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The effect of WWTP effluent zeta-potential on direct nanofiltration performance

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Abstract

Laboratory scale filtration tests utilizing wastewater treatment plants (WWTP) effluent were conducted to investigate fouling and filtration performance of nanofiltration (NF) membranes. The focus of this research is to assess the influence of the zeta-potential of the colloidal fraction in WWTP effluent on nanofiltration performance. As the work presented in this study is conducted on a real effluent rather than model water, a statistical design method has been used to account for effluent composition variations and to obtain valid and significant results. The results show that in direct filtration (NF/RO) of water with normal organic matter (NOM), maintaining a high zeta-potential is imperative to keep cake layer resistance to a minimum. The reversibility of the fouling process was shown to be independent from the changes in zeta-potential. Fouling was shown to be promoted by acidification (pH 5) of the effluent, whereas coagulant addition resulted in an increase in the reversibility of the fouling layer. The work presented in this paper suggests that selection of a proper coagulant to suppress fouling problems should be based on the interaction between membrane and coagulant, while the interaction of coagulant-NOM should be minimal to maintain a high (negative) zeta-potential.

Keywords: ANOVA; Aluminum coagulation; Fouling; Direct nanofiltration; WWTP effluent; Zeta-potential

1. Introduction

Reuse of water from wastewater treatment plants (WWTP) utilizing membrane technology has received a lot of attention in the past decade, especially microfiltration (MF) and ultrafiltration (UF). It has been proven that membrane technology is a successful technique for production of effluents free of microorganisms and suspended solids. Even higher quality of permeates can be achieved by use of nanofiltration (NF) or reverse osmosis (RO) by additional removal of soluble organics and salts. Residual organics in WWTP effluent are often characterized by less biodegradable compounds. Associated with these bio-inert compounds are humic substances and micro-contaminants like endocrine disruptors, pesticides and trace metals which are often adsorbed to humic substances. These micro-contaminants have been shown to accumulate in the environment threatening water resources [1,2]. Apart from the environmental need for enhanced treatment of WWTP effluent for water reuse programs, future change in legislation might trigger the need for effluent polishing techniques. An example would the screening of WWTP effluent on priority substances, as proposed in the EU Wastewater Framework Directive [3].

Previous pilot studies showed that direct nanofiltration could be a suitable technique for polishing WWTP effluent [4,5]. A key component in a successful sustainable and economical implementation of NF/RO in wastewater polishing is to find a disposal strategy for the resulting concentrates [6,7]. Concentrates from NF effluent polishing can most likely not be discharged due to legislation and environmental aspects as mentioned before. For any discharge concept,

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apart from dilution to meet discharge levels, it is imperative to minimize the concentrate volume [8]. Minimization of the concentrate is often hampered by severe fouling effects. The main fouling constituents in the effluent are (biologically) inert dissolved organics originating from the WWTP influent and biological residue products from the activated sludge process.

A significant number of theoretical and experimental studies on *model* waters have been conducted to identify the main fouling mechanism of natural organic matter (NOM) in membrane filtration. Physical–chemical interactions between NOM, feed water matrix and the membrane have been found to play a significant role. The most important parameters are considered to be:

1. Colloid stability (directly related to zeta-potential); decreased stability leads to loss in cake layer void space resulting in higher filter cake resistance [9].
2. NOM-membrane bridging under influence of divalent cations, especially calcium; divalent ions are shown to act as bridging material between carboxylic active groups present in many NOM and the negatively charged functional groups present at the membrane surface [10,11].
3. Hydrophobicity of the feed water constituents. The hydrophobicity of feed water constituents, expressed in their octanol–water partitioning coefficient was shown to be a relatively robust parameter in predicting the fouling potential. Components with a higher partition coefficient show more hydrophobic interactions and cause more flux decline [11–13].
4. Membrane surface properties as surface roughness, contact angle and charge [14,15].

The observed membrane performance appears to be a complex function of the feed water characteristics and the chemical and physical properties of the membrane itself. These complex interactions make process control in direct membrane filtration of WWTP effluent difficult as the feed water mixture changes rapidly (within hours to minutes). One parameter within the effluent, the zeta-potential of its colloidal matter, seems to be a good and robust indicator in operational control of a WWTP [16]. The authors hypothesized that the zeta-potential of the colloidal matter in the WWTP effluent could be a suitable parameter to assess filtration and fouling performance as the zeta-potential is directly linked to the most important fouling mechanism described before. It is important to notice that the term 'colloids' used in this paper refers to the components in the effluent, which show colloidal behavior, i.e., show electrophoretic mobility as measured in visible light. This 'chemo-centric' approach includes the colloidal pool, such as coiled proteins and humic substances if they include interacting exterior charges best treated with double layer theories. Ergo, the term 'colloids' does not refer to the terminology often used in wastewater engineering in which colloids are classified as particles with a range between 0.01 and 1.0 μm [17].

In contrast to all previous studies, we have chosen to analyze the influence of the colloidal properties of *real* feed water, expressed in zeta-potential of the colloidal matter, on direct nanofiltration performance. To cope with the complexity of the changes in the feed water composition, we have chosen a design of experiment, to obtain statistically valid and meaningful conclusions.

2. Methods and materials

2.1. Design of experiment

To assess the influence of the stability of the NOM in a real effluent matrix we have to cope with three difficulties; control of the zeta-potential during the experiment, the variance in effluent matrix composition between experiments and possible interactions of the various factors (Section 2.4) chosen in the experimental design.

Section 2.3 shows the zeta-potential to be a relatively robust parameter of the effluent, which can be controlled by pH adjustment and coagulant dosage. Choosing a NF membrane with low salt rejection (Section 2.5) helps to reduce the effect of the ionic strength on the zeta-potential during the experiment.

To account for the variance between effluents and to detect interaction effects between chosen parameters a statistical method, full factorial design (FFD) with blocking was employed (see Appendix A). A total of 40 stirred cell filtration experiments (Section 2.6) were run overnight at ambient room temperate (18–20 °C). Total duration for each experiment varied from 15 to 20 h to achieve, if possible, equal recoveries of around 95%. Nanofiltration performance was evaluated in terms of filtration resistance of the effluent and reversibility of the fouling. Fig. 1 gives a schematic overview of the required sequences of experiments and data processing needed.

2.2. Effluent characteristics

Effluent from the municipal wastewater treatment plant at Leeuwarden, the Netherlands was used in this experiment. The Leeuwarden plant consists of an activated sludge system combined with phosphate removal by chemical precipitation. Samples were drawn from the overflow of the secondary clarifiers and stored prior to analysis in dark at 5 °C. Total storage time was kept below 24 h to prevent change in effluent characteristics. General characteristics of the effluents used in the full factorial experiment are listed in Table 1. The effluent of the Leeuwarden sewage treatment plant has some site-specific characteristics:

– The moderate specific ultraviolet absorption (SUVA) (>0.02 $L\,cm^{-1}\,mg^{-1}$) of the effluent shows the aromatic nature of the effluent, which is not surprising as the drinking water of Leeuwarden contains a large amount of humic