SDI test is that it is simple to execute even by non-professionals.

However, there are growing doubts about the reliability of SDI results, e.g. several manufacturers of micro-and ultrafiltration membranes are frequently confronted with the phenomenon that the SDI of the filtered water is above 3. From a theoretical point of view, it is hard to explain that water filtered through membranes with pores smaller than 0.02 μm has an SDI higher than 3. Therefore, these observations may have to be attributed to deficiencies of the SDI test such as that it does not correct for variations in pressure, temperature, and pore size and membrane resistance of the used filters [3–7].Consequently, in the most recent standard (D 4189–07) ASTM states that the SDI is not applicable for the effluents from most RO and ultrafiltration (UF) systems. Therefore, we previously proposed corrections for the SDI, resulting in a normalized fouling index called SDI$^+$ [8].

The MFI0.45 is based on the cake filtration model, and can be corrected for pressure and temperature. However, measuring an MFI0.45 is more difficult and not very suitable for being performed in the field due to the need for accurate and expensive equipment to collect the filtration data (V , t) [9–11].

We examined the performance of a UF unit with RO pretreatment by using the SDI test with different operational regimes. We also studied the effect of using different commercial membranes with a 0.45 μm pore size. We normalized the SDI results for testing parameters and membrane resistance (leading to the SDI$^+$) with a model for the relation between the SDI and the MFI0.45 [12]. In addition, we assessed the sensitivity of SDI to the particle concentration experimentally.

1.1. Plant description

The seawater UF/RO demonstration plant is located in the south-western part of the Netherlands, and operated by water supply company Evides. The site is in the Oosterschelde estuary, as shown in

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Fig. 1. The net desalinated water production capacity of the plant is 13.5 m^3/h.

Fig. 2 shows the flowchart of the UF/RO demonstration plant. Via an open intake, the seawater is pumped to a buffer tank inside the plant. The raw water is filtered with a 50 μm micro-strainer followed by an optional coagulation and acidification step, in which coagulant and acid are added to the mixing tank. Both dosages are applied according to actual raw water quality and resultant UF behavior. After this mixing step, the UF feed is collected in a buffer tank and then pumped to the UF unit, which contains Norit Seaguard UF membranes. UF permeate is collected in another buffer tank and then pumped to the RO unit. Part of the UF permeate is used for UF backwash. Due to backwash discharge regulations, backwash treatment and recycling is mandatory and consists of application of coagulant in a sedimentation process, followed by partial recycling to the UF buffer tank.

Two RO stages operate in the plant: a seawater RO step for desalination and a subsequent, seasonally required, brackish-water RO step for boron removal (Dow Filmtec, which requires an SDI of less than 5 [13]). The RO permeate for the first RO stage is collected in a buffer tank and then pumped to the second stage. To protect the pumps and membrane units, each feed tank is followed by cartridge filter.

For research and analysis purposes, there are 54 sampling points in the plant. The water samples for our SDI tests were collected at the sampling points shown in Fig. 2.

1.2. Raw water characteristics

The plant faces an algae bloom challenge for three months in the spring season. During their active period, the algae produce a polymeric material called Transparent Exopolymer Particles (TEP). This causes fouling in UF and RO membrane installations [14–17]. Fig. 3 shows a large amount of foam generated by the algae close to the Jacobahaven plant intake in May 2010.

1.3. Fieldwork and plant operation

The spring period is the most critical operation period due to biological activity in the raw water, hence this field work was carried out from 6 April 2010 to 13 May 2010. During our study, the plant experienced a great variation in the raw water quality. Several quality parameters were monitored such as turbidity, pH and temperature. The raw water temperature during the field work varied between 8 °C and 10 °C at sampling point 20 (see Fig. 2).

The raw water was filtered by a strainer to remove colloidals larger than 50 μm. The turbidity varied between 5 and 40 FTU (Formazin Turbidity Unit), with an average of approximately 10 FTU.

The raw water had a pH of 8 to 8.4 during the fieldwork period, and the plant was operated with ferric coagulant during the entire fieldwork. When necessary, the pH was adapted to the pH required for the coagulation process (pH 8) or to prevent RO scaling (pH 6.6) [18]. The pH was also changed in order to study the effect of the pH on UF operation. The coagulant dosage was varied between 2 and 3.5 g Fe/m^3 depending on the degree of fouling (Table 1).

The variations in the operational conditions were not only due to algal blooms resulting in extreme UF fouling, but also to accidental damage to some of the plant equipment. UF performance was monitored continuously as permeability, transmembrane pressure (TMP) and flux, as plotted in Fig. 4.

Fig. 4 describes the operational conditions of the UF unit, with a near-constant flux of 55 L/h/m^2 (LHM) and permeability maintained between 200 and 400 L/h/m^2 bar. During filtration, the transmembrane pressure increased from 120 mbar to 400 mbar to maintain a constant flux. A chemically enhanced backwash cleaning, using regular chemicals (HCl, NaOH and NaClO) was performed at 200 LHM and 1 bar [19].

2. Theory and background

2.1. SDI definition

To determine the SDI, the rate of plugging of a membrane filter with pores of 0.45 μm at 207 kPa is measured. The measurement is done as follows.

a) The time t_1 is determined, which is the time required to filter the first 500 mL.
b) 15 min (t_f) after the start of this measurement, time t_2 is measured which is the time required to filter another 500 mL.
c) The index is calculated with the following formula:

$$\mathrm{SDI} = \frac{100\%}{t_f}\left(1 - \frac{t_1}{t_2}\right) = \frac{\%P}{t_f} \tag{1}$$

Here, SDI is the Silt Density Index in%/min. If the plugging ratio (%P) exceeds 75%, a shorter period t_f has to be taken, e.g. 10, 5 or 2 min.

2.2. MFI

The Modified Fouling Index (MFI0.45) was derived by Schippers and Verdouw in 1980 [20]. For determination of the MFI0.45, the flow through the membrane filter is measured as a function of time.

$$\frac{t}{V} = \frac{\mu \cdot R_M}{dP \cdot A} + \frac{\mu \cdot I}{2 \cdot \Delta P \cdot A_M^2} \cdot V \tag{2}$$

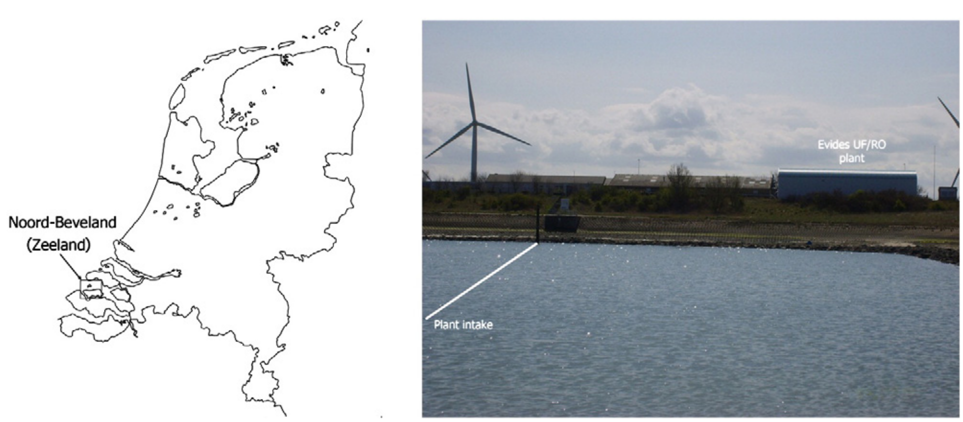

Fig. 1. Location of Jacobahaven in Zeeland, the Netherlands.
Sources: Google.