Evaluation of Filtration-backwash Modes on Membrane Fouling Control for Activated Sludge Suspensions Treatment

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Abstract. This study focused on the effects of three different filtration-backwash modes on membrane fouling control for various sludge suspensions treatment. A relatively slow flux decline profile showed that more frequent and shorter backwashing mode (Mode 1) had a less fouling tendency. Moreover, this mode possessed higher capacity to remove the reversible fouling with higher hydraulic cleaning efficiency (HCE) and lower hydraulically irreversible fouling index (HIFI). Typically, when fed with higher carbon-to-nitrogen ratio suspension (SBR6), the HCE value of Mode 1 was over twice as high as that of Mode 3 (less frequent and longer backwashing).

Introduction

Membrane fouling is a major impediment in widespread application of MBR [1]. Various hydraulic cleaning protocols are applied to combat membrane fouling. As a ubiquitous method for eliminating reversible fouling, backwashing is expected to make the cake more porous or disjoin the loosely attached fouling materials from the membrane surface. The dominating parameters for backwashing in MBRs are backwashing durations and frequencies [2]. It should be noted that prolonging the backwash duration blindly may decrease filtration productivity and the net filtration flux; on the contrary, a too short backwash fails to remove the reversible component of the cake layer completely [3]. Thus the optimization of backwashing protocols was very important in practice. Xu et al. [4] used cake filtration theory to optimize the filtration interval of a discontinuous microfiltration backwash process. Smith et al [5] implemented a new control system to automatically optimize the backwash duration in a hollow fiber membrane module, and saved 25% of the permeate volume. Additionally, backwashing frequency and duration is also dependent on influent characteristics and operational conditions [6].

In general, there are quite a few studies with respect to backwashing duration and frequency. Notwithstanding this, many studies on backwash so far have focused on single-cycle performance rather than multi-cycle operation, or just pay attention to the backwashing stage not the whole process, or merely contrapose the specific wastewater. Considering the above situations and associating with operational aspects of full-scale MBRs, six different sludge suspensions, and three different backwashing modes (Mode 1: 20 s backwashing per 5 min filtration, Mode 2: 20 s backwashing per 6 min filtration and Mode 3: 30 s backwashing per 8 min filtration) were put forward in this study. The objective of this research was, therefore, to investigate effects of different filtration-backwash modes on fouling tendency and cleaning efficiency.

Materials and Methods

Setup and Operation of SBRs

Six lab-scale SBRs were operated in this study, two of them (SBR1, SBR2) were kept running for over three years. Seeding sludge was taken from a local wastewater treatment plant in Beijing and was fed with synthetic wastewater simulating the municipal wastewater. The recipe of the synthetic wastewater, included glucose, starch soluble, nitrogen (NH4Cl) and phosphorus (NaH2PO4) in a proportion of chemical oxygen demand (COD): N: P = 63:10:1 (SBR1,2,3), 100:5:1 (SBR4,5) and...
200:5:1 (SBR6), respectively [7]. The seeding sludge in SBR3,4,5,6 was acclimated to the synthetic wastewater sixty days before the startup of operation.

### Experimental Setup

0.1 μm PVDF MF membrane was used in this study. The effective filtration area was 10.18cm². Before experiments, virgin membranes were soaked in ultrapure water for 24 h and the water was replaced at least three times. Suspensions in the influent tank were evenly mixed by a magnetic stirrer. The electronic diaphragm metering pump and a regulator were combined used to maintain the constant pressure during filtration stage. To make the backwash pressure also at a steady state value, the compressed nitrogen gas was applied to push the deionized water back to the cell. Namely, the filtration and backwash pressure were both fixed in 50 kPa. Thus it would produce comparable fouling of the various activated sludges, as well as eliminated the influence caused by pressure when discussing the impact of fouling on backwashing. The permeate and backwash weights were measured by electronic balance and recorded in a personal computer during test. Not otherwise provided for, each trial consisted of the following steps: (i) filtration of pure water and the average of the flux values is denoted as \( J_0 \); (ii) filtration of sludge suspension for 5min, 6min and 8min, respectively; (iii) as soon as the filtration stage terminated, the backwashing stage (20 s, 30 s) would start without relaxation. Each MF test was stopped when the membrane flux declined to 10% of initial flux of virgin membrane [8].

### Evaluation of Backwash Performance

The performance of filtration-backwash pattern was evaluated by following parameters:

1. **Average fouling rate**
   This reflected the degree of overall flux decline, can be defined as:
   \[
   \frac{dJ}{dt} = \frac{1}{n} \sum_{n=1}^{a} (\text{Flux}_{ini}^n - \text{Flux}_f^n) (t_f^n - t_{ini}^n) 
   \]
   Where \( \text{Flux}_{ini}^n \) and \( \text{Flux}_f^n \) (m/s) were the initial and final flux values of cycle \( n \), \( t_{ini}^n \) and \( t_f^n \) were the initial and final time of cycle \( n \).

2. **Hydraulic cleaning efficiency (HCE)**
   HCE expressed fouling reversibility after each filtration-backwash cycle:
   \[
   HCE = \frac{\text{Flux}_{ini}^{n+1} \text{Flux}_f^n}{\text{Flux}_{ini}^n \text{Flux}_f^{n+1}} = (\text{Flux}_{ini}^n - \text{Flux}_f^n) / (\text{Flux}_{ini}^n - \text{Flux}_f^n) 
   \]
   Where \( \text{Flux}_{ini}^{n+1} \) (m/s) was the initial flux value of cycle \( n+1 \); the HCE for each backwash water was the average during the whole test.

3. **Hydraulically irreversible fouling index (HIFI)**
   It indicated the fouling degree after backwashing [9]:
   \[
   1/ J_s = 1 + (HIFI)V_s 
   \]
   Where \( J_s = (J_{ini}/\text{TMP})(J_0/\text{TMP}) = J_{ini}/J_0 \), \( J_0 \) and \( J_{ini} \) (m/s) are respectively the flux of the virgin membrane and the initial flux after backwashing, and \( V_s \) (L/m²) is the volume filtered per unit membrane area.
Results and Discussion

Effects of Filtration-backwash Modes on Membrane Fouling Tendencies

Figure 1. Fouling tendencies of different SBRs suspensions under various backwash modes: instantaneous flux for SBR1 suspension under three filtration-backwash modes (Mode 1 (5min+20s), Mode 2 (6min+20s), and Mode 3 (8min+30s)) (a), SBR4 suspension under three filtration-backwash modes (b) and SBR6 suspension under three filtration-backwash modes (c); instantaneous flux for SBR1, SBR4 and SBR6 suspensions in Mode 1 (d); the average fouling rate of SBR1, SBR4 and SBR6 suspensions in Mode 1 (e). Note: Solid curves in (a), (b), (c) and (d) were connected by initial points of each filtration phase.

Fig. 1a-c depicts the time courses of the membrane flux for different SBRs sludge suspensions under various filtration-backwash modes. For SBR1 and SBR4 (Fig. 1a and b) suspensions, the flux reached about 10% initial flux of virgin membrane with filtration cycles of 7, 5, and 4 for Mode 1 (5min+20s), Mode 2 (6min+20s), and Mode 3 (8min+30s), respectively. As to SBR6 suspension (Fig. 4c), the flux reached about 10% initial flux of virgin membrane with filtration cycles of 4, 3, and 2 for Mode 1, Mode 2, and Mode 3, respectively. Obviously, more frequent and shorter backwashing mode (Mode 1) exhibited longer steady phase period with gradually decay in flux. This may be due to that, for one thing, shorter backwashing was more effective for the cake removal, and this speculation could be verified by the hydraulic cleaning efficiency (HCE) and the hydraulically irreversible fouling index (HIFI) in next section; for another, longer filtration time (8min) could enhance the cake compressibility and resulted in decreasing of cake porosity as compared to relatively short filtration time (5min) [10].

The fouling tendencies of various sludge suspensions in the same mode (e.g. Mode 1) are shown in Fig. 1d, where SBR6 suspension revealed more severe fouling propensity than others in terms of average fouling rate histograms in Fig. 1e. This is also the evidence from the backwash side of that the fouling behavior was more profound in SBR6 suspension than others. Additionally, as for multi-cycle backwash, the first few runs contributed more in fouling rate than later runs. This because the residual foulants from previous cycle constituted the dense layer of a new cake when filtration continued [11].
Effects of Filtration-backwash Modes on HCE and HIFI

![Graphs showing the effects of filtration-backwash modes on HCE and HIFI for different SBR suspensions](image)

Figure 2. HCE and HIFI of different SBRs suspensions under various backwash modes: HCE for SBR1, SBR4 and SBR6 suspensions under three filtration-backwash modes (a), HIFI for SBR1, SBR4 and SBR6 suspensions under three filtration-backwash modes (b), HIFI of SBR1, SBR4 and SBR6 suspensions for the first backwash cycle of Mode 1 (c).

Fig. 2a presents the effect of filtration-backwash modes on the HCE during the filtration of various sludge suspensions. As for SBR1 suspension, the values of HCE for Mode 1, Mode 2 and Mode 3 were 48.2%, 41.1% and 36.8%, respectively. By contrast, the backwash efficiencies for SBR4 suspension were slightly higher, with HCEs of 58.2%, 52.9% and 50.3% for Mode 1, Mode 2 and Mode 3, respectively. When fed with SBR6 suspension, the lowest HCE (24.9%) was found in Mode 3, and the values for the Mode 1 and Mode 2 were 49.9% and 37.6%, respectively. Overall, Mode 1 exhibited better cleaning performance than other modes especially for SBR6 suspension.

The hydraulically irreversible fouling also varied with different backwash modes in Fig. 2b. The lowest and the highest HIFI were found in Mode 1 (8.691 m⁻¹) and Mode 3 (30.708 m⁻¹) when SBR1 suspension was used as feed. Similarly, the HIFI ordered Mode 1 (9.947 m⁻¹)<Mode 2 (14.581 m⁻¹)<Mode 3 (19.74m⁻¹) when feed switched to SBR4 suspension. As for SBR6 suspension, less hydraulically irreversible fouling were observed in Mode 1 (10.203 m⁻¹), and no significant changes in HIFI were found in Mode 2 (16.642 m⁻¹) and Mode 3 (16.19 m⁻¹). In general, less hydraulically irreversible fouling was observed for the mode 1 compared with other two modes, and this result was in line with previous HCE analysis. One other important note is that, there were distinct variations of HIFI values for various sludge suspensions between each backwash cycle (e.g., first backwash cycle of Mode 1) (Fig. 2c): SBR6 suspension had a much higher specific flux loss (135.64 m⁻¹) in the initial of backwash cycle and achieved stability (1.9 m⁻¹) after 160s, while relatively lower initial HIFI values were obtained in SBR1 and SBR4 suspensions (34.893 and 31.557 m⁻¹) and reached constant values (3.5 and 9.2 m⁻¹) after 100s. This indicated that SBR6 suspension had a higher initial hydraulic-irreversible fouling than SBR1, and SBR4 suspensions for each backwash cycle.
Conclusions
In this work, various sludge suspensions were used to permeate with three different filtration-backwash modes. Behaviors of membrane fouling control were presented. Flux decline profile showed that more frequent and shorter backwashing mode had a less fouling tendency. Moreover, higher hydraulic cleaning efficiency (HCE) and lower hydraulically irreversible fouling index (HIFI) presented that this mode had a higher capacity to remove the reversible fouling.

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References