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Fouling of ultrafiltration membrane by effluent organic matter: A detailed characterization using different organic fractions in wastewater

H.K. Shon [a], S. Vigneswaran [a,*], In S. Kim [b], J. Cho [b], H.H. Ngo [a]

[a] *Faculty of Engineering, University of Technology, Sydney, P.O. Box 123, Broadway, Sydney, NSW 2007, Australia*

[b] *Center for Water Research (CWR), Gwangju Institute of Science and Technology, Gwangju, Republic of Korea*

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Abstract

Membrane fouling caused by hydrophobic (HP), transphilic (TP), and hydrophilic (HL) fractions in biologically treated sewage effluent (BTSE) are still not well understood. Some researches reported that the HP fraction (humic substances) were the major problem; other studies indicated that the HL fraction (polysacchrides) were the main causes for severe fouling in membrane filtration. Hence, in this study, a detailed ultrafilter experiments were conducted with the HP, TP, and HL fractions to study the membrane fouling.

The ultrafiltration (UF) removed 67.4%, 52.9%, and 19.7% of HP, TP, and HL fractions, respectively. High removal of the HP fraction is due to relatively high MW of organic matter in the HP fraction and the interaction between the HP fraction and membrane surface. The flux decline with the HP fraction was high compared with the TP and HL fractions. The membrane fouled with different fractions was characterized in terms of functional groups, zeta potential, foulant concentration, and contact angle.

Keywords: Biologically treated sewage effluent; Effluent organic matter; Fraction; Fouling; Hydrophobic; Hydrophilic; Membrane characterization; Transphilic; Ultrafiltration

1. Introduction

Wastewater reuse is increasingly seen as an essential strategy for making better use of limited freshwater, and a means of preventing deterioration in the aquatic environment from wastewater disposal. Although secondary- and tertiary-treated wastewater can be discharged into waterways, it cannot be used for non-potable purposes without further treatment. Membrane processes are now being successfully used to obtain water of recyclable quality. Reverse osmosis (RO) and nanofiltration (NF) can remove the majority of pollutants including dissolved organics. However, their operational costs are high due to their high energy requirement. Ultrafiltration (UF) is cost-effective options in terms of higher permeate flux compared to NF and RO. The problem with UF is that the UF membranes are easily fouled by effluent organic matter (EfOM) present at high levels in biologically treated sewage effluent (BTSE). EfOM-fouling, defined as the accumulation and/or adsorption of organic materials on the surface, or in the pores of a membrane, affects membrane performance including permeability and EfOM rejection [1].

Organic fractions in BTSE can be categorized into three groups, which are HP, transphilic (TP) and HL fractions. In particular, the HL fraction is usually found to be the most abundant fraction in the majority of BTSE, constituting 32–74% of total organic carbon (TOC) and hydrophobic acids are the second most dominant portion, accounting for 17–28% [2].

The foulants that cause membrane fouling and the understanding of the related processes in terms of fractions are controversial. Some have suggested that the humic substances fraction of organic matter is a major foulant which controls the rate and extent of fouling [3]. Recent studies have, however, reported that hydrophilic (non-humic) organic matter might be the most

Abbreviations: RO, reverse osmosis; NF, nanofiltration; UF, ultrafiltration; EfOM, effluent organic matter; HP, hydrophobic; TP, transphilic; HL, hydrophilic; TOC, total organic carbon; MW, molecular weight; AS, activated sludge; DOC, dissolved organic matter; MWCO, molecular weight cut off; PSS, polystyrene sulfonates; UV, ultraviolet; BTSE, biologically treated sewage effluent; HPSEC, high pressure size exclusion chromatography; ATR-FTIR, attenuated total reflection-Fourier transform infrared spectroscopy

* Corresponding author. Tel.: +61 2 9514 2641; fax: +61 2 9514 2633.

E-mail addresses: s.vigneswaran@uts.edu.au, vigid@eng.uts.edu.au (S. Vigneswaran).

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significant foulant. For example, Gray and Bolto [4] report that neutral and basic HL, and basic HP components of organic matter lead to continuous flux decline. Fan et al. [5] report the effect of potential foulants in the following order: HL neutrals > HP acids > TP acids. Jarusutthirak et al. [6] found that the colloidal fraction consisted mainly of large MW of HL character, and this was the fraction that contributed the most to fouling when BTSE was used as the feed. The fractions alone cannot represent the fouling, and it is also important to investigate on the compounds present in each fraction. For example, the adsorption tendency of the polysaccharides on the membranes was approximately three times of that of humics [6].

In order to characterize the UF membrane fouling, it is crucial to choose the correct parameters of UF membranes. To identify the fouling on the UF membrane surface, zeta potential, pyrolysis–GC/MS, attenuated total reflection-Fourier transform infrared spectroscopy (ATR-FTIR), etc. are used [7–9]. The zeta potential is used as the electrokinetic value associating a realistic magnitude of surface charge. Chun et al. [10] found that changes in membrane zeta potential could be used to examine the behavior of cake deposition and fouling during the filtration. The identification of fouling can be investigated both by extraction of organics and by ATR-FTIR analysis of deposits at the surface and in the substructure of the membrane [11]. ATR-FTIR especially is possible to identify molecular functional groups which contribute to membrane fouling. Contact angle measurements are routinely used for dense and flat surfaces due to their simple operations but these values cannot be extended to membranes which have a rough surface and pore [12,13].

None of the previous studies characterized the phenomena of the fouling using different fractions of BTSE. In order to optimize the performance of the membrane filtration of BTSE, it is important to identify the membrane fouling effect with different fractions in the wastewater. A detailed characterization of membrane fouled with different fractions will also help to select a suitable membrane and the optimum range of operating parameters.

2. Experimental

2.1. Biologically treated sewage effluent (BTSE)

The characteristics of the BTSE used are presented in Table 1. The study was conducted with BTSE drawn from a Gwangju sewage treatment plant, Korea. The wastewater treatment is a medium-sized activated sludge unit (25,000 m^3/d). The hydraulic retention time and the sludge age were 6 h and about 8 days, respectively.

Table 1
Characterization of biologically treated sewage effluent used

TOC (mg/L)	6.5–10.4
BOD_5 (mg/L)	9.4–18
pH	6.8–7.5
SS (mg/L)	3.5–5.0
TN (mg/L)	23.2–40
TP (mg/L)	2.2–5
Condutivity (μS/cm)	200–584

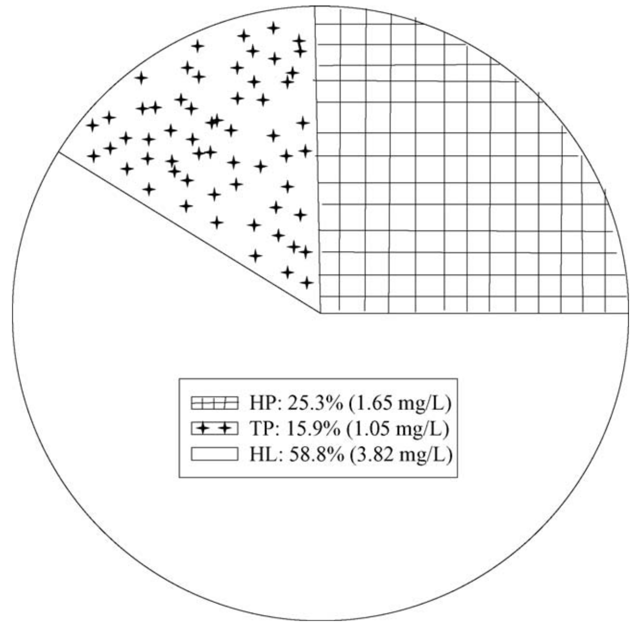

Fig. 1. HP, TP, and HL fractions in BTSE used in this study.

2.2. Fractionation of EfOM into hydrophobic and hydrophilic fractions

XAD-8 and XAD-4 resins were used for fractionating EfOM into HP EfOM (XAD-8 adsorbable; mostly HP acids with some HP neutrals) and TP EfOM (XAD-4 adsorbable; HL bases and neutrals) components. The remaining fraction escaping the XAD-4 is the HL component. The EfOM adsorbed on the XAD-8/4 was eluted using 0.1N NaOH solution. The details on the ion-exchange columns and fractionation methods are described elsewhere [13,14]. The percentages of HP, TP, and HL fractions in the BTSE were 25.3, 15.9, and 58.8, respectively (Fig. 1). These samples were taken in summer season (25–30 °C). The HL fraction was the main component in the BTSE (Fig. 1). This result is an agreement with the study of Imai et al. [2]. However, Shon et al. [15] found different results on the fractions with the HP fraction as the highest portion (HP (50.6%) > TP (17.1%) > HL (32.4%)) for the sample taken during the winter season (5–10 °C). Thus, the wastewater characteristics vary from season to season. The isolated fractions were concentrated in a freeze dryer (ilShin Lab Co. Ltd., South Korea). The initial concentration of each fraction was adjusted to a dissolved organic matter (DOC) concentration of 6.5 mg/L, which was equivalent to that of BTSE for uniformity reasons. The initial conductivity of BTSE used in this study was about 250 μS/cm. When isolating using XAD-8/4 resin, different fractions were required with HCl and NaOH which resulted in the high conductivity. Also, the fractions isolated were concentrated in a freeze dryer up to the initial concentration of BTSE alone. As such, the fractions from BTSE significantly increased the ionic strength. Furthermore, pH of different frac-