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Fouling in gravity driven Point-of-Use drinking water treatment systems

C. Chawla [a,b], A. Zwijnenburg [a], A.J.B. Kemperman [b,*], K. Nijmeijer [b,1]

[a] Wetsus, European Centre of Excellence for Sustainable Water Technology, Oostergoweg 9, 8911 MA Leeuwarden, The Netherlands
[b] Membrane Science & Technology, MESA+ Institute for Nanotechnology, University of Twente, Faculty of Science and Technology, P.O. Box 217, 7500 AE Enschede, The Netherlands

HIGHLIGHTS

- Fouling in membrane based Point-of-Use drinking water systems was studied.
- Flux stabilization was observed for hollow fiber membrane configuration.
- Two different fouling mechanisms evolved in inside/out vs outside/in configuration.
- Intermittently operated inside/out membrane resulted in lowest hydraulic resistance.

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ABSTRACT

This paper describes fouling in simulated Point-of-Use (PoU) systems based on low pressure hollow fiber ultrafiltration membranes. Various operational configurations such as recirculation of feed, discontinuous vs. continuous filtration, and inside/out vs. outside/in were compared to study their effects on fouling and permeate production. Flux values stabilized around 2 L/m^2 h for gravity driven (100 mbar) ultrafiltration. Intermittent operation resulted in lower overall hydraulic resistances compared to continuously operated systems. This was due to the low organic loading and relaxation of the fouling layer during periods of standstill. In most experiments the fouling layer mainly consisted of diatoms, inorganic particles and few microbial clusters. The PoU systems investigated can be operated for longer duration without the need for strong chemical cleaning.

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1. Introduction

Lack of potable water remains a major concern for most developing countries. Household Water Treatment (HWT) technologies are increasing in popularity to meet the safe drinking water needs of people. These so-called Point-of-Use (PoU) technologies utilize physical and/or chemical treatment (for surface water and wastewater re-use) to remove contaminants. Physical sieving by membrane filtration is one of the most favorable of all the product technologies due to its robustness in handling different types of feed water and its user friendliness. Membrane technology accounts for the largest market share in manufactured PoU systems [1].

Low pressure ultrafiltration has proven to be an effective technology for potable water production due to its low energy consumption, effective removal of microbes and ease of use [2]. However, fouling still remains a major challenge and adversely affects the water production capacity and operational lifetime of membranes. Major foulants comprise natural organic matter, inorganic elements, and microorganisms present in the feed water, which interact with the membrane surface and attach to it either reversibly or irreversibly. Membrane fouling behavior depends upon various factors such as continuous /intermittent operation [3], membrane configuration/geometries [4] and hydrodynamics [5]. It has been reported that during gravity driven ultrafiltration of surface water, intermittent operation facilitates relaxation of the fouling layer deposited on the membrane surface and leads to increased fluxes [3]. It was also observed that intermittent operation when combined with forward flushing further enhances the performance of the membrane system [3]. On the other hand, fouling was observed to be more severe under continuous operation [3]. In another study, the effect of hollow fiber membrane module design based on 4 different module geometries i.e. straight, helically coiled, twisted and sinusoidal was investigated [4]. It was shown that the mass transfer increased significantly for curved membrane geometries compared to straight ones (as reflected in the correlation between the Dean number (De) and the limiting

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[*] Corresponding author.
E-mail address: a.j.b.kemperman@utwente.nl (A.J.B. Kemperman).

[1] Current address: Membrane Materials and Processes, Eindhoven University of Technology, Department of Chemical Engineering and Chemistry, P.O. Box 513, 5600 MB Eindhoven, The Netherlands.

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permeate fluxes). Yet another study on membrane configuration compared the response of flat sheet modules against hollow fiber membrane modules during treatment of industrial wastewater [6]. It was observed that for similar feed water characteristics, fouling in the flat sheet membrane was dominated by pore blocking as opposed to cake/gel layer formation observed in case of the hollow fiber configuration [6]. The effect of hydrodynamics has also been investigated by employing different feed water flow patterns with respect to the membrane orientation, such as cross-flow and secondary flow. The positive effect of cross-flow velocity on abated fouling has been demonstrated well in literature [5,7–11]. Shamsuddin et al. [5] showed that cross-flow introduced by circular channels, with spirals on the membrane surface, reduced the boundary (fouling) layer thickness on the membranes surface and improved foulant re-dissolution, thereby enhancing fluxes.

The present work concerns hollow fiber configurations that are frequently implemented in PoU systems, due to their relative higher specific membrane filtration area per unit module volume [12]. One experimental study [13] on the use of hollow fiber membranes during gravity driven membrane filtration can be found, reporting the application of hollow fibers in a membrane bioreactor for onsite greywater treatment [13]. The authors observed severe flux decline during one week of operation and stabilizing fluxes within 15 days. The influence of different aeration rates on biological degradation and biomass development was studied to improve wastewater treatment efficiency [13]. Considering fouling development as a temporal phenomenon, understanding the long term effects of the aforementioned factors on fouling becomes essential in order to accurately assess its overall impact on the efficiency of PoU systems. Despite this fact, most studies available in the literature investigate fouling development over short time scales i.e. for periods of 1 h to 24 h. Especially for low pressure filtration, fouling development is slow and a minimum period of 1 week has been shown to stabilize flux rates [14]. The present work hence highlights the fouling behavior in hollow fiber PoU systems operated over longer durations unlike previous studies (>20 days). The specific objectives of the study were to optimize and understand the effects of various operational parameters that affect the fouling development as discussed above, such as intermittent use of the system, inside/out vs. outside/in operation of the hollow fiber configuration, and recirculation of feed water over the membrane surface. These parameters can be useful in designing more efficient hollow fiber based PoU systems. There are only a few studies [3,14,15] addressing fouling under gravity pressures for flat sheet membrane configurations using surface water as feed. We know from literature that membrane geometry and configuration affect fouling development [4]. Hence, in the present work fouling development is studied under gravity pressures using hollow fiber membranes simulating PoU systems. The advantages of low-pressure membrane operation, in this case gravity pressure, are minimal energy consumption since pumping is not required, and almost no manual maintenance. This broadens the applicability of PoU systems.

In the present work we constructed hollow fiber modules to simulate PoU systems for onsite drinking water treatment applications. In the study, we used surface water containing higher natural organic matter and lower biomass content compared to Jabornig et al. [13] as key foulants. Two hollow fiber configurations with 3 different intermittent intervals of operation and the effect of feed recirculation on fouling development were investigated.

2. Experimental section

2.1. Experimental set-up

A schematic representation of the experimental set-up is shown in Fig. 1. A hydrostatic head provides 100 mbar as transmembrane pressure. Each experimental run was duplicated using two identical modules. All the experiments were conducted at 20 ± 2 °C. Intermittent operations were performed using magnetic valves (M&M International, Italy) coupled with automatic timers (Grassini, Germany). The permeate flux was measured manually every day using a graduated cylinder and a stopwatch. At least two measurements were recorded each day and the average value of the flux was considered.

The viscosity was temperature corrected and plugged in expression (1) to calculate the hydraulic resistance using the following equation [12]:

$$R = \frac{TMP}{\eta J_s} \tag{1}$$

where R is the total hydraulic resistance (1/m), TMP is the transmembrane pressure (Pa), η is the dynamic viscosity of the permeate (Pa·s) and J_s is the flux ($m^3/m^2 \cdot s$).

2.2. Membrane modules

Polyethersulphone (PES) inside/out (I/O) hollow fiber membranes (3 mm ID, 4.5 mm OD) with a MWCO of 100–150 kDa were kindly supplied by Pentair X-Flow BV (Enschede, The Netherlands). These I/O hollow fibers were used to construct membrane modules mimicking commercial PoU systems, with a membrane area of 0.15 m^2 (O/I) and 0.07 m^2 (I/O). For module construction, the membranes were stacked inside a PVC housing, and subsequently potted into the housing with an epoxy resin cured overnight. Clean water permeability for these hollow fiber membrane modules ranged from 260 to 400 $L/m^2 \cdot h \cdot bar$.

Flat sheet PES membranes (type UP 150, MWCO 150 kDa) were purchased from Microdyn Nadir (Germany). Its clean water permeability is >286 $L/m^2 \cdot h \cdot bar$ as per manufacturer. Polycarbonate membrane holders (48 mm, Whatman, VWR, The Netherlands) were used for flat sheet experiments (membrane filtration area 0.0018 m^2).

Prior to filtration, all hollow fiber membrane modules were soaked in demi water overnight, and then rinsed once with 20% ethanol and twice with demi water as recommended by the manufacturer to remove conservation agents prior to the filtration experiments. Hollow fiber modules were checked for leakages by an air-leak test before installing them in the experimental set-up. All installed modules were subsequently checked for leakage at the start of each experiment by determining the number of total coliforms in feed and permeate samples, whereby leaking modules (rejection of coliform <100%) were discarded.

2.3. Chemical analyses and feed water characteristics

Surface water from the Potmarge river (Leeuwarden, The Netherlands) was collected once every 2–3 days and used directly. The total carbon, total organic carbon (TOC) and inorganic carbon of feed and permeate were analyzed by a TOC analyzer (Shimadzu Scientific instruments, Kyoto, Japan). Chemical oxygen demand (COD) of feed and permeate were measured daily using a Hach Lange cuvette test kit (LCK 414 effluent 5–60 mg/L). pH and conductivity were measured using portable meters (WTW, Germany). Turbidity was measured using a Hach 2100N-IS Turbidity meter (ISO Method 7027). Dissolved Oxygen (DO) was measured using a DO probe (HQ30d, Hach). Natural Organic Matter (NOM) fractions were analyzed by Liquid Chromatography-Organic Carbon Detection (LC-OCD) with a UV and organic nitrogen detector (OND) attached to it (Model 8, DOC Labor, Germany). NOM comprises of biopolymers, humic acids, low molecular weight acids

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