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Influence of various operating conditions on cleaning efficiency in sequencing batch reactor (SBR) activated sludge process. Part II: Backwash and water rinsing introduced membrane filtration process

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ABSTRACT

In this paper, the influences of backwashing conditions on the washing efficiency (P) were systematically investigated by a combination of orthogonal table and multivariate linear regression methods. The experiments were performed with the feed suspension from SBR and deionized water in laboratory-scale dead-end microfiltration test unit with 0.1 μm PES microfiltration membrane. The impact of shearing stress on the backwashing recovery (r_i), and mass-transfer coefficient on washing efficiency (P) were studied respectively. The results showed that backwash and water rinsing introduced membrane filtration process could restore the declined flux close to 100%. However, the ability of backwashing was gradually reducing with the increase of backwashing cycle, which was associated with the increasing accumulation of irreversible fouling onto and into the membrane pores. r_i and P increased with the increase of transmembrane pressure (*TMP*), and decreased with the increase of operating temperature. Since the foulants are more susceptible to be washed away from the membrane pores during a longer backwash, the r_i got a high value, on the contrary, the productivity decreased with an increase of backwash duration due to the back pumping of more detergent. The average contribution of backwashing conditions on P were detergent temperature (50.49%)> transmembrane pressure (39.84%)>backwashing times (7.27%)>backwashing time (2.39%). The backwashing conditions were optimized and the relationship between backwashing conditions and washing efficiency (P) was analyzed and defined quantitatively.

1. Introduction

Over the past twenty years, the membrane bioreactor (*MBR*) process has been widely employed in the treatment of industrial wastewater, human excrement, and especially domestic wastewater [1–4] due to its small footprint, high quality effluent, low sludge production rate, highly retentive concentration of activated sludge and easy management [5,6]. To solve the membrane fouling problem in membrane filtration process that decreases the life of membrane modules and increases costs [7], many strategies, such as pretreatment of the feed suspension, optimization of operating conditions in the membrane module and preparation of antifouling membranes [8] are employed. None of that approaches can eliminate the foulant completely. So membrane cleaning is an inescapable and essential step in maintaining membrane filtration process [9], and many physical and chemical cleaning methods have been employed to remove the deposit layers on membrane surface and in the pores.

Water rinsing is a necessary step in the entire membrane cleaning process [10], however, it cannot remove the deposits formed in the pores effectively [11]. Compared with water rinsing process, backwashing process exhibits excellent cleaning effect and good ability in restoring the membrane flux to initial level, so it has become an important step of the practical membrane cleaning process [10] and several authors have dealt with this matter. For example, Katsoufidou et al. [12,13] represented that periodic backwashing could remove the irreversible membrane fouling caused by humic acid. Xu et al. [14] defined a residual factor to take into account the washing efficiency in the backwash stage. Chen et al. [15] pointed that those significant factors affecting physical cleaning were production interval between cleaning duration of backwash and pressure during forward flush. Hong et al. [16] reported that the backwashing efficiency decreased significantly with the increase of solution ionic strength, while it unchanged with the variety of particle concentration and operating pressure.

Various possibilities to optimize backwashing have been reported in literatures [17–19]. A variety of different backwash scenarios have

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been tested to determine their impact on membrane fouling. Operating cost must be controlled in order to develop an optimized backwashing strategy [18,19]. But frequent backwashing decreases the efficiency of the membrane system and increases the energy requirement [20]. Fane et al. discussed strategies to reduce energy usage in low pressure membrane introduced backwashing processes [21]. Vargas et al. [22] reported that a new control algorithm was able to prevent some fouling on the membrane by performing a backflush process. However, up to now, the aspect of quantitatively defining the contribution of the operating conditions to the backwashing efficiency has received limited attention. Therefore, the present paper is aimed at optimization of washing conditions in backwashing and water rinsing introduced membrane filtration process and establishment of the quantitative contribution of cleaning operating conditions to cleaning efficiency. Moreover, in order to focus on the effect of backwash conditions on filtration performance, all experiments in present paper were set to fix water rinsing conditions.

2. Experimental

2.1. System and methods

The laboratory-scale experimental system was described elsewhere in the literature [11]. The synthetic wastewater with recipe is shown in Table 1. The reactor was kept running for over half a year with conditions as described elsewhere [11]. Before each experiment, the membrane (0.1 μm *PES* hydrophilic membranes purchased from Beijing Ande Membrane Separation Technology and Engineering) was soaked in deionized water for 12 h to remove glycerin (protectant). The main parameters of feed suspension for membrane cell used in this experiment were *TOC* (31.5–37.8 $mg \cdot L^{-1}$), $NH_3–N$ (9.4–11.22 $mg \cdot L^{-1}$) and *COD* (34.6–40.7 $mg \cdot L^{-1}$).

2.2. Experimental procedure

The experimental work started when *COD*, NH_3–N concentration and *MLSS* unchanged with time. Before each experiment, the membrane flux was measured at transmembrane pressure (*TMP*) 0.08 MPa to check membrane defects and determinate the intrinsic resistance of membrane by deionized water at room temperature. The intrinsic resistance of membrane R_m was calculated by the following formula:

$$R_m = \frac{TMP}{\mu J_0} \tag{1}$$

where R_m is the intrinsic resistance of the virgin membrane (m^{-1}), *TMP* is the transmembrane pressure (*MPa*), μ is the fluid viscosity ($Pa \cdot s$), J_0 is initial flux of virgin membrane ($m^3 \cdot m^{-2} \cdot s^{-1}$).

The experimental procedure was as follows: (1) the filtration test with feed solution was conducted at TMP 0.08 MPa and membrane flux was measured at different temperature (15 °C, 20 °C, 25 °C, 30 °C, 35 °C); (2) stopping filtration test when the membrane flux declined to 10% of initial membrane flux and rinsing the membrane with the detergent (deionized water) under fixed conditions (rinsing time is 120 s, agitation speed is 150 min^{-1} and the temperature is 20 °C); and (3) backwashing the membrane with detergent according to the designed backwashing operating condition, then the filtration test with feed solution was repeated again. In the end, the cumulative membrane permeate filtrate volume (*CMPFV*) was collected for each whole procedure.

Table 1
Components and concentrations of synthetic wastewater water.

Component	Concentration (mg/L)	Component	Concentration (mg/L)
glucose	278	$CaCl_2$	6
starch soluble	278	$MgSO_4 \cdot 7\,H_2O$	66
peptone	28	$MnSO_4 \cdot 7\,H_2O$	6
NH_4Cl	297	$FeSO_4$	0.3
$NaHCO_3$	111	NaH_2PO_4	52.8

3. Analytical methods

3.1. The recovery of membrane permeability

The recovery of membrane permeability (r_i) that provides a measure of membrane irreversible fouling is calculated by:

$$r_i = \frac{J_i}{J_0} \tag{2}$$

where J_i is the initial suspension flux after each water rinsing or backwashing cycle ($m^3 \cdot m^{-2} \cdot s^{-1}$), J_0 is the initial suspension flux value of virgin membrane ($m^3 \cdot m^{-2} \cdot s^{-1}$).

3.2. Fouling mechanism

The Blocking Law was first put forward by Herman et al. [23] in 1935, and the common form was as follows [24]:

$$\frac{d^2t}{dV^2} = k_0\left[\frac{dt}{dV}\right]^n \tag{3}$$

where t is the filtration time (s), V is the total filtered volume (ml), k_0 is the proportional coefficient. The exponent n characterizes the fouling mechanism, with $n = 0$ for cake filtration, $n = 1$ for intermediate blocking, $n = {}^3/_2$ for pore constriction (also called standard blocking) and $n = 2$for complete pore blocking [25].

3.3. Determination of filtration resistances

According to the resistance-in-series model, the total membrane resistance $R_t(t)$ at time t can be written as:

$$R_t(t) = \frac{TMP}{\mu J} = R_m + R_{irr} + R_r \tag{4}$$

where *TMP* is the transmembrane pressure (*Pa*), μ is liquid viscosity ($Pa \cdot s$), J is the permeate flux ($m^3 \cdot m^{-2} \cdot s^{-1}$), R_m is the intrinsic resistance of the virgin membrane (m^{-1}), R_{irr} is the irreversible membrane resistances (m^{-1}), R_r is the reversible membrane resistances (m^{-1}).

3.4. Determination of shearing stress in membrane pores

The shearing stress in the membrane pores can be defined according to the following relationship [26]:

$$\tau = \frac{f}{2}\rho u^2 \tag{5}$$

where τ is the shearing stress in the membrane pores (s^{-1}), f is the Fanning friction factor, ρ is density of membrane permeate ($kg \cdot m^{-3}$), u is the fluid flow velocity in the membrane pores($m \cdot s^{-1}$).

The value of f is calculated by the formula (6):

$$f = \frac{16}{\mathrm{Re}} \tag{6}$$

where Re is the Reynolds number.