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Hollow fiber ultrafiltration: The concept of partial backwashing

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ABSTRACT

In dead-end hollow fiber filtration with humic acid solutions, we observed that the humic material accumulates in the final part of the fiber. We proved the hypothesis that backwashing of the last part of the fiber is sufficient to operate the filtration process in a sustainable manner. This strategy works very well for feed solutions that result in either local accumulation of the material at the end of the fiber, or that form a well-defined concentration polarization layer that does not lead to deposition. When deposition throughout the whole module occurs, the proposed cleaning strategy is unsuccessful. This overall deposition occurs when a force balance over the particle, results in net transport to the membrane surface over the entire length of the module. We simulated such conditions by the addition of calcium to the feed solutions. The latter results in large aggregates carried towards the whole membrane area by convective water flow, and an increased interaction between the aggregates and the membrane.
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1. Introduction

Successful operation of a dead-end membrane filtration process relies strongly on fouling management. The nature of the process causes fouling and polarization phenomena, leading to an increase in pressure during constant flux filtration. The extent of membrane fouling and polarization phenomena relies on the filtration settings, like the flux, and depends on the properties of the feed and the membrane. Periodically, the accumulated matter in the fiber has to be removed which is typically done by a combination of backwash and forward flush procedures. During backwashing, the flow is temporarily reversed and previously produced clean permeate is used to wash the material from the membrane surface. Since the backwash uses produced clean water and requires energy, the operation must be short and effective. A forward flush is performed by flushing feed water or permeate from the feed side of the module to the concentrate outlet.

Various possibilities to optimize backwashing have been reported in literature. In practice, the optimization of backwash operation is generally based on the outcome of pilot plant studies (e.g. [1,2]), or based on practical experience. Modeling the backwash operation combined with dynamic optimization, as proposed by Blankert [3] shows that operating at the maximum backwash flux gives the highest backwash efficiency (at a fixed total water recovery). From an economical point of view it might be more beneficial to perform the backwash at lower flux at the start and to increase it towards the end of the backwash. Not relying on modeling of the backwash operation, Smith et al. [4], designed a controller to minimize the backwash volume used by measuring the transmembrane pressure during backwashing and the definition of a stop criterion (no change in the transmembrane pressure for 5 s).

Using short pulsing instead of full length backwashing offers an alternative approach. Kennedy et al. [5] describe the combination of a short back pulse, between 1 and 10 s, and fast forward flushing (‘crossflushing’). Jacobs et al. [6] also describe alternations of short back pulses with short forward flushes every 10 min. Occasionally, a regular backwash is performed. Pressure (up to 90 kPa) is quickly (1–2 s) built-up on the permeate side and then released. Gironès i Nogue et al. [7] describe a method where a polymeric microsieve is operated in crossflow mode while applying frequent backpulsing of the membrane. The authors claim that displacement of the membrane, rather than flow reversal is the driving mechanism behind fouling reduction in their system.

Optimization of backwash frequency and time, alternative backwash strategies and module designs are also reported. Injecting air into the feed side of the fibers during backwashing is a popular method to enhance backwash operation. It reduces backwash time and increases its efficiency [8]. Even at low air flow rates, it can be highly efficient in removing fouling from the membrane surface and reducing fouling rate during the filtration period [9]. Air flushing is

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applied in inside-out capillary or tubular modules, when they are either vertically or horizontally mounted, although vertical mounting is preferred [10]. Combining backwashing with a flush with feed water and simultaneous air injection can successfully be performed when backwashing immersed outside-in capillaries [11].

None of the papers take into account that in dead-end filtration with fibers fouling is not necessarily equally distributed over the length of the fiber. Due to the geometry of fiber modules, a small crossflow exists over almost the entire length of the module. The crossflow is highest at the entrance of the module and decreases to zero at the end. The average crossflow velocity depends on the applied flux, the length and diameter of the fibers. Panglisch [12] showed that the axial location where non-Brownian particles (with a diameter >1 μm) deposit on the membrane surface is determined by particle size, electrostatic interaction, and the local crossflow. Similar work was performed by Chellam and Wiesner [13], who predicted particle trajectories in crossflow filtration. In our own work, we showed that humic matter, consisting of Brownian matter, deposits primarily at the end of the module [14]. The driving force for this is a combination of the small crossflow velocity and charge interactions.

We, as well as Panglisch and Gimbel [15], suggest to design a system with two modules. The first module is the main filtration module that produces the majority of permeate, the second, smaller module is used for backwashing. The combined, complete module contributes to filtration but backwashing is only performed with a small module (Fig. 1). Backwashing only a small part of the module increases the recovery, as less water is required. The backwashing is also expected to be more efficient as the backwash volume is expected to be used more efficiently: The local filtration flux varies over the length of the fiber and is lower in regions with higher resistance [16]. The backwash flux can be expected to follow the same pattern (e.g. lower in areas with high resistance). For the humic matter, we also observed that the retention of the complete fiber module is governed mainly by the small module in which all material accumulates. Separating the permeate streams from the large and the small module, gives a high quality permeate stream from the large module, and a small, lower quality permeate stream from the small module.

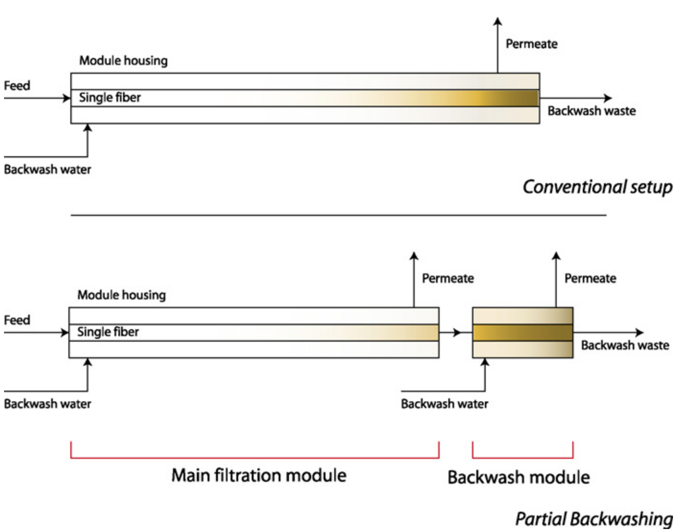

Fig. 1. The concept of partial backwashing compared to conventional backwash operation. The color indicates the degree of fouling or polarization. In the partial backwash concept, a second small module is put in series with the main filtration module. Ideally, only this small module is backwashed, and backwashing of the large module is only performed occasionally. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

In this work we demonstrate for the first time the application of a partial backwash concept (Fig. 1) for various feed solutions. First we show experiments using sodium alginate and humic acid. Then we add calcium, to study the effect of the increased particle–particle and particle–membrane interactions on the filtration process. Finally, we demonstrate partial backwashing with surface water from the local Twente Canal.

2. Experimental

2.1. Materials

Feed solutions for the experiments were prepared from alginic acid, sodium salt (sodium alginate, Acros Organics) or humic acid (50–60% technical solution, Aldrich). The anionic sodium alginate has a broad molar mass distribution between 20 and 100 kDa (measured by flow-FFF and multi-angle light scattering). The charge of the humic acid colloids was −40 mV, measured at neutral pH in a 10 mM KCl solution using a Malvern Zetasizer. Although the molar mass of humic acid is reported to be low, Aldrich humic acid is known to also contain higher, >50 kDa, molar mass material and colloids [17,18]. The feed solutions were prepared with ultrapure water (MilliQ, >18.2 MΩ). Calcium chloride (Acros Organics) was slowly added to the feed tanks while they were filled. Canal water was extracted from the Twente Canal and prefiltered using a metal filter with a 40 μm mesh. The alkaline cleaning agent was prepared from a mixture of Car 12 and Fer 11 (Aquacare Europe, the Netherlands), according to the manufacturer's guidelines. The main component of Fer 11 is EDTA while Car 12 is a mixture of imminodisuccinic acid and non-ionic surfactants. Using sodium hydroxide, the pH of the resulting mixture was increased to 12.5–13. The acidic cleaning solution consisted of nitric acid at a pH of 1–1.5. All chemicals were used without any further purification.

2.2. Membranes

Membrane fibers were received from X-Flow, the Netherlands. The polymeric membranes are made of a blend of polyethersulphone (PES) with a small amount of polyvinylpyrollidone (PVP). The molecular weight cut-off of the membranes is 150–200 $kg\,mol^{-1}$ (manufacturer's data), and the clean water resistance of the membranes is around of $6 \times 10^{11}\,m^{-1}$, corresponding to a clean water permeability of $600\,L^{-1}\,m^{-2}\,h^{-1}\,bar^{-1}$. The membranes are negatively charged at the pH of the feed water (streaming potential measurements showed values around $-20 \times 10^{-7}\,V\,Pa^{-1}$ for the streaming potential coefficient (for the definition see [19]) at a pH of 5.5–6 using 10 mM KCl as the electrolyte, and measured both through the capillary wall as well as along the fiber axis). Ten fibers are potted in 8 mm PVC tubes (inner diameter 6.5 mm) using a polyurethane resin and each module is fitted with two permeate connections. For the experiments 5 small modules were prepared and put in series (see Fig. 2). The active filtration length of the fibers was about 8 cm per module. The initial clean water resistance of the 5 modules in series was $8.6 \times 10^{11}\,m^{-1}$, which is 25% higher than the clean water flux reported by the manufacturer. This difference is attributed to the relatively large error (20%) that is made in estimating the active length of the fibers.

2.3. Experimental setup

The filtration setup can be used to accurately and reproducibly perform filtration and backwash runs and was described in detail before [20]. The setup was specifically designed for constant flux dead-end filtration, and uses two high precision mass flow controllers (MFC) (Coriflow, Bronkhorst, NL) to measure and control

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