

Influence of Aeration and Biomass Concentration on Critical Flux Enhancement

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Abstract

In the present study, the effect of operational parameters on critical flux values was investigated including different aeration and different MLSS concentration. Experiments were carried out on a pilot-scale membrane bioreactor (MBR) treated wastewater. The results indicated that an increase of air sparging rate is very effective on enhancing critical flux, while high biomass concentration influenced in the greater fouling phenomena, resulting in lower critical flux.

1. Introduction

For submerged membrane technology, fouling is considered as the most severe hindrance to the system operation. There is a suggested border to handle this fouling problem called critical flux. Critical flux was initially defined in two ways: one is that the flux through the membrane has no increase in trans-membrane pressure (TMP) with time [1] and another is the flux below which there is no deposition of colloids on the membrane [2]. In general, these will not give the same flux value. Above the critical flux, irreversible fouling of suspended solids forms a stagnant, consolidated and aggregated layer on the membrane surface, which can make flux decline rapidly. On the other hand, below the critical flux condition, called sub-critical flux, it has been reported that the fouling is not observed [3]. Consequently, the concept of critical flux is a key parameter for characterizing fouling.

Fane (2002) [4] described three factors affecting critical flux and membrane fouling, which include membrane materials, operating parameters and sludge characteristics. The effects of mixed liquor suspended solids (MLSS) concentration on critical flux have been subjected to numerous studies because membrane fouling is often considered to be caused by the particle cake formation on the membrane surfaces. Madaeni *et al.* (1999) [5] observed that critical flux was inversely related to MLSS range 0 to 10 g/L.

On the other hand, Le Clech *et al.* (2003) [6] indicated that significant increase in critical flux happened only when the MLSS concentration was 12 g/L but with no difference of critical flux for MLSS range 4-8 g/L. Although the same type of membrane and similar hydrodynamic conditions were used in the experiments, significantly different critical flux values were reported by Madaeni *et al.* (1999) [5] and Cho and Fane (2002) [7]: 62 L/m².h for 4 g/L MLSS and 22 L/m².h at 2.5 g/L, respectively. This observation demonstrates the importance of carrying out tests under the same biological conditions for assessing hydrodynamic parameters and impacts. The actual method of changing MLSS concentration can impact microorganism characteristics, since it can be changed both with and without acclimatization [8].

Membrane operation with little to no fouling and low energy consumption is a desirable target for any membrane plant. Hence, the relationship between aeration

and critical flux should be studied and optimized as they are the main parameters determining economic viability. Bouhabila *et al.* (2001) [9] reported that increasing the air intensity from 1.2 to 3.6 m³/m².h decreases the total filtration resistance, thus increasing the filtrate flux by a ratio of 3 in a pilot submerged MBR. Chang *et al.* (2002) [3] applied two coarse bubble aerations in a submerged tubular MBR and reported that the flux was increased by 43%. Ueda *et al.* (1997) [10] also described aeration as a significant factor governing the filtration conditions and cake removal.

In most of the previous critical flux analysis, filtration was carried out with lab scale and sometimes fed with synthetic wastewater which, in fact, has substantially different fouling propensities compared to those of pilot or full scale operating with real wastewater. Moreover, there are very few studies focused on the same time variation of both aeration and biomass concentration on the enhancement of critical flux. The aims of this study are therefore twofold: (1) to determine critical flux using a pilot scale SMBR fed with domestic wastewater; (2) to understand the impacts of operational variables on the critical flux including MLSS concentration and aeration.

2. Experimental Materials and Method

2.1 Experimental Facility

A pilot scale 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. Pressure gauge was also located on the permeate line. The aeration process was conducted using a blower and controlled using air rota-meter. The characteristics of domestic wastewater (from Chongnonsee canal) used in the experiment were shown in table 1.

Table 1 Characteristics of wastewater used in the experiment

Parameter	Inlet	SMBR	Permeate
pH	7.14 ± 0.10	7.06 ± 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
Conduct. (μS)	1050 ± 30	1139 ± 22	1006 ± 25
ORP (mV)	-54.3 ± 6.3	244 ± 15	172 ± 10.3
MLSS (g/L)	0.21 ± 0.034	5 to 10	0.0 ± 0.0
NH ₄ -N (mg/L)	37.5 ± 3.1	0.7 ± 0.5	0.0 ± 0.0
NO ₃ -N (mg/L)	0.0 ± 0.0	25.0 ± 3.0	22.8 ± 2.5
PO ₄ -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: ± term is represent standard deviation

2.2 Experimental Design

For testing the influence of aeration and sludge concentration, four aerations (50, 100, 150 and 200 l/min) and three MLSS concentrations (5, 7.5 and 10 g/L) were carried out in a total of 12 runs. The TMP and permeate data of the experiments were recorded every 5 minutes. After finishing each test, membrane surface cleaning with soft sponge was adopted to ensure removal of sludge particles from 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.

3. Results and discussion

Results and discussion of the experiments are described in the following sections including clean water flux test, critical flux assessment based on 90% permeability, and influence of aeration and MLSS concentration on critical flux enhancement

3.1 Clean water flux tests at different aeration

Clean water flux tests at different aeration rates were conducted as a reference for new membrane performance before replacing clean tap water with activated sludge in the aerobic membrane unit. As shown in Fig. 1, aeration showed no significant influence on the water filtration rates. A linear relationship between the permeate flux increase and the TMP increase was observed. The new membrane resistance is 1.285×10^{11} (1/m) estimated using Darcy’s Law in Equation 1 by neglecting the fouling resistance term due to clean water filtration.

Darcy’s Law:

$$J = \frac{\Delta P}{\mu R_i} = \frac{\Delta P}{\mu (R_m + R_f)} \tag{1}$$

where J is the permeate flux, ΔP the trans-membrane pressure (TMP), μ the viscosity, R_i the total resistance which includes R_m (the intrinsic membrane resistance) and R_f (the resistance induced by membrane fouling).

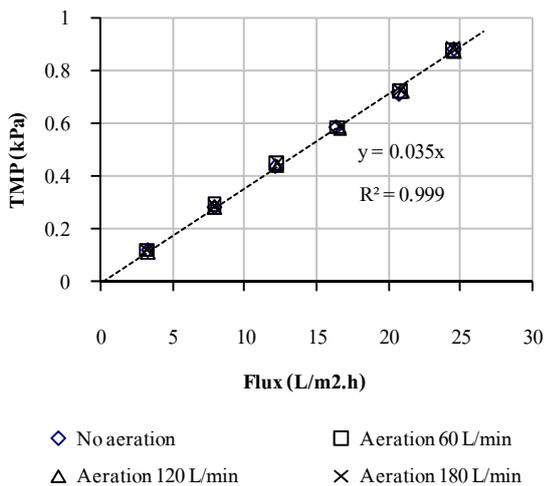


Fig. 1 Clean water flux test at different aeration

3.2 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:

$$K = \frac{J}{\Delta P} \tag{2}$$

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. 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]. Fig. 2 showed the example trend of permeability and imposed fluxes.

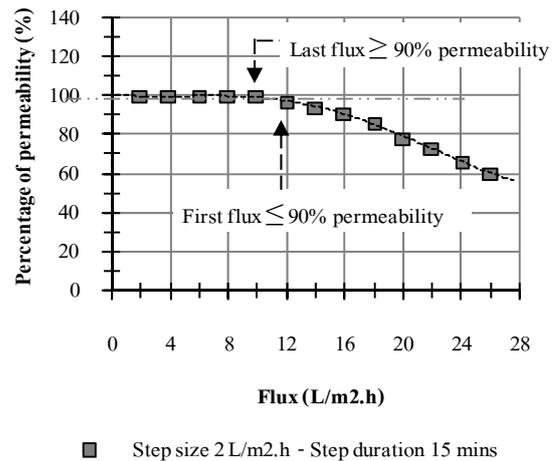


Fig. 2 Permeability at step heights 2 L/m².h and 15 min step length (MLSS 7.5 g/L, aeration 50 L/min)

3.2 Influence of aeration and MLSS concentration on critical flux enhancement

According to literatures, critical flux can be affected by certain controllable parameters, including aeration rate and sludge concentration. Fig. 3 - Fig. 5 presented experimental results showing the variations of critical fluxes at different aeration intensities and different MLSS concentration. In Fig. 3 - Fig. 5, a 2 L/m²h step height and 15 minute step length with the 90% permeability was used for the critical flux determination, due to its simplicity. From Fig. 3 - Fig. 5, MLSS concentration strongly affects the critical flux. An increase in MLSS concentration will increase the convective flow of solids towards the membrane surface resulting in the lessening of critical flux. On the other hand, greater aeration intensity can generate higher cross-flow velocity with more turbulence, which induces a greater shear against the membrane surface. Therefore, an increase in the sparged air flow rate will increase the back transport of solids from the membrane surface, thus increasing the critical flux.

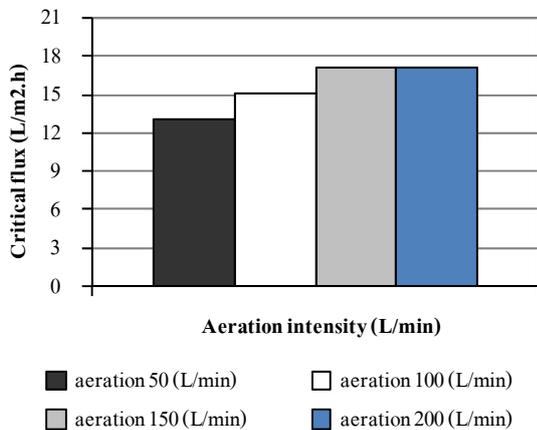


Fig. 3 Critical flux at different aeration and MLSS concentration 5 g/L

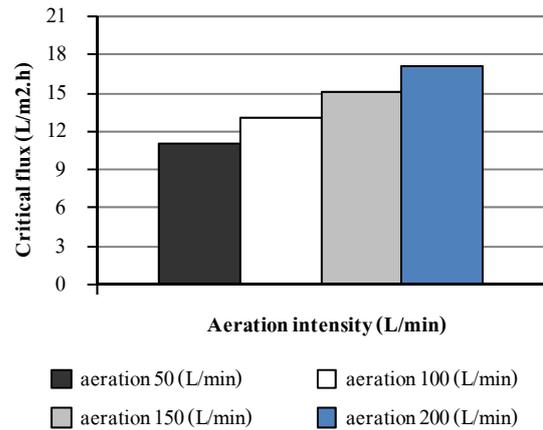


Fig. 4 Critical flux at different aeration and MLSS concentration 7.5 g/L

For SMBR operating under high sludge concentration, large aeration intensity would be required in order to maintain a certain value of critical flux. In practical applications, even the improved aeration intensity can enhance the critical flux; however, it will increase the energy cost of the system. Therefore, further studies concerning the optimal aeration intensity and optimal sludge concentration are recommended.

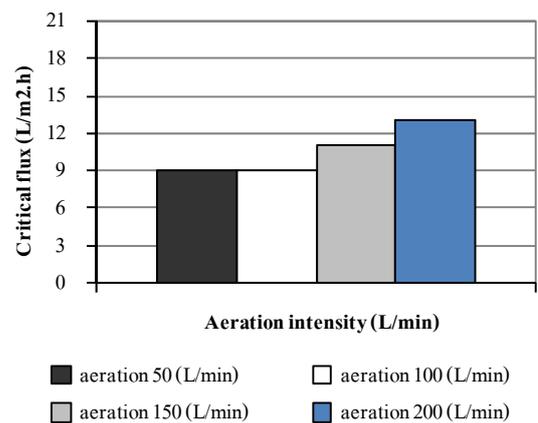


Fig. 5 Critical flux at different aeration and MLSS concentration 10 g/L

In other studies, it was also reported that an increase in aeration restrained fouling and increased critical

flux [12-14]; however the reports on the effects of sludge concentration on critical flux among researches are different because of the complexity and variability of the biomass components. The increase in MLSS concentration alone was reported to have a mostly negative effect on the flux obtained in a side-stream MBR [15], while some other studies have discovered no effect of MLSS on fouling up to a threshold concentration [16]. Silva and his co-workers [17] also observed that in membrane tanks with high shear rates, particle transport is dominated by hydrodynamic-induced shear, which is proportional to the square of the particle size. Consequently, the larger particles deposited on the membrane surfaces would become much easier to be sheared away from the membrane surface than would small particles.

Over a similar type of membrane and similar range of hydraulic condition, critical flux values differed significantly, i.e., $62 \text{ L/m}^2\text{h}$ for an MLSS 4 g/L reported by Madaeni *et al.* (1999) [5] compared with a value of $22 \text{ L/m}^2\text{h}$ at MLSS 2.5 g/L reported by Cho and Fan (1999) [18]. Such disparities could imply that it is very essential to perform tests under the same sludge conditions for classifying the impacts of hydraulic parameters on critical flux. In this study, the same sludge characteristics were maintained to the determination of critical flux values, and the results were expected to provide a sensible understanding of the influence of MLSS concentration and aeration.

4. Conclusions

This study has examined the effect of operational parameters on critical flux including aeration and MLSS concentration in a submerged flat sheet membrane bioreactor. The results indicated that different aeration intensities have shown that an increase of air sparging leads to increased critical flux,

while high biomass concentration influenced the greater fouling phenomena, resulting in lower critical flux.

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