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Membrane fouling caused by extracellular polymeric substances during microfiltration processes

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Abstract

The effects of both extractable extracellular polymeric substances (EPS) and the supernatant of sludge flocs on the membrane fouling in submerged membrane bioreactors (SMBRs) were invesetigated. Three laboratory-scale SMBRs were operated at a constant permeate flux (12.5 L/m^2 h) with a flat-sheet microfiltration membrane (hydrophilic polyolefin, pore size of 0.25 μm) at different solids retention times (8, 20 and 80 days, respectively). The concentrations of extractable EPS (i.e., extracted by the cation-exchange resin method) and dissolved organic carbon (DOC) in the supernatant at the steady-state period were compared. The results showed that as SRT increased, the organic carbon content in extractable EPS decreased, whereas DOC in the supernatant tended to be independent of SRT. Batch filtration tests were conducted to determine the specific cake resistances of the fouling layer using both the raw sludge and the twice-washed sludge with buffer solution. The supernatant contributed approximately 50% to the total specific cake resistance. The organic carbon and protein content in the extractable EPS decreased with increasing SRT, and protein content in the supernatant also had the same tendency. Therefore, the supernatant played a relatively significant role in membrane fouling.

Keywords: Submerged membrane bioreactor; Fouling; Extracellular polymeric substances; Specific cake resistance; Cation-exchange resin

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1. Introduction

Submerged membrane bioreactor (SMBR) systems are being increasingly used in the treatment of municipal wastewater due to their compact size and energy efficiency compared with conventional systems. However, a key obstacle for practical application of SMBR systems is membrane fouling, which is caused by attachment of suspended solids and soluble substances on the membrane surface [1]. Nagaoka et al. found that the concentrated sludge cake layer on the membrane surface principally consisted of bacterial cells and bacterially produced substances, such as extracellular polymeric substances (EPS) [2].

Activated sludge flocs contain a heterogeneous mix of bacteria, EPS and various organic and inorganic molecules [3]. Characteristics of the floc are dependent of the surrounding environment of wastewater composition and operating conditions [4–6]. EPS concentration in activated sludge flocs has been extensively investigated and reported as a controlling factor in membrane fouling [7–9]. For instance, filterability of sludge decreased with increasing bound EPS [2]. Chang and Lee reported that an increase in EPS concentration was one of the factors causing flux decline in the membrane-coupled activated sludge [10].

Cho et al. showed experimentally that as the amount of bound EPS increased, the specific cake resistance became higher. From this observation, they proposed a sigmoid relationship between the bound EPS and specific cake resistance. This functional relationship could be induced mathematically using the dimensional analysis, and an experimental result fit very well with this function [11].

EPS are generally subdivided into two categories: bound EPS (sheaths, capsular polymers, condensed gel, loosely bound polymers, and attached organic material), and soluble EPS (soluble macromolecules, colloids, and slimes) [12]. The bound and soluble EPS include bacterially produced polymers, lysis products, and hydrolysis products. Soluble EPS are biodegradable and a product of the dissolution of bound EPS [13,14]. Bound EPS are dissolved/hydrolyzed by bacterial hydrolases [13]. In addition, another way to divide EPS is related to the origin of EPS; utilization associate products (UAP) stem from microbial utilization and bio-mass associated products (BAP) come from excretion of cell lysis. The UAP and BAP are usually called soluble microbial products (SMP). However, more information is still needed on the exact macromolecular composition of EPS matrix from activated sludge flocs.

Most of the studies analyzed bound EPS using a certain kind of extraction method, which means the exact term of the EPS is extractable EPS. In some cases, the relative influence of the extractable EPS or total activated sludge on membrane fouling was controversial. Kim et al. [15] found that filterability decreased with increasing the supernatant in activated sludge while Nagaoka et al. [2] reported that filterability decreased with increasing the bound EPS.

Previous studies mainly focused on the roles of extractable EPS or the supernatant in activated sludge in membrane fouling. This research simultaneously investigated the effects of both extractable EPS and the supernatant of sludge flocs on the membrane fouling using the SMBRs and batch filtration tests.

2. Materials and methods

2.1. Submerged membrane bioreactor systems

The laboratory-scale SMBR system consisted of a flat-sheet membrane (pore size of 0.25 μm), which was placed in the center of the bioreactor with a working volume of 6.25 L as shown in Fig. 1. The membrane was made from polyolefin with a hydrophilic coating. The filtration area of each side of flat membrane was 0.05 m^2, creating a total filtration area of 0.1 m^2. Three SMBRs were operated under the same hydraulic retention