Critical Flux Evaluation Based on Flux Cycling and Flux Stepping Methods

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Abstract

In the present study, the effect of filtration methods on critical flux assessment was investigated including flux stepping method and flux cycling method. Experiments were carried out on a pilot-scale membrane bioreactor (MBR) treated wastewater. The results indicated a decline in critical flux values as the step height increased based upon the flux cycling method, while there is a positive relationship between critical flux values and step height presenting in the flux stepping filtration. On the other hand, the step length has no obvious effect on critical flux values evaluated by both critical flux determination methods.

1. Introduction

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 of the effluent, replacing sedimentation, which reduces the plant size due to the absence of settling tanks. 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. 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 fouling is not observed [3]. Consequently, the concept of critical flux is a key parameter for characterizing fouling.

Critical flux can be considered in two forms: the strong form and the weak form. The strong form states that the sub-critical flux and TMP relationship shows a linear relationship with the same slope as that of pure water filtration. The weak form is also linear, but the slope is different from that of pure water [4-5]. Until now, there is no standard methodology or precisely agreed-upon protocol to define the exact value of the weak form of critical flux.

Some studies suggested that it is possible to identify the weak form critical flux as the point at which TMP and flux profile become non-linear by using flux stepping method [6]. Espinasse *et al.* (2002) [7] showed an assessment of weak form critical flux based on a concept of fouling reversibility by using flux cycling method. In general, the main variables involved in these short-term critical flux tests are step height and step length. Le Clech *et al.* (2003) [8] were the first one focused on the effect of these variables on the critical flux evaluation. They have shown that the step length between 5 to 60 minutes did not

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significantly affect the critical flux value, but the increasing of step height from 3 to 9 $L/m^2.h$ increased membrane fouling.

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 domestic wastewater. The aims of this study are therefore threefold: (1) to determine critical flux using a pilot scale SMBR fed with real wastewater; (2) to compare the critical flux values obtained from two determination methods (flux stepping and flux cycling); (3) to understand the impacts of assessment variables on the critical flux including step length and step height of filtration.

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 flatsheet 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 wastewater (from Chongnonsi 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	172.2 ± 10.3
MLSS (g/L)	0.21 ± 0.034	7.8 ± 0.045	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

The influences of step height (or the size of flux increasing in each step), step length (or the duration of filtration in each step) and determination methods of critical flux were investigated. Three flux step lengths (5, 10 and 20 minutes) and three flux step heights (2, 4 and 6 $L/m^2.h$) were carried out using both filtration methods (flux stepping and flux cycling methods) in a total of 18 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.

2.3 Flux Stepping and Flux Cycling Methods

In this study, critical flux was assessed using short-term tests based on flux stepping and flux cycling methods. The flux stepping method has been widely used for critical flux assessment [8-10]. In this method, the filtration is carried out at a fixed flux for a certain time (Fig. 1). This procedure is repeated by incrementally increasing the flux until a noticeable increase in trans-membrane pressure (TMP) is observed [11]. The hysteresis curve can also be done by stepping the filtration downward.

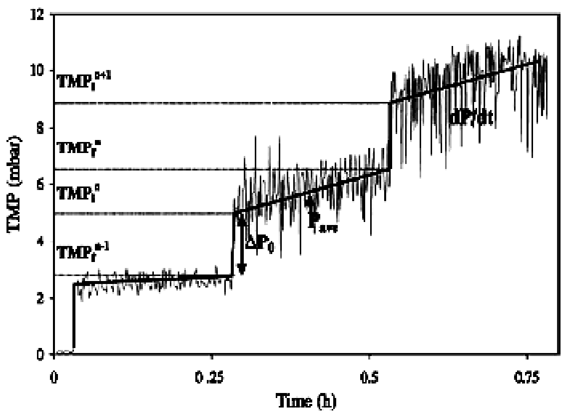

Fig. 1 Flux stepping filtration [8]

On the other hand, the flux cycling procedure proposed by Espinasse *et al.* (2002) [7] is to alternate positive and negative pressure changes, as shown schematically in Fig. 2. Anytime the pressure is set to any new value, the flux is monitored and the system waits until the flux stabilizes over time. A new pressure value can then be set. By comparing the steady-state flux obtained at steps 1 and 4, one can deduce if a flux limitation observed in step 3 is due to an irreversible fouling or to reversible phenomena. For example, if the flux in step 4 is on point *b*, fouling is 100% irreversible, and, if the flux is on point *a*, fouling is totally reversible; therefore, a fraction of reversibility can be ascribed according to the flux value at step 4 (included on segment *a-b*) [7].

Such a procedure makes possible the differentiation between reversible fouling and a deposit all along a range of pressure and flux. This procedure is developed for searching critical flux as a decrease in pressure after each increasing pressure step allows determining fouling irreversibility [12-13]. In this study, the flux cycling filtration was operated followed Bacchin *et al.* (2006) [14] by increasing flux two steps and then decreasing one step and TMP was measured at each operating step.

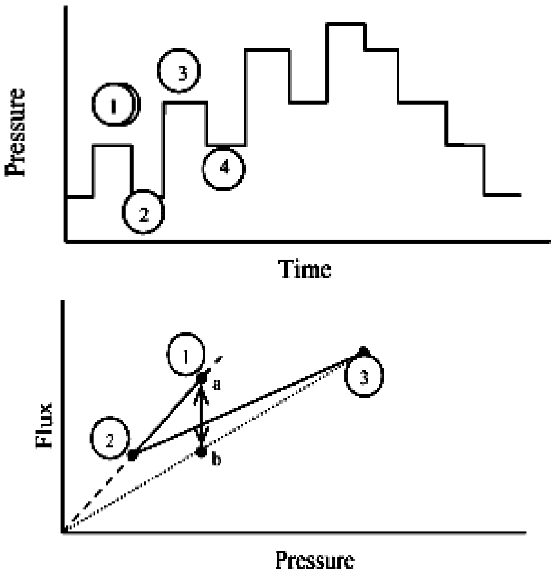

Fig. 2 Critical flux determination by flux cycling [7]

3. Results and Discussion

Membrane fouling reversibility can be accomplished using both flux stepping and flux cycling methods. To assess the reversibility of fouling using flux stepping, steps of filtration have been carried out upwards and then downwards to the initial flux (Fig. 3). Hysteresis of TMP was observed when the flux was reduced, as it had been when the flux was being increased. This hysteresis technique was useful to identify critical flux based on reversible fouling *in situ* the submerged MBR processes [15]. The reversibility of fouling can also be evaluated using the flux cycling method [8, 14] (see Fig. 4). Differences in TMP measured at the same flux represent the points of when irreversible fouling occurs in the system. Compared with Fig 3, the flux cycling technique (in Fig 4) gives slightly greater TMP recovery than the hysteresis of flux stepping. However, flux cycling technique can reduce the disadvantage of accumulative TMP in the low flux stage because it allows immediate flux recovery. The decline in flux (in Fig. 4) decreased the convection towards the membrane, which makes it possible for solute to back-diffuse away from the membrane surface.

In this study, experiments operated using the hysteresis of flux stepping and flux cycling methods were also carried out at various step heights (2, 4 and 6 L/m^2h) and step lengths (5, 10 and 20 min). A critical flux determination is taken between two experimental points: the reversible and irreversible filtration points, respectively, and an average flux are taken of these two fluxes. If irreversible flux occurred in the system, it means a balance between convective transport and back transport at such a flux condition cannot be maintained, thus exceeding a critical flux condition.

In fact, not all membrane experiments display reversibility in the fouling hysteresis using this flux stepping technique. Many studies have reported that there were significant differences between the first and next cycles of filtration and the hysteresis affects the way in which subsequent fouling can occur [15-16]. With similar step height and step length, changing filtration methods (flux stepping/flux cycling) has a significant impact on the reversible flux as illustrated in Fig. 5 and Fig. 6 as examples.

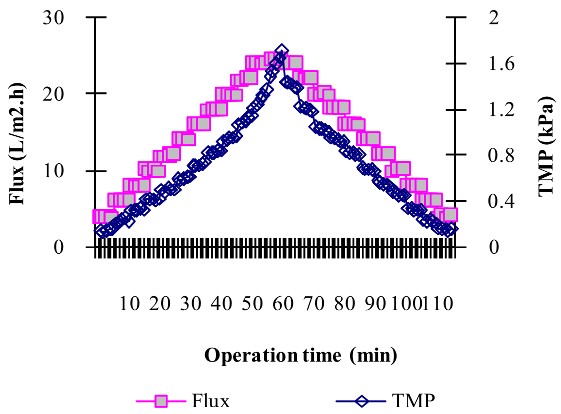

Fig. 3 Stepping filtration at step height 4 L/m^2h and 10 min step length

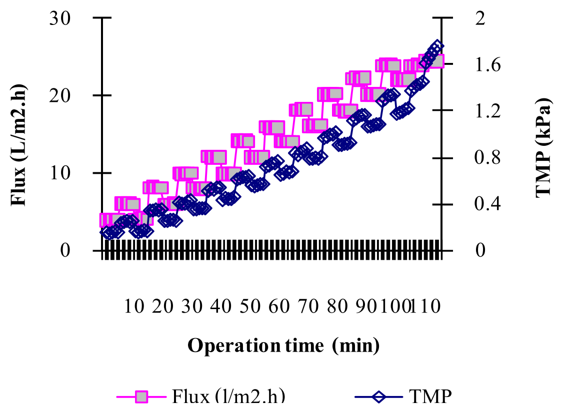

Fig. 4 Cyclic filtration at step height 4 L/m^2h and 10 min step length

It can be seen that the critical fluxes achieved from the flux cycling technique were considerably greater than critical fluxes obtained from the hysteresis of flux stepping technique (Fig. 6 and Fig. 7). With the same filtration method, there is almost no significant effect of step lengths (5, 10 and 20 min) on the critical fluxes obtained for all tests performed using different step heights.

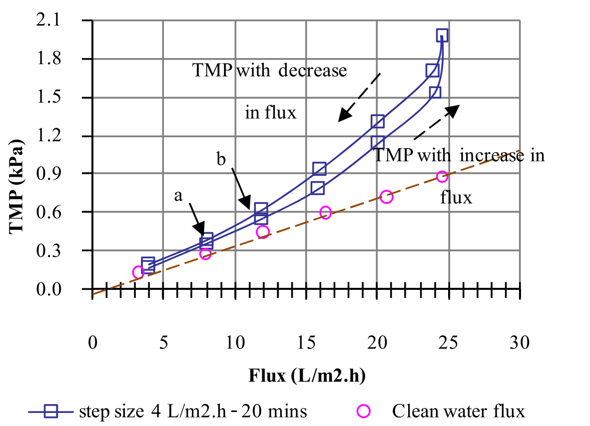

Fig. 5 Flux reversibility of stepping filtration, where a = the last reversible flux and b = the first irreversible flux

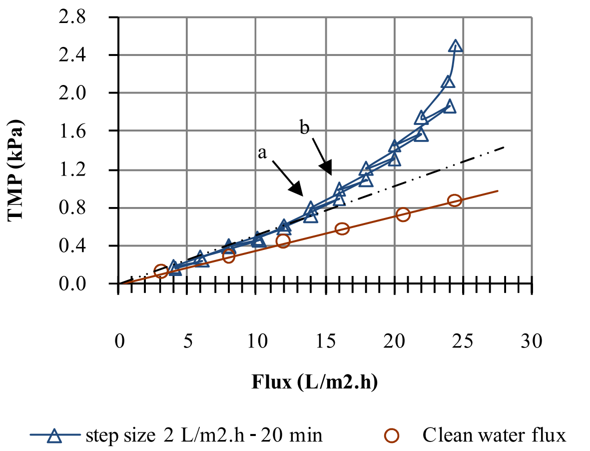

Fig. 6 Flux reversibility of cyclic filtration, where a = the last reversible flux and b = the first irreversible flux.

For all tests using the flux cycling method, the inverse relationship between the step heights and critical flux values is obviously found (Fig. 8). This is because the additional fouling from the previous filtration of the small step height can be easily recovered when the next instantly reduced flux cycling is performed and results in the greater reversible flux and higher critical flux compared to the bigger step height.

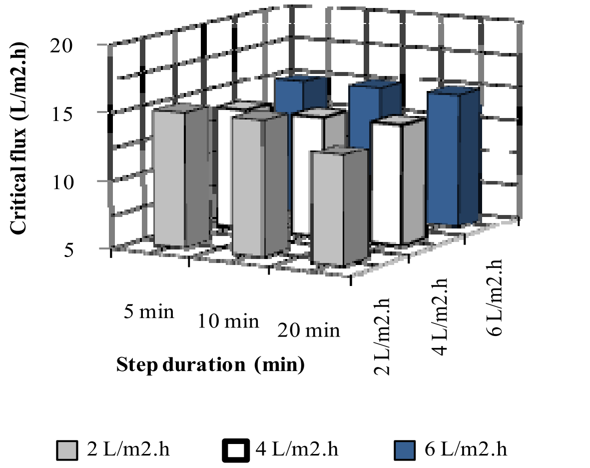

Fig. 7 Critical flux based on flux stepping method

On the other hand, a relative increase in critical flux because of the step height increase was discovered in the hysteresis of the stepping filtration (Fig. 7). This is probably because the smaller flux increment in the repeated filtration retains more filtration time and more number of steps than the bigger step height. Consequently, it produces more liquid filtered and more fouling which is more difficult to fully re-disperse those fouling even when the flux was descending. This indicates the formation of residual fouling resulting in the low or sometimes no reversible flux from this hysteresis of stepping filtration technique, which leads to a requirement of the membrane cleaning.

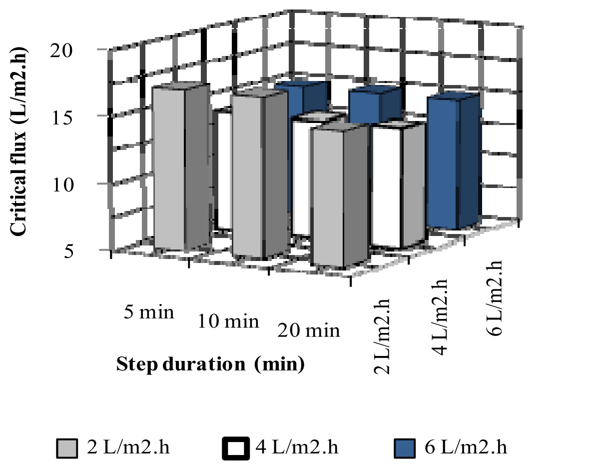

Fig. 8 Critical flux based on flux cycling method

4. Conclusions

This study has examined the effect of assessment parameters on critical flux including step heights, step lengths and determination methods (flux stepping and flux cycling) in a submerged flat sheet membrane bioreactor. The results indicated that the decline of critical flux as the step height increased has been noticed in flux cycling method, while there is a positive relationship between critical flux and step height presenting in the stepping filtration. In order to prevent a large error from flux averaging, smaller step heights are recommended for critical flux determinations. On the other hand, the step length has almost no effect on critical flux, regardless of the determination methods employed.

5. Acknowledgement

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