Role of microbial concentration on membrane fouling

under different flux operations

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Abstract

In the present study, the influence of MLSS concentration on membrane fouling mechanisms was investigated. The resistance series model with different steps of fouling removal was applied to estimate fouling resistance in each experiment. The results showed that membrane total fouling resistance had a positive correlation with MLSS concentration under supra-critical flux operation, while there was no significant change in total resistance with MLSS variation under sub-critical flux. In contrast, the MLSS increasing resulted in the pore fouling enlargement under sub-critical flux operation. The higher the MLSS was, the greater the cake fouling resistance was observed under supra-critical flux operation.

1. Introduction

One disadvantage of the activated sludge process is the difficulty of separating suspended matter from the effluent by settling [1] which requires large-size tanks [2]. Over the last decades, a modification of the conventional activated sludge process using submerged membranes technology called submerged membrane bioreactor (SMBR) has been used to separate the effluent, replacing sedimentation, which reduces the plant size due to the absence of settling tanks. It has been shown that all microorganisms from wastewater were retained and treated effectively by this SMBR system. Although their several advantages are well recognized, the SMBR process also has as its principal limitation on membrane fouling, which causes permeate flux decline and necessitates frequent cleaning and/or replacement of membranes.

In the 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. However, the effects of MLSS on membrane fouling are not yet fully understood and controversial reports about the effects of this parameter have been presented. Magara and Itoh (1991) [3] reported that membrane fouling took place more rapidly at higher MLSS concentration similar to the study of Sato and Ishii (1991) [4]. Chang *et al.* (2002) [5] also came to the same conclusion. On the other hand, some author have claimed that sludge concentration is not a main influencing factor or has little impact on membrane fouling [6].

Besides, Lee *et al.* (2003) [7] suggested that higher MLSS concentration is beneficial to fouling control. An exponential relationship between MLSS

concentration and membrane fouling resistance was reported in the study of Meng *et al.* (2006) [8]. Nevertheless, all these experiments were carried out on different scales, different operational conditions and different ranges of MLSS concentration.

As indicated above, the information of sludge is uncertain and, as such, should be further investigated. In addition, no research to date indicates role of different flux operation on membrane fouling behavior. Therefore, the aims of this research are to demonstrate the effects of sludge at different filtration stages (sub-critical fluxes and supra-critical fluxes) on membrane fouling mechanisms including pore blocking and cake 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. Schematic system is shown in Figure 1.
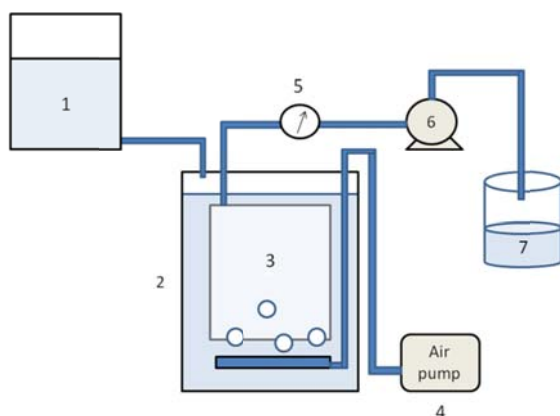

Figure 1 Schematic diagram of the system (1) feed tank, (2) SMBR tank with submerged membrane, (3) flat plate membrane, (4) blower, (5) pressure gauge, (6) suction pump, (7) Permeate tank

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. The characteristics of wastewater used in experiment were shown in table 1.

Table 1 Characteristics of wastewater

Parameter	Inlet	SMBR	Permeate
pH	7.34 ± 0.10	7.16 ± 0.11	7.09 ± 0.10
Temp ($^{\circ}$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
Conductivity (μS)	1286 ± 77	1080 ± 65	1005 ± 62
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

Note: $\pm$ terms represent standard deviation

2.2 Experimental procedure

The influence of microbial flocs on membrane fouling mechanisms was investigated at different levels. Three values for MLSS and two filtration modes (sub-critical flux and supra-critical flux) were adopted as the base of six experimental runs. The systems were operated for 200 minutes for both supra-critical and sub-critical flux operations. Sub-critical flux and supra-critical flux were operated at 80% and 120% of critical flux, respectively. The critical flux evaluation using short-term flux stepping technique and 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

every minute 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 Membrane fouling analysis

The degree of membrane fouling was quantitatively calculated, using the resistance series model [9]:

$$R_t = \Delta P/\mu J = R_m + R_c + R_p \qquad (1)$$

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.
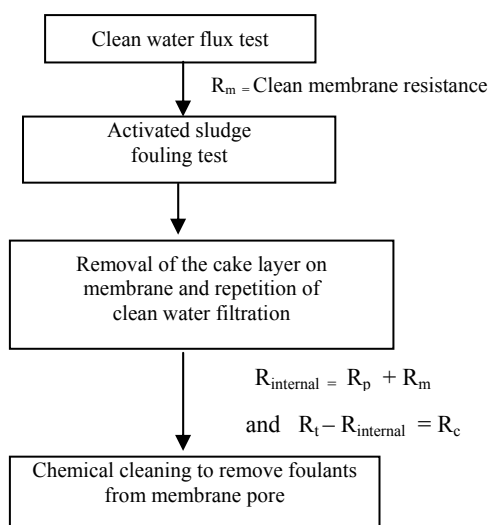
On the other hand, colloids and dissolved material from the supernatant was assumed to cause pore blocking that could only be removed by chemicals and so called irreversible fouling [10]. The filtration resistance was measured step by step as follows (Figure 2), and calculated using equation (1).

3. Results and discussion

3.1 Determination of critical flux through 90% permeability

According to the permeability definition in equation 2, critical flux can be defined at the maximum flux for which K remains linear.

Permeability of the system: $K = J/\Delta P$ (2)

where J is the permeate flux, ΔP the trans-membrane pressure (TMP), K the permeability.

Le Clech *et al.* (2003) [6] assumed critical flux to be the flux at which permeability decreases to below 90% of the permeability recorded for the first filtration step.
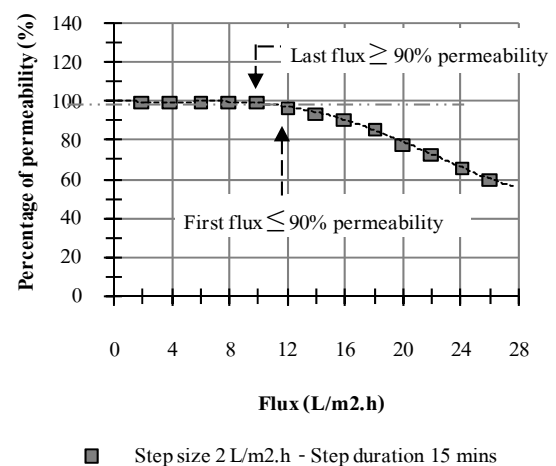

Figure 2 Steps to measure filtration resistance

■   Step size 2 L/m2.h - Step duration 15 mins

Figure 3 Permeability at step heights 2 L/m^{2}h and 15 min step length (MLSS 6.3 g/L, aeration 50 L/min)

Therefore, the critical flux can be taken as the mean of the maximum flux at which K is higher than $0.9K_0$ and the subsequent flux-step value, since these two values, respectively, represent the lower and upper boundaries of the critical flux region [11]. Figure 3 showed the example trend of permeability and imposed fluxes.

3.2 Effect of MLSS on total membrane fouling

The impact of MLSS on MBR total fouling were examined and shown in Figure 4. From Figure 4, total fouling resistance did not vary with the increase of MLSS under sub-critical flux operation, while the increase of MLSS had positive relationship with the gaining of total fouling resistance only under supra-critical flux operation.
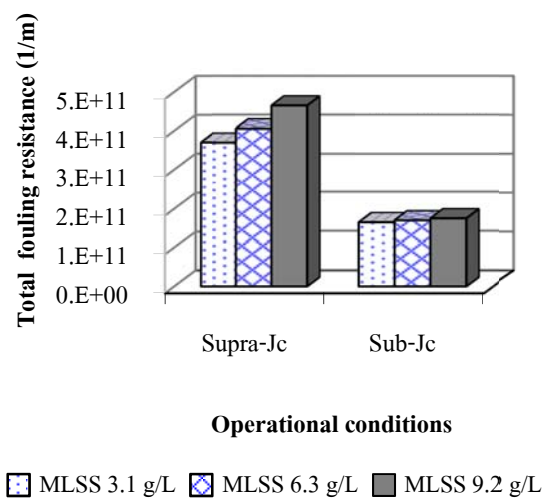

Figure 4 MLSS and total fouling resistance

This finding may suggested that the impact of shear created by air bubbles under sub-critical flux mode was adequate to maintain a very low membrane fouling behaviors reducing the effect of MLSS. Severe effect of MLSS increase on the gaining of total fouling

propensity was clearly showed only under the supra-critical zone operation.

The importance of biomass concentration on membrane fouling has been recognized by several research groups. The general consensus among the existing studies was that membrane fouling increased with increasing MLSS concentration, depending on the nature of the biological process (e.g. aerobic and anaerobic). However, some studies reported that fouling was independent of MLSS concentration until a very high value was reached [12-13]. Manem and Sanderson (1996) [14] showed that some fouling was observed for sludge concentrations between 5 -12 g/L.

3.3 Effect of MLSS on membrane pore fouling

The effect of activated sludge on membrane pore fouling was also investigated and shown in Figure 5. Results in Figure 5 illustrates that the pore fouling resistances were higher under sub-critical flux than supra-critical flux operation. Besides, the higher pore fouling resistances happened with the higher MLSS levels.
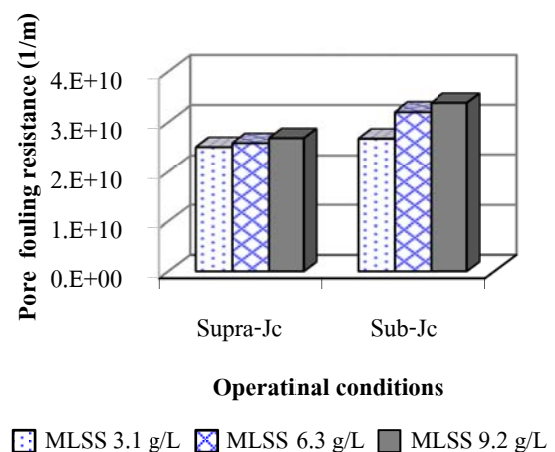

Figure 5 MLSS and pore fouling resistance

The positive correlation between pore fouling resistance and MLSS found in this study concurs with the findings of several previous studies [15-16]. On the other hand, some other study showed that membrane pore fouling was independent of MLSS [17]. The discrepancy is likely due to the difference in the membrane and sludge characteristics.

3.4 Effect of MLSS on membrane cake fouling

Figure 6 showed the cake fouling resistance with different MLSS concentrations. Obviously, cake fouling resistance occurred and increased along with the increase of MLSS concentration only under supra-critical flux operation. 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).
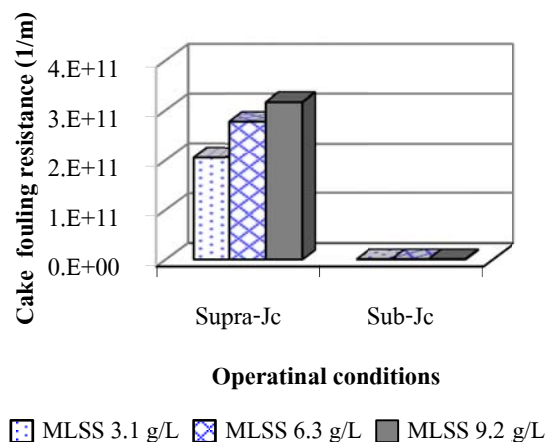

Figure 6 MLSS and cake fouling resistance

Thus, the higher the MLSS was (or the higher C_b), the greater the cake fouling resistance can be expected and the increase in MLSS also had a negative effect on membrane filterability, resulting in filtration efficiency reduction.

4. Conclusions

In the present study, the influence of MLSS concentration on membrane fouling mechanisms was investigated. The resistance series model with different steps of fouling removal was applied to estimate fouling resistance in each experiment. The results showed that membrane total fouling resistance increased with the increase of MLSS only under supra-critical flux operation and no significant change in total resistance under sub-critical flux. The enlarged of pore fouling resistance occurred significantly with MLSS increasing only under sub-critical flux. Cake fouling resistance was clearly observed only under supra-critical flux and also showed a positive correlation with the MLSS concentration.

5. Acknowledgement

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