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Performance of submerged anaerobic membrane bioreactor for thermomechanical pulping wastewater treatment

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ABSTRACT

A hollow fiber submerged anaerobic membrane bioreactor (SAnMBR) was operated for 160 days for thermo-mechanical pulping pressate treatment. A COD removal efficiency of 83 ± 4% was achieved under all tested conditions, although the residual COD in permeate increased slightly with an increase in influent COD. The biogas yield slightly decreased with a higher feed concentration. The EPS production increased with an increase in organic loading rate. Membrane performance was affected by both the influent COD concentration and biogas sparging rate. The fouling layer samples were characterized using various analytical tools. The results suggest that it is feasible and attractive to treat thermomechanical pulping wastewater by a hollow fiber SAnMBR. Cake layer formation was the dominant mechanism of membrane fouling. An increase in biogas sparging rate actively mitigated the accumulation and deposition of sludge on/in membrane module, thus favored the enhancement of membrane flux and an efficient long-term operation.

1. Introduction

Anaerobic process has been widely used in the treatment and reclamation of wastewater due to its high loading rate, low sludge production, and renewable energy source production (i.e. CH_4) [1,2]. The coupling of membrane separation with anaerobic process offers numerous advantages over conventional process, including complete solid-liquid separation, complete retention of slow-growing microorganisms, high effluent quality, and small footprint [3,4]. Therefore, anaerobic membrane bioreactors (AnMBR) technology has received much attention in recent years for industrial wastewater treatment. A number of lab-scale, pilot- scale studies, and full-scale applications have been reported [3–7]. The results demonstrated that AnMBR is a promising technology for pulp and paper effluent treatment [5], food processing wastewater treatment [6], and stillage wastewater treatment [7].

However, the flux decline or *trans*-membrane pressure (TMP) rise, caused by membrane fouling, is one of the major problems that limit the wider application of AnMBRs [3,4]. In recent year, considerable efforts have been made by a number of research groups to address membrane fouling issues in AnMBRs [8–12]. Factors, such as temperature [8,9], biogas sparging rate [10], solids retention time [11] and sludge properties [12,13], that affect membrane fouling, were investigated. The results show that membrane fouling can be effectively controlled using different fouling control strategies. It is desirable to develop improved fundamental understanding of membrane fouling mechanisms and new strategies for fouling control.

For different configurations of AnMBRs, submerged anaerobic membrane bioreactor (SAnMBR) has gained great attention. As compared to side-stream AnMBR, SAnMBR can reduce energy costs and biomass stress associated with recirculation. In addition, such a configuration allows for self-cleaning of the membrane surface by recirculating the biogas produced. Gas sparging is an important parameter in the design and operation of an MBR. For an aerobic MBR, air sparging achieves good mechanical mixing conditions and contributes to membrane fouling control and enhancement of filtration performance [14]. Several strategies regarding air sparging, such as intermittent air sparging [15], different aerator configurations [16], bubble flow properties [17], and using NaCl [18] have been evaluated to enhance membrane performance and reduce energy cost. For AnMBRs, a reduction in

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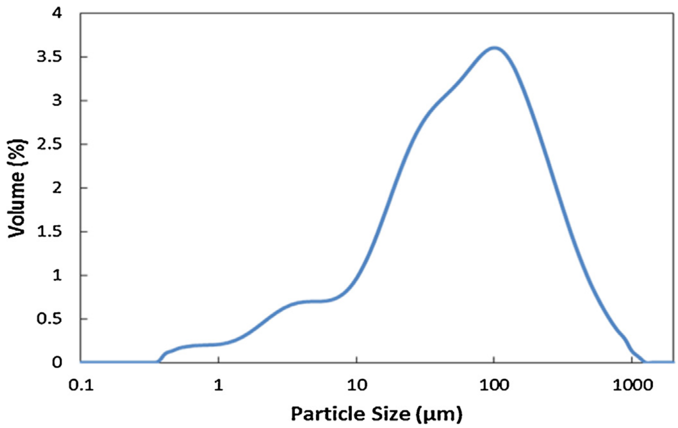

Fig. 1. Size distribution of particles in thermomechanical pulping pressate wastewater.

biogas sparging time caused an increase in TMP and a decrease in effluent quality [19]. An increase in biogas sparging level also increased the critical flux [10,20]. A higher flux without deteriorating wastewater treatment efficiency implies a high productivity accompanied by low unit cost. Hence, pursuance of flux enhancement is always crucial for the broad application of SAnMBRs in the future. However, limited work has been done on the effect of biogas sparging rate and influent chemical oxygen demand (COD) concentration on performance and membrane fouling behaviors for SAnMBRs.

Because of the variable nature of industrial wastewaters, seasonal variations in feed strength are often encountered for either short-term transient or a long-term change. These variations can affect the performance of SAnMBRs by affecting the microbial balance among the fast-growing acidogens and the slow-growing methanogens. A low feed concentration may disfavor the reaction rate and cause serious membrane fouling, because long-term starvation can lead to loss of cell activity and even biomass decay releasing large amounts of biomass-associated products (BAPs). On the other hand, a high feed concentration may result in either metabolism inhibition or a great biological growth by providing more sufficient substrate to the biomass. Depending on the influent COD concentration (3800–15,900 mg/L) and hydraulic retention time (HRT) applied, the COD removal efficiencies ranged from 64% to 85% for the treatment of municipal landfill leachate using lab-scale anaerobic sequencing batch reactors [21]. During practical operation, the reactor stability to feed strength is one of the most important considerations.

Thermomechanical puling pressate wastewater is generated during thermomechanical pulping processes and has the most concentrated COD level (high strength wastewater) in all thermomechanical pulping wastewater streams [22]. It is usually treated using an activated sludge process. However, the interest for system closure and water reuse in pulp and paper mills makes the in-mill treatment of individual wastewater streams attractive [23]. The feasibility of using novel SAnMBR technology for thermomechanical pulping pressate treatment for bioenergy recovery and potential system closure and water reuse has not been studied yet. Therefore, the aims of this study were to evaluate the effects of biogas sparging rate and influent COD concentration on the performance and membrane fouling behavior of an SAnMBR treating thermomechanical pulping pressate wastewater, in terms of COD removal, biogas production, particle size distributions (PSDs), TMP rise and fouling layer characteristics.

2. Materials and methods

2.1. Experimental setup

The hollow fiber SAnMBR has an effective working volume of 6.0 L. Thermomechanical pulping pressate wastewater from a local pulp and paper mill was used as influent. Wastewater was either used as received (influent COD: 4300–5100 mg/L) or diluted using distilled water to maintain influent COD of approximately COD 3000 mg/L to test the effect of influent COD concentration, prior to feeding and pH adjustment. Characteristics of the thermomechanical pulping pressate used in this study are listed as follows: pH: 4.0–4.2; total suspended solid (TSS): 180–510 mg/L; COD: 4300–5100 mg/L; biochemical oxygen demand (BOD_5): 1553–1652 mg/L; total nitrogen: 0.1–0.5 mg/L; total phosphorus: 1.01–1.41 mg/L; total sulfur: 42.44–47.5 mg/L; aluminum: 0.2–0.24 mg/L; barium: 0.386–0.429 mg/L; calcium: 33.424–37.609 mg/L; copper 0.008–0.019 mg/L; iron:0.147–0.183 mg/L; potassium: 39.41–44.28 mg/L; magnesium: 6.49–7.26 mg/L; manganese: 2.746–3.082 mg/L; sodium: 43.05–48.75 mg/L; strontium: 0.101–0.114 mg/L, and zinc: 0.164–0.241 mg/L. Fig. 1 shows size distribution of particles in thermomechanical pulping pressate. Thermomechanical pulping pressate was used as received from the mill or diluted and no primary treatment was applied. The feed was introduced from the bottom of the bioreactor automatically by a level sensor (Madison Co., USA) and controller (Flowline, USA). NH_4Cl and KH_2PO_4 were fed in a proportion of COD:N:P of 100:2.6:0.4 as a source of nitrogen and phosphorous to sustain the nutrient concentrations required for biomass growth in an anaerobic environment [24]. To prevent trace metal limitations of the methanogens, a trace element solution [25] was supplemented to the influent.

A vertically oriented hollow fiber membrane module (GE Water UF/MBR solutions, Oakville, Canada) with a membrane surface area of 0.03 m^2 and a nominal pore size of 0.04 μm was submerged in the reactor. The hollow fiber membranes used in this study were made of polyvinylidene fluoride (PVDF). The headspace biogas was recirculated by two biogas recycle pumps (Masterflex Console Drive, Model 7520-40, Thermo-Fisher Scientific, USA) to an upward diffuser located at the bottom header for the purpose of provide mixing and to control solids deposition on/between the hollow fibers. The hollow fiber SAnMBR was operated at three biogas sparging rates (2.4, 4.3 and 6.1 L/min (LPM)). The whole operation period was divided into 4 phases according to the differences in biogas sparging rates and influent concentrations as illustrated in Table 1.

The seeded sludge was obtained from an up-flow anaerobic sludge blanket (UASB) reactor treating pulping wastewater at a local pulp and paper mill. During the operation of the reactors,

Table 1
Operating conditions at each stage.

Days	Start-up 0–20th	Phase 1 21st–60th	Phase 2 61st– 89th	Phase 3 90th–131st	Phase 4 132nd–160th
Influent COD (mg/L)	3022 ± 100	3022 ± 100	3022 ± 100	4599 ± 259	4599 ± 259
Biogas Sparging Rate (LPM)	2.4	2.4	4.3	4.3	6.1