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The potential of standard and modified feed spacers for biofouling control

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ABSTRACT

The impact of feed spacers on initial feed channel pressure (FCP) drop, FCP increase and biomass accumulation has been studied in membrane fouling simulators using feed spacers applied in commercially available nanofiltration and reverse osmosis spiral wound membrane modules. All spacers had a similar geometry.

Our studies showed that biofouling was not prevented by (i) variation of spacer thickness, (ii) feed spacer orientation, (iii) feed spacer coating with silver, copper or gold and (iv) using a biostatic feed spacer. At constant feed flow, a lower FCP and FCP increase were observed for a thicker feed spacer. At constant linear flow velocity, roughly the same FCP development and biomass accumulation were found irrespective of the feed spacer thickness: hydrodynamics and substrate load were more important for development and impact of biofouling than the thickness of currently applied spacers. Use of biostatic and metal coated spacers were not effective for biofouling control. The same small reduction of biofouling rate was observed with copper and silver coated spacers as well as uncoated 45° rotated spacers.

The studied modified spacers were not effective for biofouling prevention and control. The impact of biofouling on FCP increase was reduced significantly by a lower linear flow velocity, while spacer orientation and spacer thickness in membrane modules had a smaller but still significant effect.

1. Introduction

Membrane filtration processes like nanofiltration (NF) and reverse osmosis (RO) can produce high quality drinking water from water sources including seawater and sewage. Because the global demand for clean freshwater is growing, these membrane technologies are increasing in importance. One of the most serious problems in NF and RO applications is biofouling – excessive growth of biomass – affecting the performance of these membrane systems, influencing the (i) amount and quality of the produced fresh water, (ii) reliability of water production and (iii) costs [1]. Numerous authors have described biofouling problems in membrane installations [2–6]. Recently, the study of membrane biofouling has even intensified, showing that biofouling is still considered as an important problem in practice.

In spiral-wound membrane modules, two types of pressure drop can be distinguished: the feed channel pressure drop (FCP), the pressure drop between feed and concentrate lines and the transmembrane pressure drop (TMP), the differential pressure between feed and permeate lines. When the TMP is increased, i.e. by biofouling, the membrane flux is declined. Biofouling in spiral-wound NF and RO membranes has been studied on monitor, test rig, pilot and full scale for extensively pre-treated water [7,8]. The membrane fouling simulator (MFS), the monitor used in this paper has in many research efforts shown to be representative for spiral-wound membrane modules used in practice [9,10]. Identical behaviour with respect to biofouling and FCP development was observed in membrane elements in the same position in a nanofiltration installation operated with and without flux (Fig. 1). Irrespective whether a flux was applied or not, the FCP and biofilm concentration increased. Calculations on mass transfer aspects supported the observations that the flux is not playing a significant role in substrate supply to the fouling layer. Also, test-rig and full-scale studies with different types of fresh feed water showed that biofouling of membrane modules correlated very well with FCP-increase [11]. Moreover, in systems suffering from biofouling cleaning cycles are governed by the pressure drop over the feed channel. Therefore, biofouling is considered a FCP problem [8,12]. The MFS operated under cross flow conditions without permeate production, gives almost identical results as fouling in a full scale membrane module [9].

Baker et al. [13] reported that initial deposits of fouling were found to accumulate alongside the membrane feed channel spacer and with time these deposits encroached upon the remaining free membrane area. Van Paassen et al. [14] observed an exponential

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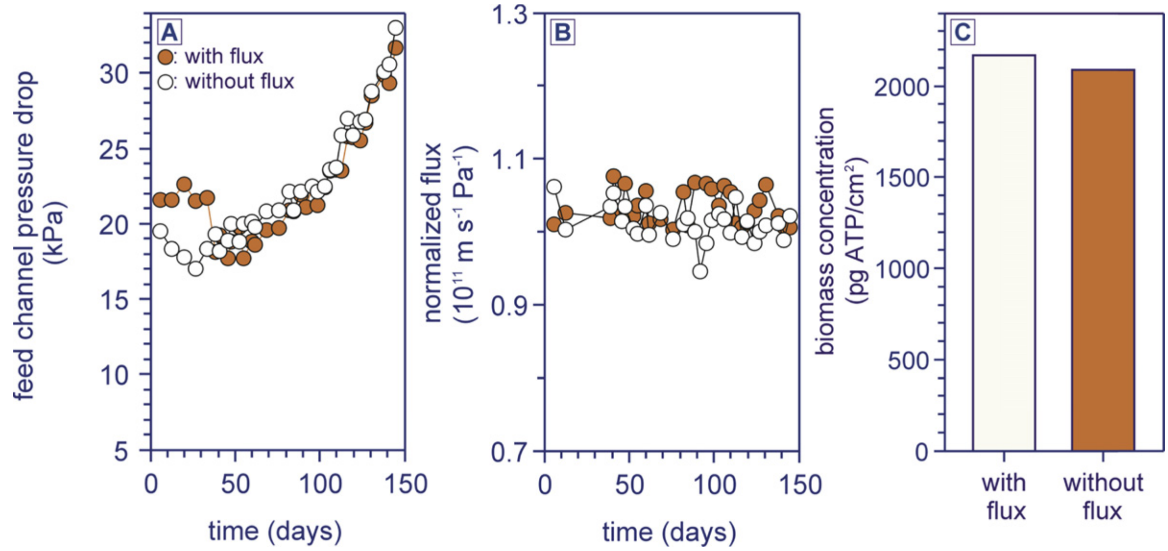

Fig. 1. Feed channel pressure drop (A) and normalized flux (B) over nanofiltration lead membrane modules in time (pilot plant data). Biomass concentrations (C) in the membrane modules determined after 146 days continuous operation with and without flux. Periodically, the permeate side of the element operated without flux was shortly (about 20 min) opened to determine the flux. The flux was normalized for pressure and temperature.
Adapted from [7].

increase of the feed channel pressure drop caused by biofouling build up onto the feed spacer of the membrane modules. This biofouling proved to be related with chemicals dosed to the feed water. Tran et al. [15] found that the vicinity of the feed spacer strands was most affected by fouling. Strategies to reduce feed spacer biofouling have been addressed, e.g. periodic air/water flushing [16] and applying thick feed spacers [17]. Feed spacers are important for membrane performance and play an important part in biofouling of membrane systems.

The objective of this study was to determine the influence of feed spacers on biofouling development, addressing feed spacers applied in commercially available spiral wound membrane modules. Monitor studies were performed (i) without feed spacer presence, (ii) and with reference spacer, (iii) different spacer thicknesses, and (iv) modified spacers.

2. Materials and methods

2.1. Experimental set-up

An overview of the experimental conditions is shown in Table 1. Standard feed spacers and membranes applied in commercially available spiral wound membrane modules were used. Only new, unused spacers and membranes were applied. Spacers were sputter coated with silver, copper and gold and the biostatic spacer contained 0.5% Triclosan as prepared by the manufacturer. The feed spacers used in the MFS research had the same spatial orientation as in spiral wound membrane modules unless mentioned otherwise. Table 2 shows the experimental conditions of the studies with varying feed spacer thicknesses.

2.2. Feed spacers

2.2.1. Inventory feed spacers used in practice

Feed spacers used in spiral-wound membrane modules applied in water treatment were provided by four major global membrane module manufacturers (coded I–IV, Fig. 2, see Section 3).

2.2.2. Reference feed spacer

The reference spacer is a 31 mil (787 μm) thick polypropylene feed spacer, with spacer strands at a 90° position and a porosity of ∼0.85, most commonly used in spiral wound NF and RO modules for water treatment in The Netherlands.

2.2.3. Feed spacer coating: silver, copper and gold

Reference feed spacer sheets with dimensions matching the MFS (0.04 m × 0.20 m) were sputter coated with copper or silver by AIMT Nederland Heat and Surface Treatment (H&ST) BV, Eindhoven, The Netherlands. The thickness of the coating was 210 ± 5 nm (reported by AIMT). A standard spacer was coated with gold using a sputter device commonly used to prepare samples for scanning electron microscopy (SEM). The thickness of the gold coating is not known. The thickness determined of uncoated and coated feed spacers using an accurate thickness gauge (Mitutoyo, accuracy of 0.001 mm) showed similar average thicknesses (780 ± 10 μm) for the uncoated and coated 31 mil reference feed spacers. The MFS sight window enabled visual observations of the coating and spacer orientation (Fig. S1 in supplementary material).

2.2.4. Biostatic feed spacer

A 34 mil blue coloured biostatic feed spacer has been provided by a membrane module manufacturer. For comparison a colourless feed spacer, not containing an anti-biofouling compound with identical geometry and thickness, has been delivered (Fig. S2 in supplementary material). The anti-biofouling component of the biostatic feed spacer was Triclosan, used in 0.5 wt.%.

2.3. Membrane fouling simulator

2.3.1. General

In all experiments, a membrane fouling simulator (MFS) with external dimensions of 0.07 m × 0.30 m × 0.04 m was used [9]. A steel (SMO254) MFS was used for the studies described in Sections 4.1, 4.2, 4.4.1 and 4.4.2 (Table 1).

A polyvinylchloride (PVC) MFS, was developed to enable biofouling studies with varying spacer thicknesses. This MFS showed the same hydrodynamic behaviour and the same fouling development as the steel MFS (unpublished data) but is lighter and