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Pilot-scale investigation of drinking water ultrafiltration membrane fouling rates using advanced data analysis techniques

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ABSTRACT

A pilot-scale investigation of the performance of biofiltration as a pre-treatment to ultrafiltration for drinking water treatment was conducted between 2008 and 2010. The objective of this study was to further understand the fouling behaviour of ultrafiltration at pilot scale and assess the utility of different foulant monitoring tools. Various fractions of natural organic matter (NOM) and colloidal/particulate matter of raw water, biofilter effluents, and membrane permeate were characterized by employing two advanced NOM characterization techniques: liquid chromatography – organic carbon detection (LC-OCD) and fluorescence excitation-emission matrices (FEEM) combined with principal component analysis (PCA). A framework of fouling rate quantification and classification was also developed and utilized in this study. In cases such as the present one where raw water quality and therefore fouling potential vary substantially, such classification can be considered essential for proper data interpretation. The individual and combined contributions of various NOM fractions and colloidal/particulate matter to hydraulically reversible and irreversible fouling were investigated using various multivariate statistical analysis techniques. Protein-like substances and biopolymers were identified as major contributors to both reversible and irreversible fouling, whereas colloidal/particulate matter can alleviate the extent of irreversible fouling. Humic-like substances contributed little to either reversible or irreversible fouling at low level fouling rates. The complementary nature of FEEM-PCA and LC-OCD for assessing the fouling potential of complex water matrices was also illustrated by this pilot-scale study.

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Nomenclature

AIC	Akaike information criterion
BIC	Bayesian information criterion
BW	backwash
C/P	colloidal/particulate matter
cTMP	corrected transmembrane pressure
DFA	discriminant function analysis
DOC	dissolved organic carbon
EBCT	empty bed contact time
FEEM	fluorescence excitation-emission matrices
GRW	Grand River water
IRF	irreversible fouling
LC-OCD	liquid chromatography – organic carbon detection
MLR	multiple linear regression
NOM	natural organic matter
PARAFAC	parallel factor analysis
PCA	principal component analysis
Protein-C/P	protein-colloidal/particulate matter interaction
PCs	principal components
PVDF	polyvinylidene fluoride
RF	reversible fouling
SLC	significance level criterion
SPR	surface plasmon resonance
T	temperature
TMP	transmembrane pressure
TOC	total organic carbon
UF	ultrafiltration

1. Introduction

Due to their small footprints and reliable performance for colloidal/particulate matter and pathogenic microorganism removal, ultrafiltration (UF) membranes have gained considerable acceptance throughout the drinking water industry and are being increasingly used in place of traditional granular media filtration, in drinking water treatment. However, as one of the major challenges in the operation and maintenance of this advanced treatment technology, organic fouling can significantly increase the maintenance costs and operational complexity, and decrease productivity, therefore reducing the attractiveness for adoption of UF membranes in the drinking water industry. Regular maintenance of the full-scale UF membrane system usually employs backwashing, disinfection, and chemical cleaning as fouling mitigation measures (e.g. Peter-Varbanets et al., 2011).

Recent fouling studies, using either model solutions or natural waters, have revealed that colloidal/particulate matter and various fractions of natural organic matter (NOM) are major contributors to the organic fouling of UF membranes (Jermann et al., 2007, 2008; Hallé et al., 2009; Peiris et al., 2011; Peldszus et al., 2011; Peter-Varbanets et al., 2011). Various NOM characterization techniques have been adopted in UF fouling research and are gaining prominence with respect to the characterization and quantification of NOM fractions and colloidal/particulate matter. Two of the most promising NOM characterization techniques include liquid chromatography – organic carbon detection (LC-OCD) and fluorescence excitation and emission matrices (FEEM). LC-OCD can quantify five NOM fractions, including biopolymers (e.g. polysaccharides, proteins, and amino sugars), humic substances, building blocks, low molecular-weight acids and neutrals (Huber et al., 2011). FEEM combined with multivariate statistical analysis techniques, such as principal component analysis (PCA) and parallel factor analysis (PARAFAC), can further enhance the utility of the FEEM technique and were demonstrated to be an effective approach to indirectly quantify humic and fulvic acid-like substances, protein-like substances, and colloidal/particulate matter (Peiris et al., 2010a, b; Baghoth et al., 2011).

Several methods to quantify the hydraulically reversible and irreversible fouling rates of hollow-fibre low pressure membranes operated at constant flux have been proposed (Huang et al., 2008, 2009; Nguyen et al., 2011; Peldszus et al., 2011). Fouling rates can be quantified using process measurement data such as transmembrane pressure and flux. Furthermore, realistic cleaning practices (e.g. automatic backwashing, maintenance cleaning) in full-scale membrane operation can significantly complicate the evaluation of fouling rates (Nguyen et al., 2011) and therefore should be taken into account in order to ensure the validity of fouling rate quantification.

The objective of this study was to employ both LC-OCD and FEEM-based techniques to characterize various potential UF membrane foulants in natural water, including NOM fractions and colloidal/particulate matter using data from a pilot scale study. First, a framework of fouling rate quantification and classification for pilot- and full-scale membrane operations was developed. This was followed by assessing the individual and combined contributions of different potential foulants to UF membrane fouling using LC-OCD data and PCA analysis of FEEM data.

2. Materials and methods

2.1. *Source water*

Grand River water (GRW, Southwestern Ontario, Canada), which is impacted by agricultural and municipal activities, was used as source water during this study. The chemical and physical water quality of GRW varied seasonally (e.g. total organic carbon (TOC): 5.8–8.2 mgC/L; Temperature: 0.7–25.3 °C). Detailed characteristics of GRW during the study period can be found in Peldszus et al. (2012).

2.2. *Pilot-scale biofiltration-ultrafiltration set-up*

Between 2008 and 2010, an investigation of the performance of rapid biofiltration (without prior coagulation) as a pre-