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Effect of surface roughness of hollow fiber membranes with gear-shaped structure on membrane fouling by sodium alginate

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ABSTRACT

In this work, the relationship between surface roughness of the membrane and membrane fouling was investigated with sodium alginate which is a kind of extracellular polymeric substances (EPS) and is regarded as a main foulant in membrane bioreactor (MBR). Cellulose acetate butyrate polymer which is superior in heat-resistance and mechanical strength was used as membrane material. The membranes having the gear-shaped structures of different heights on the outer surface were prepared by using the several spinnerets via thermally induced phase separation. The membrane having the higher projection on the outer surface showed higher antifouling property. The recovery of the permeability by backwashing also increased by the higher projection of the outer surface of the membrane. Although the membrane permeability decreased by adding calcium chloride into the alginate solution, the membrane with the higher projection also showed higher permeability and recovery by backwashing. The increase of the permeability and the recovery by backwashing was not owing to the increase of the outer surface area by the gear-shaped structure formation. From the observation of the membrane outer surface after filtration of sodium alginate and humic acid, it was revealed that foulants were accumulated in the valley between projections, while the top of the projection was clean. This is the reason for the higher antifouling property for the membrane with the higher projection structure.

1. Introduction

Membrane technology has spread to the water processing applications such as drinking water purification and wastewater treatment as well as industrial applications such as semiconductor industry, and pharmaceutical and food industries. In recent years, membrane bioreactor (MBR), in which microfiltration (MF) or ultrafiltration (UF) membrane as a solid–liquid separation method is combined with biological treatment, attracts attention as an effective municipal and industrial wastewater treatment technology due to several advantages over the conventional activated sludge process. MBR, having a high capability of solid–liquid separation by membrane and containing a high biomass concentration, offers an effluent of excellent quality, a small footprint and a low sludge production [1].

Although MBR has many advantage superior to the conventional technology, its spread is sometimes limited by a problem of so-called membrane fouling. Membrane fouling, which increases filtration resistance, results in increase of energy consumption, chemical consumption due to frequent chemical washing, and membrane replace cost [2]. Many studies have been carried out on membrane fouling in MBR process from the view point of biological treatment and membrane filtration [3,4]. With respect to membrane filtration, the influence of permeate flux [5–7], aeration rate in the reactor [8,9], and backwashing [8,10] on membrane fouling have been examined. Fan et al. [5] and Guglielmi et al. [7] have reported an exponential relationship between transmembrane pressure increase and permeate flux. With regard to biological treatment, the influence of solid retention time (SRT) [11,12], concentration of mixed liquor suspended solids (MLSS) [13,14], and food-to-microorganism ratio (F/M ratio) [15] on membrane fouling have been reported.

In recent years, extracellular polymeric substances (EPS) and soluble microbial products (SMP), which are derived from microbial activity, have been regarded as a main membrane foulant in MBR [16–19]. EPS consists of protein, humic compounds, carbohydrate, uronic acids and DNA [20]. On the other hand, SMP includes humic and fulvic acids, polysaccharides, protein, nucleic acid, organic acids, amino acids, and so on [21]. Laspidou and Rittmann have reported that soluble EPS is actually SMP [22]. Concentration and constitution of EPS and SMP are influenced by mean cell residence time (MCRT). With decreasing MCRT, the concentrations of

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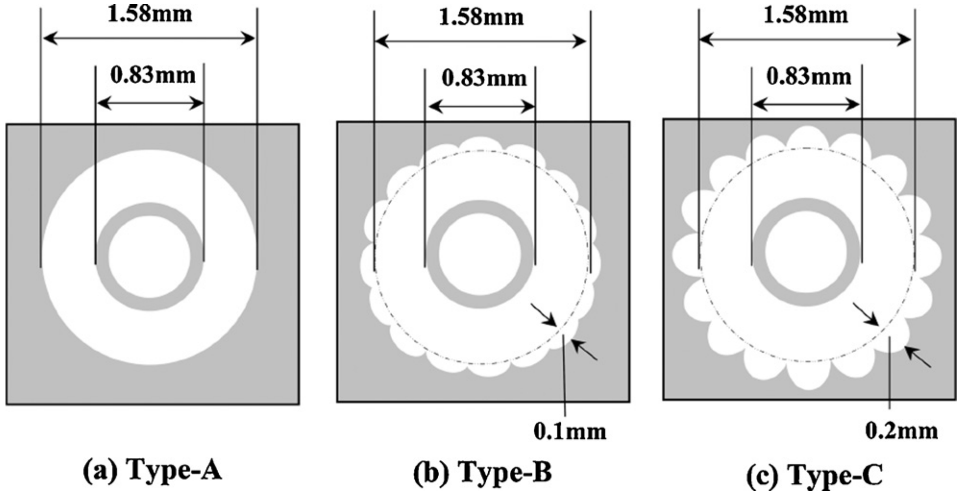

Fig. 1. Spinnerets used in preparation of hollow fiber membranes. (a) Type-A without projection; (b) type-B with the projection of 0.1 mm height on the outer tube; (c) type-C with the projection of 0.2 mm height on the outer tube.

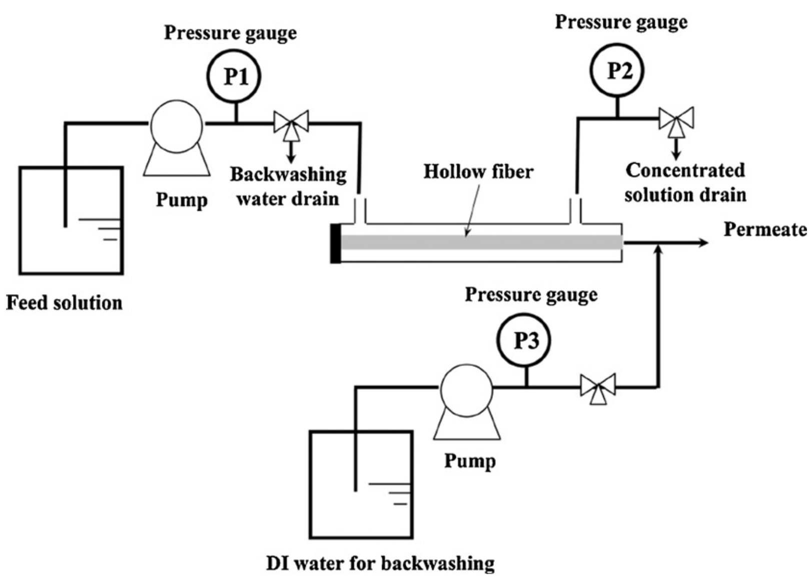

Fig. 2. Schematic diagram of the filtration–backwashing experiments using the single hollow fiber module.

EPS and SMP increase and result in increasing membrane fouling [16]. Some researchers have studied membrane fouling with alginate as a model of polysaccharides which are constituent of EPS and SMP [23,24]. Ye et al. have reported that the alginate cake formed by MF and UF was characterized by low compressibility, low porosity, and strong intermolecular attractive interactions [23]. The presence of divalent calcium ions increases RO membrane fouling due to calcium–alginate complexation and cross-linking of alginate macromolecules by calcium [24].

There is much information about the influence of operating conditions of biological treatment and membrane filtration on membrane fouling. However, few studies have been carried out about the influence of the characteristics of the membrane on fouling in MBR [4]. Madaeni et al. [6] and Le-Clech et al. [14] found no significant impact of pore size on critical flux. Chang et al. [11] have revealed that the flux decline of hydrophobic membrane was more remarkable than that of hydrophilic membrane. Yamato et al. [25] have compared polyvinylidene fluoride (PVDF) membrane with polyethylene (PE) membrane by filtration of real municipal wastewater and found that compositions of the foulants deposited on the membranes were different by membrane materials. Generally surface roughness, zeta potential, and hydrophobicity are the factors to control the membrane fouling. Among them, surface roughness influenced RO fouling most significantly and the membrane with smoother surfaces was believed to bring about lower fouling rates [26].

Table 1
Preparation conditions for hollow fiber membranes.

	Membrane A	Membrane B	Membrane C
Spinneret type	Type-A	Type-B	Type-C
Spinneret size (mm)		1.53/0.83 (outer/inner diameter)	
Polymer solution		CAB (20 wt%)–TEG	
Solution temperature (K)		443	
Polymer solution flow rate (m/s)		0.17–0.19	
Inner coagulant		TEG	
Inner coagulant flow rate (m/s)		0.17–0.19	
Inner coagulant temperature (K)		298	
Take-up speed (m/s)		0.21–0.26	
Air gap (mm)		0	
Bath composition		Water	
Bath temperature (K)		273 (iced water)	