Impact of sludge composition on membrane fouling contributions under different filtration modes

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Abstract

The main goal of this research was to investigate how different factors of sludge compositions and stages of filtration affecting on membrane fouling mechanisms. The eight designed experiments based on two different levels (low and high) of each factor including sludge concentration, EPS concentration and flux stage (supra-critical flux and sub-critical flux) were adopted. The membrane fouling mechanisms was monitored using the resistance series model with different steps of fouling removal. The results showed that a great portion of cake fouling appeared under supra-critical flux operation. Minor development of pore fouling was observed for both under sub-critical flux and supra-critical flux operations. Besides, the total fouling resistance was increased with the enhancement of sludge concentration supra-critical flux operation under resulting in cake thickness increasing.

1. Introduction

In the submerged membrane bioreactor (SMBR) process, direct contact between membrane and mix liquor sludge is inevitable and causes membrane fouling attributed to deposition and interaction between sludge and membrane surfaces. Previous study reported that the higher microbial sludge concentration caused more fouling in SMBR [1], while other suggested that less fouling at the higher sludge occurred under their certain conditions [2]. It was implied that membrane fouling is related to not only sludge quantity but also sludge characteristics.

In spite of the differences of these results, the extra-cellular polymeric substance (EPS) of activated sludge is a well known factor affecting membrane fouling [3]. EPS comes from the natural secretions of bacteria, cell lysis and hydrolysis products, and is mainly composed of proteins and carbohydrates. Lee *et al.* (2003) [4] found that the protein to carbohydrate ratio in EPS appeared more important than the total quantity of EPS with respect to sludge fouling, while there was no relationship between EPS composition and properties on the supernatant fouling. On the other hand, Rojas et al. (2005) [3] reported that soluble EPS in liquid fraction was responsible for membrane fouling.

As indicated above, the information of sludge and supernatant fouling is uncertain and, as such, should be further investigated. In addition, no research to date indicates role of different sludge components at different filtration stage (sub-critical flux and supra-critical flux) on membrane fouling behavior.

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Accordingly, these parameters should also be tested for a better understanding of how fouling mechanisms varied with different concentrations of each sludge fraction and stages of operation. Therefore, the aim of this research is to demonstrate the impact of sludge composition (microbial flocs and supernatant) at different flux operation (sub-critical fluxes and supra-critical fluxes) on membrane fouling.

2. Experimental Materials and Method

2.1 Experimental Facility

A SMBR used in this study was consisted of a 120 liter aerobic unit fitted with a submerged flat sheet membranes. The membrane material is chlorinated polyethylene with nominal pore size 0.4 μm. Permeate was removed using a pump passing through permeate line coupling with pressure gauge. The aeration process was conducted using a blower and controlled using an air rotameter. Schematic diagram of the system was shown in Figure 1. The characteristics of wastewater used in experiment were shown in table 1.

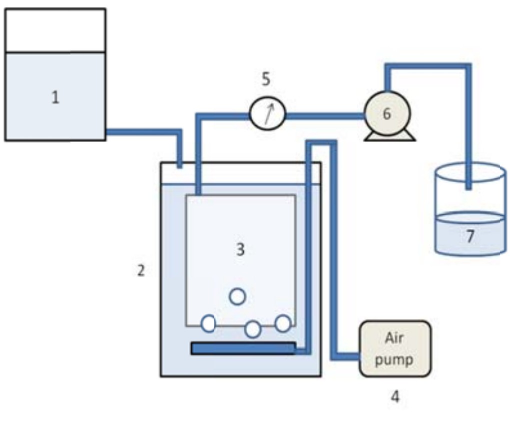

Figure 1 Schematic diagram of the system (1) feed tank, (2) MBR tank with submerged membrane, (3) flat plate membrane, (4) blower, (5) pressure gauge, (6) suction pump, (7) Permeate tank

Table 1 Characteristics of wastewater

Parameter	Inlet	SMBR	Permeate
pH	7.34 ± 0.10	7.16 ± 0.11	7.09 ± 0.10
Temp (°C)	26.2 ± 0.4	27.2 ± 0.4	27.1 ± 0.5
DO (mg/L)	0.54 ± 0.13	3.02 ± 0.21	2.97 ± 0.16
NH4-N (mg/L)	37.5 ± 3.1	0.7 ± 0.5	0.0 ± 0.0
NO3-N (mg/L)	0.0 ± 0.0	25.0 ± 3.0	22.8 ± 2.5
PO4-P (mg/L)	14.1 ± 1.0	11.0 ± 1.1	7.7 ± 0.6
COD (mg/L)	337 ± 38	45 ± 13	13 ± 8

2.2 Experimental design

High and low values for MLSS (5 and 10 g/L), supernatant EPS (46 and 87 mg/g MLSS) and filtration modes (sub-critical flux and supra-critical flux) were adopted as the base of eight experimental runs. The systems were operated for 200 minutes for both supra-critical and sub-critical flux operation. Sub-critical flux and supra-critical flux were operated at 80% and 120% of critical flux, respectively. The critical flux evaluation using 90% permeability was performed primarily in order to know the stage of filtration. The trans-membrane pressure (TMP) and permeate of the experiments were logged on the PLC device. After finishing each test, the membrane surface was cleaned with soft sponge, which was adopted to ensure removal of sludge particles from the membrane surface and a chemical cleaning of 0.5% sodium hypochlorite was proceeded in place to remove irreversible fouling from membrane pore blocking. Then the next test was continued.

2.3 Laboratory analysis

Soluble EPS was measured from supernatant after centrifugation of the samples at 2000g for 30 min and was calculated by summing the contents of carbohydrate and protein substances [5]. Modified Hartree-Lowry and Anthrone assays were applied for assessment of protein and carbohydrate respectively. For bound EPS, the settled pellets were suspended in a pH 7 buffer and extraction of bound EPS was then performed by mixing this sample with a cation exchange resin (DOWEX 50X) at 4 ^{o}C for 45 min at 500 rpm [5]. Then the sample (resin+sludge) was settled for 5 minutes and the recovered liquid phase was centrifuged at 20,000g for 15 minutes to separate the EPS from the biomass. Afterwards, protein and carbohydrate analyses were made.

2.4 Membrane fouling analysis

The degree of membrane fouling was quantitatively calculated, using the resistance series model [6]:

$$Rt = \Delta P/\mu J = Rm + Rc + Rp \quad (1)$$

where J is the permeate flux ($m^3/m^2.s$), ΔP the TMP (Pa), μ the viscosity of the permeate (Pa.s), R_t the total filtration resistance (1/m), R_m membrane resistance (1/m), R_c cake resistance (1/m) and R_p pore resistance (1/m).

In this study, membrane cake fouling was assumed to be reversible fouling and readily removable. On the other hand, the EPS supernatant was assumed to cause pore blocking that could only be removed by chemicals and so called irreversible fouling. The filtration resistance was measured step by step as follows (Figure 2), and calculated using equation (1).

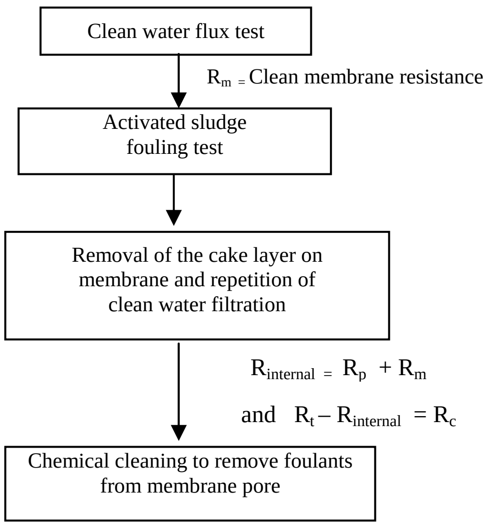

Figure 2 Steps to measure filtration resistance

2.5 Observation of membrane fouling morphology

The cake surface and cross-sectional structure were observed using a scanning electron microscope (SEM) (JEOL JSM-5600LV, Tokyo, Japan). After each experimental run, a membrane sample was cut for analysis. The samples were fixed with 3.0% glutaraldehyde in 0.1M phosphate buffer at pH 7.2. The samples were dehydrated with ethanol, gold-coated by a sputtering and observed in the SEM [7].

3. Results and discussion

3.1 Membrane fouling contributions

The analysis of membrane fouling resistances was presented in Figure 3 and Figure 4. It was observed that filtration resistance was much higher in the supra-critical flux region compared with the sub-critical flux operation due to the accumulation of a cake layer. Beyond critical flux operation, high suction force resulted in more particle accumulation which will affect on increasing of cake thickness and compactness [7]. Accordingly, under supra-critical flux, cake formation accounted for a large portion of total resistance (more than 50%) while the fouling resistance caused by pore plugging under supra-critical flux was subsidiary (less than %).

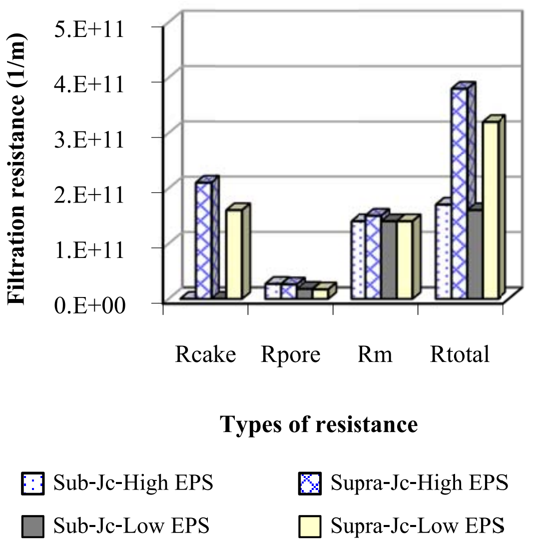

Figure 3 Membrane fouling contribution for MLSS 5 g/L under different fluxes

Under sub-critical flux operation (see Figure 3 and Figure 4), the total hydraulic resistance for all sludge fractions was much lower (1-2 lesser) than that of supra-critical flux filtration. These results indicated that the reduction of total resistance of the sub-critical flux system mainly came from the absent in the cake layer. Consequently, operating at sub-critical flux is a key factor to minimize membrane fouling. In comparison, pore fouling resistance has more responsible in the sub-critical flux filtration than in the supra-critical flux operation.

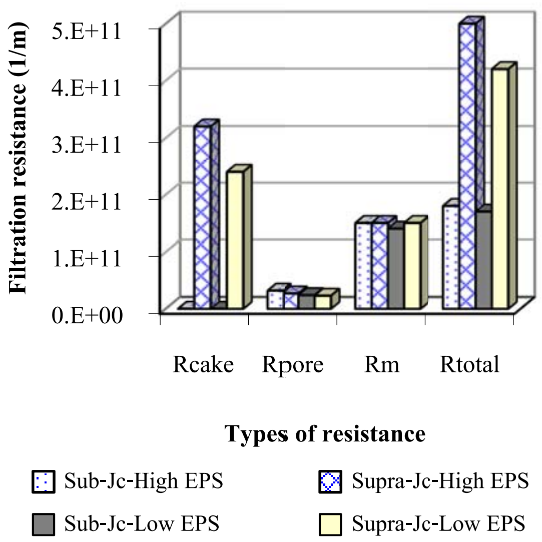

Figure 4 Membrane fouling contribution for MLSS 10 g/L under different fluxes

3.2 Membrane fouling Morphology

Scanning electron microscope (SEM) images of the membrane surfaces under sub-critical flux were showed in Figure 5 as an example, (based on MLSS 10 g/L and high EPS) and it could be observed that these surfaces were visibly porous, almost free of particles and no significant different for all sludge composition used in the experiments (figure not shown for other conditions). Note that, the experiments run in this study were based on a short term tests which might not be covered in the long term operation.

The presence of cake layer on membrane surface under supra-critical flux operation was showed in Figure 6 as an example (based on MLSS 10 g/L and high EPS), representing progressive coverage of the surface by sludge cake, reaching complete coverage (figure not shown for other conditions).

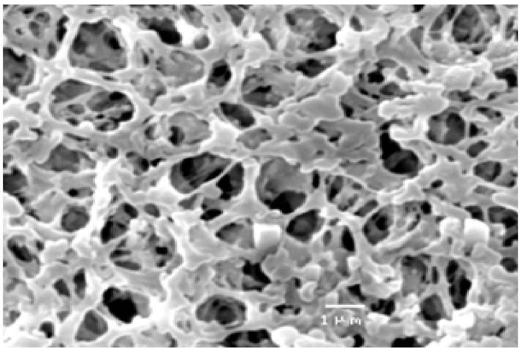

Figure 5 Pore fouling under sub-critical flux on sludge 10 g/L and high EPS contents

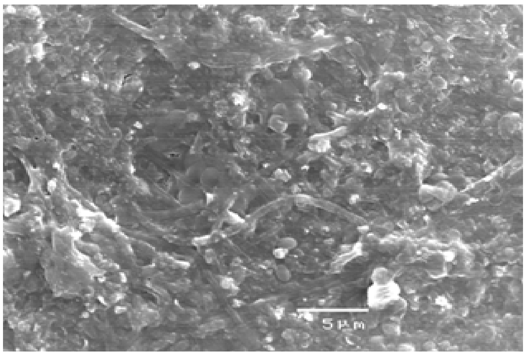

Figure 6 Cake fouling under supra-critical flux on sludge 10 g/L and high EPS contents

The different cake thickness coincided roughly with the sludge concentration. Presumably, the greater the sludge concentration, the thicker the cake layer were. The relationship between the cake resistance (Rc) and the sludge concentration can be expressed by the following Equation [15]:

$$R_C = \alpha V C_b / A_m = \alpha w \qquad (3)$$

where Rc is cake resistance (1/m), α (m/kg) a specific cake resistance, V a permeate volume (m^3), C_b the biosolids concentration (kg/m^3), Am is surface area (m^2) and w is a mass of dry solids per unit area (kg/m^2).

The later increasing fouling rate could also be due to compression of the cake layer by the over-increasing TMP and the cake layer was seemed to be dense and non-porous. Meng *et al.* (2005) [7] reported the cake porosity and cake permeability were decreased as TMP increased and the increase of cake layer thickness was also consistent with the decline tendency of porosity.

4. Conclusions

In the present study, the influence of sludge compositions and stages of filtration on membrane fouling mechanisms was investigated. The critical flux determination was firstly performed as a preliminary consideration. Next, eight designed experiments based on two different levels (low and high) of each factor including MLSS concentration, EPS concentration and flux stage (supra-critical flux and sub-critical flux) were adopted. The experimental results showed that cake resistance accounted for a large portion of fouling contribution under supra-critical flux operation while pore fouling contributions are minor for both under sub-critical flux and supra-critical flux operations. Under supra-critical flux operation, sludge concentration has a major influence on total fouling resistance due to cake formation whose thickness increase with sludge concentration increase.

5. Acknowledgement

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