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Membrane fouling and physical characteristics of sludge in MBR system

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ABSTRACT

The objective of this paper is (i) to investigate correlations between MBR membrane fouling and MBR sludge physical properties, and (ii) to develop the parameters for control membrane fouling especially physical properties in term of dewatering parameters. The experiments are performed in a submerged membrane bioreactor, in sub-critical flux conditions. The physical sludge characteristic is studied for two running periods, characterized by different organic loads (VLR) and/or solid retention times (SRT). The physical sludge characteristics (SMP, SCOD, CST, SRF, viscosity and SVI) are quantified and correlated with the fouling rate. The soluble fraction is the major parameter affecting physical sludge characteristics, with the polymeric linkage. The CST can be a reliable parameter to predict the extent of second stage membrane fouling rate in MBR filtration and can be useful for monitoring the MBR system.

Keywords: Sludge characteristic; Dewaterability; Membrane fouling; CST

1. Introduction

Membrane separation process combined with biological treatment system is now successfully developed for the treatment of municipal and industrial wastewater. The development of membrane bioreactor (MBR) technology for wastewater treatment is significant due to the strict regulation on water quality, essential for water reuse/recycling, and to the improvement of membrane technology. However, membrane fouling always results in severe flux decline involving high-energy consumption and frequent membrane cleaning or replacement. It has been demonstrated that the membrane fouling mechanisms are very complicated due to physiological characteristics of mixed liquors [1]. Practically, correlations between supernatant composition, physical characteristic and filtration performance are not clearly compared at lab-scale studies [2–4]. Besides, the MBR system retaining high biomass concentration allows high sludge retention time (SRT) operation, which is good for minimizing excess sludge production. However, the implementation of high sludge retention MBR is still in question because of the sustainability of physical characteristics and dewaterability of the sludge. Sludge characteristics are affecting on the dewatering and fouling mechanisms which can be the indicating parameter in the system. Mostly, foulants are small particles, soluble fraction in term of SMP and EPS, and colloid fraction. Recent research suggests that components of the liquid phase of sludge (soluble and colloid) are primarily responsible for the fouling of membranes [5–7].

Hence, this study was conducted to investigate (i) the correlation between membrane fouling and physical properties of sludge, and (ii) parameters which developed to control membrane fouling.

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2. Methods

2.1. Experimental set-up and operating conditions

The experiment unit is performed in a submerged membrane bioreactor with a working volume of 50 L. Hollow fiber membranes of polysulphone (UFL2, Polymem) with a pore size 0.08 µm are used with a total filtration area of 0.2 m^2. Before the beginning of the MBR operation, the critical flux is determined by flux step method [8]. Filtration was performed in continue under sub-critical flow, without relaxation, in an outside to inside mode at a constant permeate flux is equal to 4.8 LMH. Pressure transducers placed on the permeate side allow the monitoring of the Trans-Membrane Pressure (TMP) and consequently the estimation of the membrane fouling over all the period. Synthetic feed water is used, composed of acetate and meat extract (Viandox®) in ratio 1:1. The physical sludge characteristic is studied for two running periods (R_I and R_{II}), characterized by different organic loads (VLR) and/or solid retention times (SRT). The operating conditions are associated with the different running periods. They are presented in Table 1.

2.2. Analytical methods

Measurements of TSS (Total Suspended Solid), Soluble COD (SCOD) and Sludge Volume Index (SVI) were determined according to Standard method [9]. Soluble COD (SCOD) samples were obtained by filtrating the MBR sludge (50 mL) following by a filtration of the supernatant through a 0.45 µm filter. Soluble Microbial Products (SMP) is quantified in the soluble fraction of the bulk suspension. These soluble microbial products are mainly made up of polysaccharides and proteins; for proteins quantification, Lowry method using Bovine Serum Albumin (BSA) as the standard is used and for polysaccharides quantification, Anthrone method using sucrose as the standard is chosen.

The dewaterability of the sludge is represented by the specific resistance to filtration (SRF) at 0.5 bar and by the capillary suction time (CST). SFR was measured by stirred and pressurized filtration cell (Amicon 8010) with membrane cellulose nitrate 0.2 µm (Sartorius). CST was measured as using a capillary suction timer by Triton 319. Dynamic viscosity is investigating to complete the sludge characterization, was analyzed by a coaxial measurement device with a double gap measuring system by Haake Rheometer (Rheostress RS 100).

3. Results and discussion

3.1. MBR performance and sludge characteristics

The COD removal efficiency obtained during the two running experiments is always higher to 90%. Despite the organic load increases in the second period of the running II, the removal efficiency was maintained at a very high level. Bacterial population can ensure very rapidly the removal of an excess of organic matter and so their adaptation to a load peak can be rapid and efficient. Concerning the MBR sludge characterization results, Fig. 1 presents the evolution of SCOD, SMP, viscosity (µ), SVI, CST and SRF during running I and running II.

In the running I, the concentration of SCOD, SMP and SRF are stayed constant at 120, 200 mg/L and 3×10^{12} m/kg, respectively. The SVI representing the settlability of the sludge, first decreased in an exponential line and then stabilized around 70 mL × g^{-1}. As while the viscosity is increasing in exponential law. CST values are increased due to the TSS concentration increasing. This running is operated with high sludge retention time, the TSS content increases, the interactions between the flocs, and so between the solids, are favored, leading to a more rigid structure of the sludge network and to an increase of the sludge cohesion and also bound water [10]. However, these values are closed to the ones measured in other MBR systems working with high SRT [11]. These values are not so different than the ones of conventional activated sludge system.

In the running II, these parameters vary due to the change of the loading condition and a rapid increase of the measured parameters is observed with the VLR

Table 1
Operating condition in the system.

Operating condition	Running I	Running II	
	R_I	$R_{II.1}$	$R_{II.2}$
Hydraulic retention time (HRT), d	2	2	2
Solid retention time (SRT), d	125	40	40
Volumetric organic loading (VLR), $kg_{COD}.m^3.d^{-1}$	0.9	1	3
Running duration, d	140	50	30

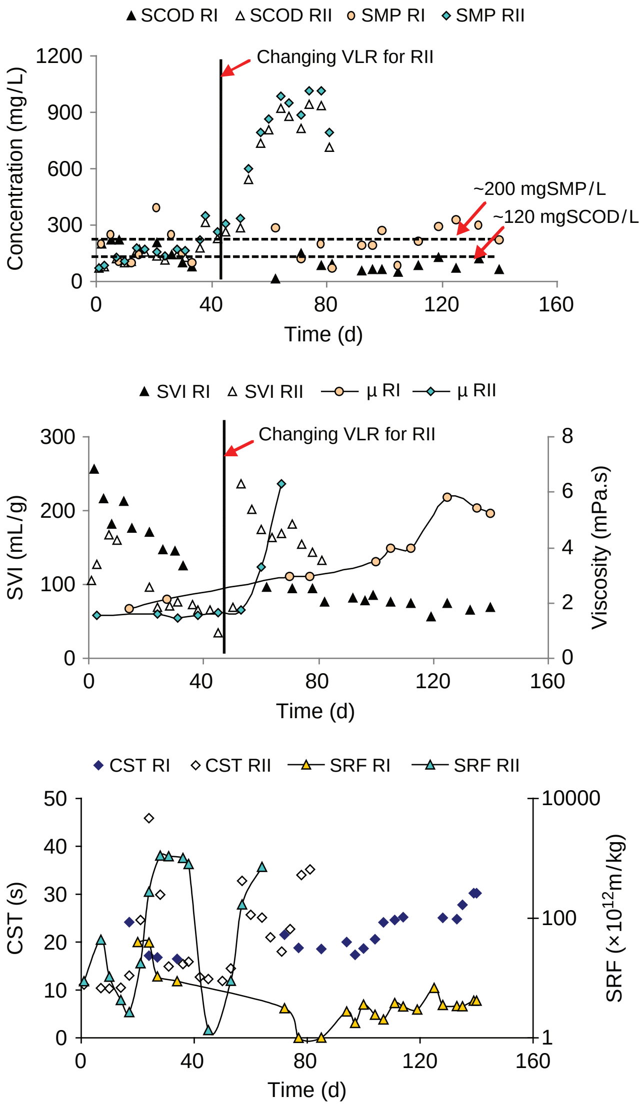

Fig. 1. The evolutions of physical sludge characteristics.

change. The variation of CST, SRF and viscosity could be related to the increase of soluble microbial products and SCOD are dealing with the bacterial adaptation for the changing environmental [12]. They are likely to create linkages between the flocs, leading to a much more rigid structure of the sludge and then to an increase of the cohesion of the sludge network. This result reveals that the composition of the liquid phase, especially soluble organic microbial products are very important for sludge behaviors.

3.2. TMP evolution

Figure 2 presents the evolution of the trans-membrane pressure (TMP) of both submerged mem brane reactor runnings. Even though filtration is carried out under sub-critical regime, the evolution of TMP shows a two-phase evolution whatever the running may be:

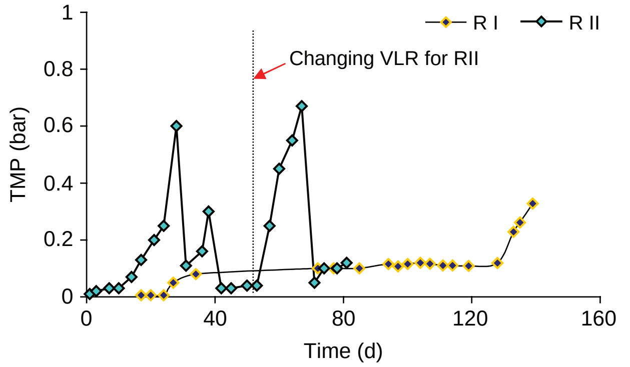

Fig. 2. TMP variation versus operating time during the MBRs operation.

(i) The pressure rises slowly and the evolution of the pressure over the time (dTMP/dt) stays under 0.01 Pa × s^{-1}; interactions between some compounds of the mixed liquor and the membrane surface occur and reduce the open area, despite a constant flow. This causes a gradual increase of the local flux through the open pores, until the reach of the critical flux value [13, 14].
(ii) The pressure increases rapidly because of a cake formation on membrane surface.

The evolution of TMP in long term operation with high sludge retention time did not show an important membrane fouling, despite of high biomass concentration present in the system. High SRT did not induce high fouling phenomena (e.g. Running I). In the running II, the sudden TMP increase corresponds to a change in the operational conditions with the organic loading (VLR) pick. The previous results show that this change in VLR has induced a CST pick and some modifications in SCOD and SMP concentrations. As it was demonstrated in many studies, the composition of the soluble fraction is important and effects on the filtration performance.

3.3. TMP evolution and correlation of sludge dewaterability

The following of the Trans-Membrane Pressure (TMP) allows quantifying the membrane fouling during the running. TMP shows a classical two-phase evolution that is linked to the average value of dewatering parameters for each phase of the running II (in Table 2).

These correlations show the different interval between CST and SRF, certainly due to the different mechanisms to quantify the both parameters. The CST

Table 2
Fouling rate and the mean value of dewatering parameters.

Periods	Fouling rate (dR/dt) ($m^{-1} \times d^{-1}$)	CST (s)	SRF (x 10^{12} m $\times$ kg^{-1})
Slow	8.67×10^{10}	20	16
Fast	2.47×10^{12}	28	180

test gives information about the water movement in the cake; according to Jin et al. [15], there is no assurance that it will invariably predicts the efficiency of a specific dewatering device. On the other hand, SRF gives information about the way that a filtration cake is formed and about the resistance that it opposites to the water movement. Whatever the considered phenomena may be, the soluble organic matter, essentially assimilated to polymeric microbial products, contributes greatly to the creation of a network, increasing the rigidity of the sludge binding force in the sludge flocs and resulting in an increase of CST and SRF values. After cake formation, in the second fouling stage, the fouling rates, and the CST and SRF values, were improved by the high porosity and connectivity of the deposited sludge cake.

CST is a rapid and easy measurement that is susceptible to be use to evaluate the membrane fouling. A relationship between the CST and the second stage fouling rates of the MBR was investigated. Figure 3 shows a linear relationship between CST and the second stage fouling rates with an r-squared value of 0.94.

Following the relationship, it can be postulated that CST can be a reliable parameter to predict the extent of second stage membrane fouling rate in MBR filtration process in Eq. (1).

$$\frac{dR}{dt} = 5 \times 10^{11} \mathrm{CST}_{\mathrm{average}}(s) + 2 \times 10^{11} \quad (1)$$

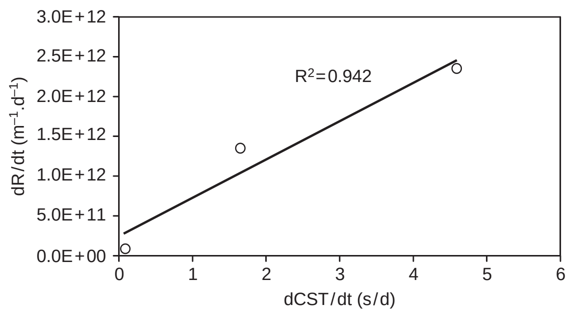

Fig. 3. Relationship between the CST and the second stage fouling rates of the MBR.

4. Conclusions

The objective of this paper was (i) to investigate the correlation between MBR membrane fouling and sludge physical properties, and (ii) to develop the parameters for control membrane fouling, especially physical properties in term of dewatering parameters. Experimental results demonstrate that the physical properties may be correlated with membrane fouling rate. Both physical parameters are connected with the solid-liquid interaction and notably with polymer linkage. The results show clearly that membrane fouling corresponds to changes in the physical characteristics of the sludge due to the composition of the soluble fraction with polymeric binding interaction.

The CST, obtained with simple equipment and short time, could be good indicators to anticipate and control membrane fouling.

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