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# Identification and Quantification of Major Organic Foulants in Ultrafiltration of Treated Domestic Wastewater and their Removal by Slow Sand Filtration as Pre-treatment

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**Abstract**

The present study investigates major organic foulants in ultrafiltration (UF) of treated domestic wastewater and their removal in slow sand filtration. Identification and quantification of major foulants was conducted in lab-scale experiments. Quantified results suggest that biopolymers (large molecular protein-like and polysaccharide-like materials) are major organic foulants in UF. This conclusion was verified to be reproducible in pilot-scale UF tests. The removal of biopolymers in slow sand filtration was carried out using pilot-scale sand filters. Longer than one year investigation demonstrates that the elimination of biopolymers takes place in the active upper sand layer mainly due to biological degradation. Filtration rate, temperature and biopolymer concentration in feed water affect the performance of slow sand filtration. Though slow sand filtration removes biopolymers and slow down fouling development in downstream membrane filtration, operational conditions of UF (filtration flux and duration) exhibit a significant influence on trans-membrane pressure (TMP) development. Based on pilot-scale tests, sustainable operational conditions are suggested in the present work for UF of slow sand filtrate. Additionally, the effect of chemically enhanced backwash on fouling control is also presented.

**Keywords:** treated domestic wastewater, slow sand filtration, ultrafiltration, fouling, biopolymer

Introduction

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# 1 Introduction

For safe water reuse UF has been recognized as a promising treatment option as it can produce hygienically safe and particle free water. However, membrane fouling seriously limits the application of this technique. Without suitable pre-treatment, optimized operational conditions and/or suitable cleaning strategy, the membrane would be fouled seriously in a short time and this leads to an unreasonable high treatment cost.

Within the SWITCH financed WP3.2 (Safe Water Reuse), one of the tasks (D3.2.2.d) is to assess the effect of bio-filtration as pre-treatment prior to UF for fouling control. To evaluate the process in fouling control, it is necessary to identify and quantify major foulants in UF firstly. In treated domestic wastewater, major foulants in low-pressure membrane processes are considered as dissolved extracellular polymer substances (EPS) and/or soluble microbiological products (SMPs) (Laabs et al., 2006; Shon et al., 2006). Considering size, characterization and quantification, they are mostly measured as biopolymers which are determined using liquid chromatography with online organic carbon, $UV_{254}$ absorbance and organic nitrogen detectors (LC-OCD-UVD-OND) (Amy, 2008). Nevertheless, the previously mentioned researches have the defect of a quantified correlation between biopolymer content and the performance of UF. In the present work the relationship between biopolymer content and filterability of water sample and reversibility of corresponding formed fouling is quantitatively investigated.

Compared to other pre-treatment processes, bio-filtration demonstrates the potential to remove fouling specific EPS/SMP fractions as a simple and cost effective measure (Huck and Sozanski, 2008). Natural bio-filtration processes such as bank filtration (filtration rate $< 0.05$ m/h) were verified as effective fouling control processes (Sperlich et al., 2008). The present study focuses on investigating fouling control effect of slow sand filtration simulating bank filtration at higher filtration rates (filtration rates within 0.1 to 0.5 m/h). The influence of operational conditions such as filtration rate, temperature et al on the removal of foulants is presented.

Although pre-treatment processes can remove foulants to a large extent, fouling is still inevitable. A realistic objective for fouling control is then to operate membrane filtration in a sustainable way under which the trans-membrane pressure (TMP) increases gradually at an acceptable rate, such that chemical cleaning is not necessary within a certain period or permeate volume (Ng et al., 2005). In the current work, the effect of operational conditions (filtration flux and duration) and chemically enhanced backwash are presented to identify their influence on the performance of UF.

# 2 Materials and Methods

## 2.1 Secondary Effluent and Slow Sand Filtration

Treated domestic wastewater used in the present work is secondary effluent and subsequent slow sand filtrate through slow sand filtration at WWTP Ruhleben (Berlin, Germany). The wastewater treatment process in the plant includes a conventional activated sludge process and biological phosphorus and nitrogen removal. Two pilot-scale slow sand filters were set up to pre-treat the secondary effluent prior to UF. The filters were operated at a filtration rate of 0.2 and 0.5 m/h, respectively.

### 2.2 Lab and Pilot-scale UF Experiments

Lab-scale membrane experiments were conducted using a filtration cell (Amicon 8200, Millipore, U.S.A) and a hydrophilized polyethersulfone (PES) membrane (NADIR@ UP150) with a molecule weight cut off (MWCO) 150 k Da. The filterability of different water samples and the reversibility of corresponding formed fouling can be measured using the membrane cell.

An UF pilot plant with PES membrane (Dizzer 450, MWCO 100 to 150 k Da, Inge AG, Germany) was used to filter different waters. The membrane module has a filtration area of 4.5m$^2$. It was operated in dead-end filtration mode at constant flux.

### 2.3 Quantification of Biopolymers Using LC-OCD-UVD-OND System

The LC-OCD-UVD-OND system (DOC-LABOR Dr. Huber, Germany) is equipped with a size exclusion column HW55S (GROM Analytik + HPLC GmbH, Germany) and online detectors. The LC unit separates organic compounds according to their molecular size and the separated compounds are detected by the detectors. The biopolymer concentration in the present study is given in mg C/L.

## 3 Results and Discussions

### 3.1 Identification and Quantification of Biopolymer as Major Organic Foulants in UF of Treated Domestic Wastewater

It was demonstrated that in UF major foulants are dissolved organics (Poele, 2006). In the present work, filterability contribution of size fractioned substances was tested. As shown in Fig.1, the fraction

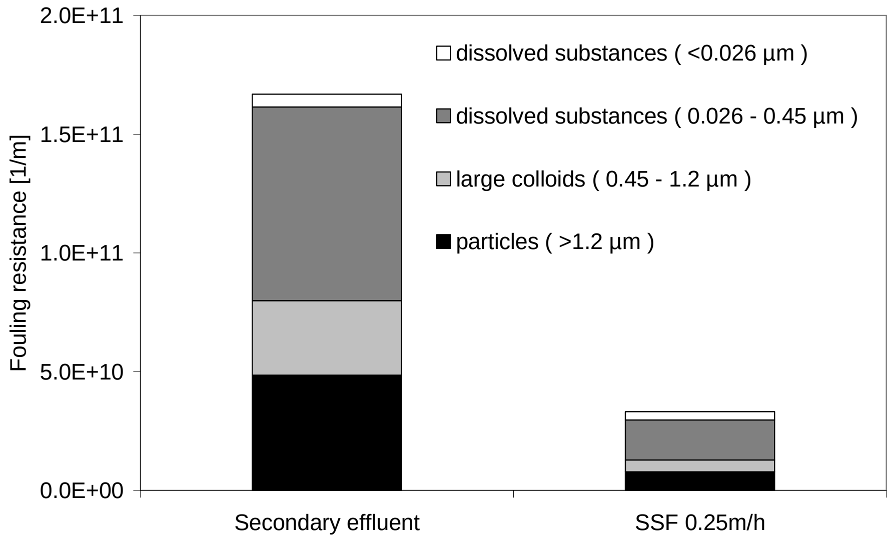


Figure 1: Fouling resistance attributed from different fractioned substances in secondary effluent and its slow sand filtrate

of dissolved substances larger than UF membrane pore size in secondary effluent and its slow sand filtrate contributes to the most hydraulic resistance. Further identification of these substances using LC-OCD shows that they are mostly biopolymers (Fig.2 (a)). Their concentration influences the filterability of water sample proportionally (Fig.2 (b)) and affects the reversibility of corresponding formed fouling remarkably (data not shown). The lab-scale results suggest that biopolymers are major foulants in UF of treated domestic wastewater. The deduction has been proved to be reproducible by pilot-scale UF of either secondary effluent or slow sand filtrate.

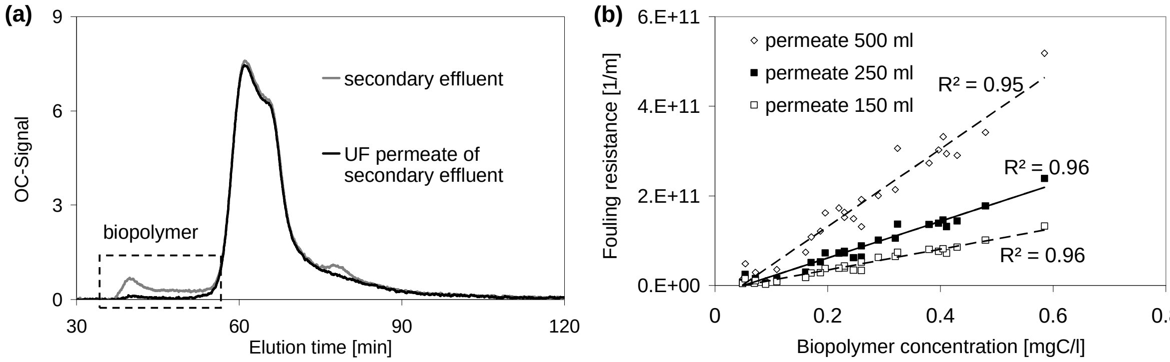


Figure 2: Liquid chromatograms (LC-OCD) of (a) secondary effluent and its UF permeate, (b) relationship between biopolymer concentration and (b) fouling resistance under permeate volume 150 ml, 250 ml and 500 ml (n=26)

## 3.2 Organic Foulants Removal by Slow Sand Filtration

Taking biopolymers as major organic foulants, the removal of them in slow sand filtration was investigated. The results indicate that most of the removal takes place in the upper sand layer. In this zone dissolved oxygen concentration falls sharply and pH decreases also to some degree (Fig. 3). The correlation of these phenomena implies that the ultimate removal of biopolymers is based on biological processes. The biodegradability of biopolymers is further verified by batch test.

Within longer than one year pilot-scale investigation, the influence of temperature, filtration rate and biopolymer concentration in secondary effluent on biopolymer removal was noted. The results demonstrate that higher temperature, lower filtration rate lead to a higher removal effect.

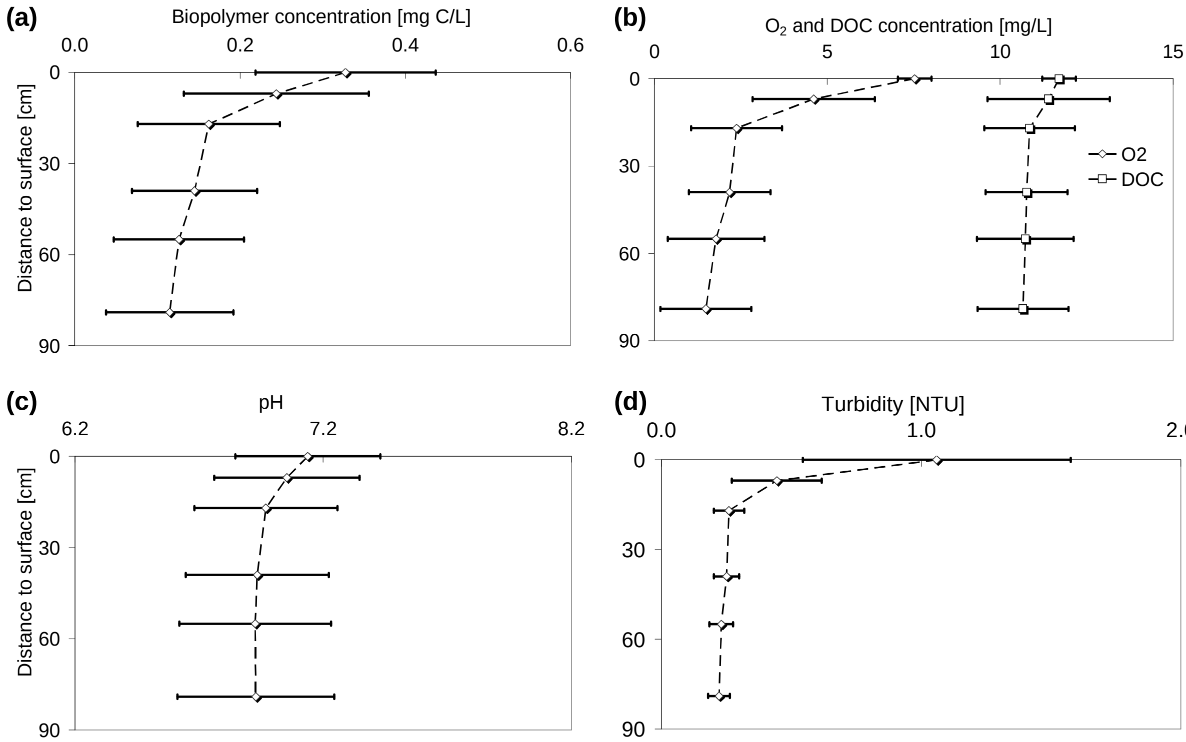


Fig. 1 Removal profile of (a) biopolymer (n=14), (b) dissolved oxygen and DOC (n=10), (c) pH (n=14), (d) turbidity (n=14) in slow sand filter operated at filtration of 0.5 m/h from July 2007 to November 2007

### 3.3 Influence of Operational Conditions on the Performance of UF Filtering Slow Sand Filtrate

Although slow sand filtration removes particles and biopolymers to a large extent, the UF operated at high flux and long backwash interval (BWI) displays TMP increase. Lower flux and/or shorter BWI were then tested to operate the plant aiming at controlling TMP improvement. Results show that operated at a flux of 50 L/m²-h (LMH), BWI of 10 minutes and backwashing at a flux of 260 LMH, backwashing time from 10 to 20 seconds, fouling by UF of slow sand filtrate can be effectively controlled (Fig.4). In the case of filtering slow sand filtrate with a low biopolymer concentration (< 0.1 mg C/L), TMP of the UF plant increased only 210 mbar within 47 days.

Under extreme operational conditions (high flux and long BWI) chemically enhanced backwash (CEBW) is necessary to stabilize the performance of membrane systems. In the present work the effect of sodium hydroxide, hydrogen peroxide and sodium hydrochloride were tested individually as enhanced backwash reagent. During the tests the UF plant was operated at a flux of 89 LMH, BWI of 40 minutes, chemically enhanced backwash of 50 seconds and a subsequent disinfection time of 5 minutes. TMP control results (Fig. 5) show that the best fouling control effect was achieved by using NaClO (active Cl concentration 8 – 10 mg/L). Dosing $H_2O_2$ (concentration 20 mg/L) was also identified as an effective fouling control method. It is presented as a reliable chlorine-free fouling control reagent compared with the usage of chlorine.

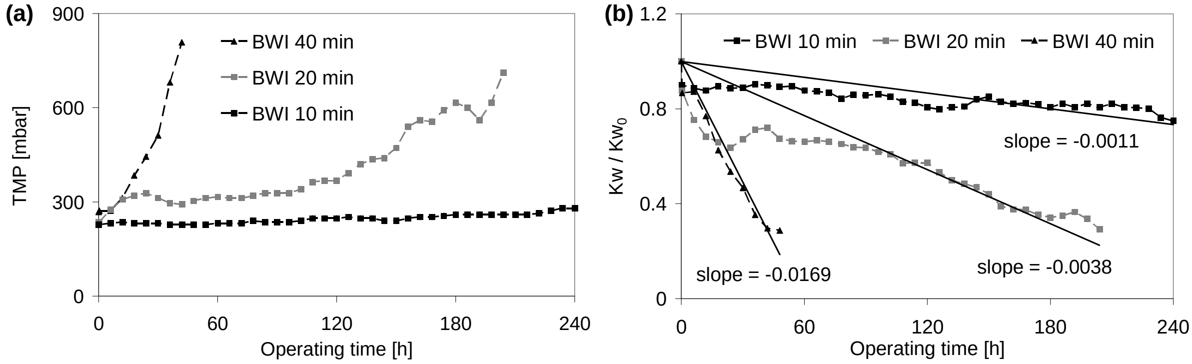


Fig. 4 (a) TMP development vs. operating time at different BWI (b) $K_w/K_{w0}$ vs. operating time at different BWI, (c) TMP development vs. permeate volume at different BWI (d) $K_w/K_{w0}$ vs. permeate volume at different BWI (Other operating parameters were identical: BWI 10 minutes, BWT 20 seconds, BWF 260 LMH).

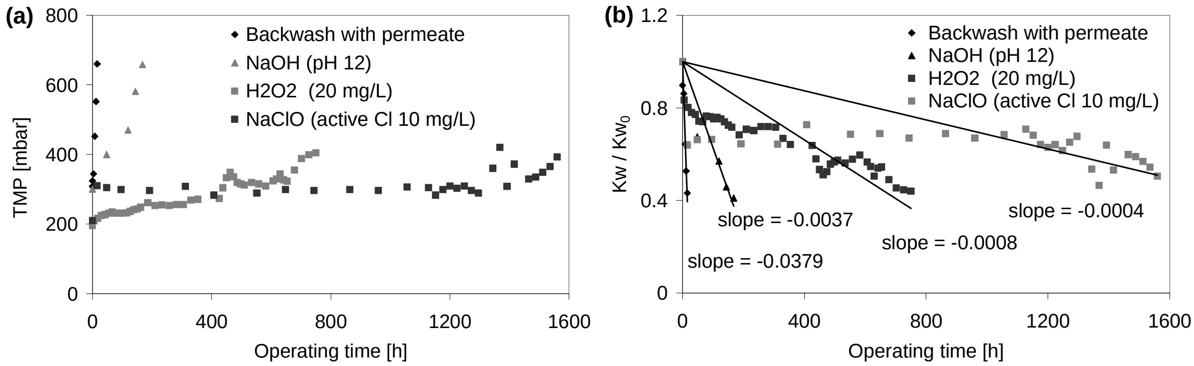


Fig. 5 (a) TMP development vs. operating time using permeate backwash and enhanced backwash reagents (b) $K_w/K_{w0}$ vs. operating time using permeate backwash and enhanced backwash reagents

# 4 Conclusions

Based on lab-scale and pilot-scale experiments, the following conclusions can be drawn in the present study:

- Biopolymers (large molecular protein-like and polysaccharide-like substances) are major organic foulants in treated domestic wastewater for UF. Their content influences the performance of UF predominantly.
- Slow sand filtration is an effective fouling control pre-treatment unit prior to UF. It removes biopolymers through biological processes. The effect of the removal is influenced by temperature, filtration rate and also biopolymer concentration in feed water.

- Fouling development in UF is affected significantly by operational conditions. In the present work a sustainable operation of UF was achieved in filtering slow sand filtrate. With the help of chemically enhanced backwash, UF can be economically operated


## Acknowledgments

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