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Performance of a Novel Hybrid Membrane Bioreactor: Effect of Bacterial Floc Size on Fouling

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In this study, the impact of bacterial floc size on membrane fouling in hybrid submerged membrane bioreactors (airlift oxidation ditch membrane bioreactor, AOXMBR) was investigated. The system was consisted of three sections ((i) airlift pump, (ii) oxidation channel and (iii) membrane) and was operated for a period of 5 months. The average floc size of activated sludge decreased with time from 78 μm to 38 μm. The concentration of soluble protein and polysaccharide in the supernatant increased with time; on the other hand, the permeate COD (Treated water chemical oxygen demand) was almost lower than 20 $mg.L^{-1}$. It was observed that when substrate overload occurred, the flocs were more prone to breakup (pin-point floc effect) which induced a high concentration of released soluble polysaccharides and a significant increase in membrane fouling.

1. Introduction

In recent years, membrane bioreactors (MBRs) have received much attention, due to their advantages for sustainable wastewater treatment. The membrane bioreactor is an efficient technology for wastewater treatment and reuse. MBR systems have inherent features that make them more economical when compared to conventional activated sludge processes. These features include: the ability to operate with no settling limitations which allows operation at very high sludge ages, and to improve effluent quality due to the membrane separation efficiency. Another feature that makes MBR systems economic is their ability to operate at high MLSS (Mixed Liquor Suspended Solids) levels which allow high organic loading (Delgado et al., 2008; Wisniewski, 2007).
The key to the success of internal membrane filtration is the direct application of air for membrane cleaning at the base of the membrane modules. For flat membrane, the air bubbles and air-lifted liquid move upward along the membrane surface. Because the membrane elements are very close together in the membrane module, this upward motion causes a scouring effect on the flat membranes that provides surface cleaning. In addition to the riser section sparged with air, this kind of airlift reactor also has a

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downcomer section with liquid moving downward between the membrane module and the wall of the bioreactor (Vorapongsathorn et al., 2001).

The benefits of using the MBR technology for oxidation ditch are no extra land requirement and high SRT; also, this system produces a high quality effluent for reuse, no odour, and allows treatment of much higher capacity of wastewater (Li et al., 2008; Fayollea et al., 2010). Based on the research about oxidation channel, airlift and MBR, we propose a new type oxidation ditch, Airlift Oxidation ditch Membrane Bioreactor (AOXMBR) that has three different sections called as riser, down comer (airlift and channel section) and membrane separation unit. This operating mode limits the energy consumption because no impeller is needed for the fluid circulation in the channel.

Previous research has shown that, with increasing solids retention time (SRT), the sludge concentrations in the MBRs increases, whereas the ratio of volatile suspended solids to the total solids decreases, and the size of sludge floc diminishes. This can result in better organic removal efficiency. Furthermore, a longer SRT is advantages for the growth of nitrifiers (Massé et al., 2009; Al-Halbounia et al., 2008). The performance of these AOXMBRs for the removal of COD and NH4+-N did not change much with different SRTs.

Starting from those results, the aim of the present study was to investigate the influence of high SRT on soluble polysaccharide and protein concentration and sludge characteristics on membrane fouling in AOXMBR.Understanding this effect is essential to successful design of AOXMBR for wastewater treatment applications.

2. Materials and Methods

2.1. Experimental setup and operating conditions

Fig. 1 shows the experimental setup of airlift oxidation ditch membrane bioreactor system (AOXMBR). In order to obtain an effective flow pattern an airlift pump was installed to achieve an air-induced liquid circulation in the bioreactor. This airlift pump included two vertical flat plates separating the cross-section of the bioreactor into the riser section, which contained the membrane module, and the downcomer section. These plates were installed between each side of the A3 flat sheet membrane module (A3 Company, Germany) and the reactor wall. The membrane module was located 0.04 m above the sparger.

The pressure gauge was installed between the membrane and a peristaltic pump in order to monitor the variation of the transmembrane pressure. To maintain a constant level in the reactor, a peristaltic pump providing influent wastewater and a level sensor were used. Air was supplied through the diffuser below the membrane module. The study was performed during 120 d in which the organic load was successively increased from 2 to 6 kg COD.m^3.d^{-1}), whereas the hydraulic retention time (HRT) was kept constant and equal to 24 h. Under these conditions, the influence of the rising effect of the organic loading rate was then investigated. Afterwards, during 50 d, organic loading rate was kept constant at a value close to 6 kg COD.m^3.d^{-1}.

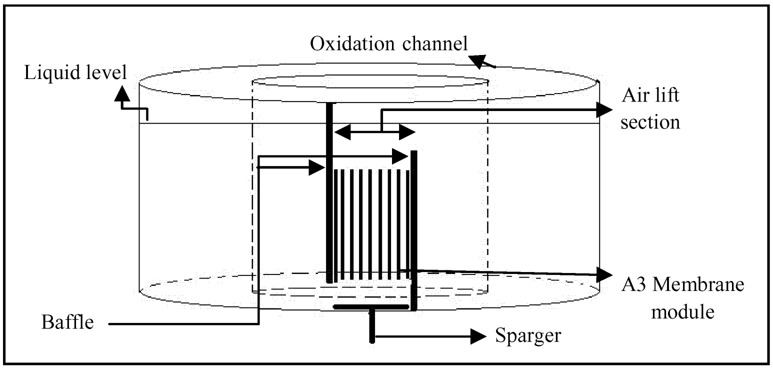

Figure 1: Schematic construction diagram of the airlift oxidation ditch membrane bioreactor system (AOXMBR)

During the whole experiment, the pilot was operated with the same operating conditions. Temperature, pH, soluble polysaccharide, soluble protein, mean floc size, oxygen concentration and transmembrane pressure were continuously recorded.

Table 1: Operating conditions

Organic loading rate (kg COD.m^{-3}.d^{-1})	2-6	6
Temperature (C)	20-25	20-25
pH	7.5	7.5
Aeration rate ((L.min^{-1})	45	45
HRT (h)	24	24
Flux (L.m^{-2}.h^{-1})	15	15-25
Sludge Retention Time, SRT(d)	---	no sludge extracted

2.2. Analytical methods

Chemical oxygen demand (COD), mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) were measured according to the Standard Methods (APHA, 1998). COD was measured after filtration using a 0.45 µm filter (polyamide). Protein content, expressed in mg equivalent of bovine serum albumin per gram of MLVSS (mg.L^{-1} for the soluble polymer), was determined according to the method of Lowry (Lowry et al., 1951). Polysaccharides were determined according to the method of Dubois (Dubois et al., 1956) and the results expressed in mg equivalent of glucose per gram of MLVSS (mg.L^{-1}for the soluble polymer). Mean floc size (d50) and fractal dimension (Df) were obtained with a laser particle size analyser (MasterSizer 2000).

3. Results and Discussion

3.1. Overall performance

The rupture of the chains of bacteria and the destructuration of the floc have two main consequences for the organic matter distribution in the biological culture: (i) a decrease in the settleable fraction due to the reduction in the floc size and the release of bacterial polymers whose characteristics can reduce the suspension settleability and (ii) an increase in the non-settleable fraction of the suspension related to the high amount of microflocs. The MLSS and MLVSS in the AOXMBR are shown in Fig. 2. It could be seen that the MLSS and MLVSS increased versus time. Moreover, it can be seen that the slope of MLSS versus time also increases with increase in organic loading rate.

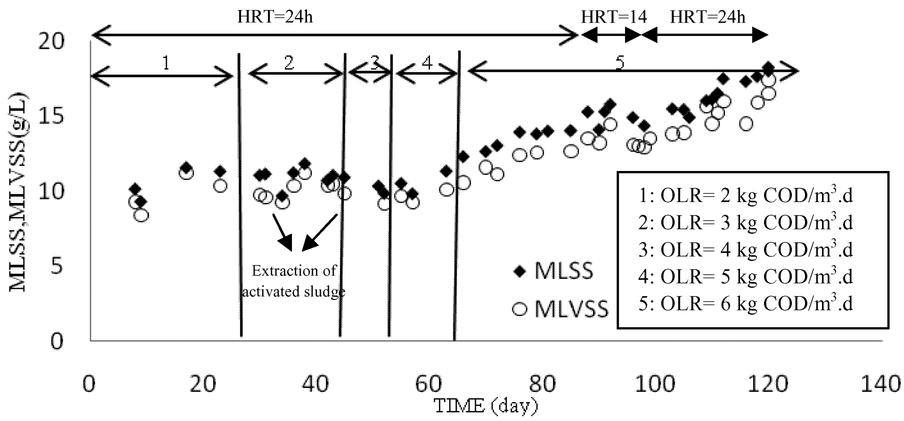

Figure 2: MLSS, MLVSS concentration versus time with increasing organic loading rate (OLR).

3.2. Impact of biofilm on membrane rejection

Analyses of the supernatant and permeate indicated that proteins and polysaccharides, which are components of SMP, were present in these streams. Fig. 3 presents the data of soluble protein and polysaccharide concentrations measured in the supernatant and permeate of the AOXMBR. The lower and limit value of protein concentration before and after cleaning the membrane (92 d and 106 d) indicated that only a small part of protein and polysaccharide pass through the membrane. Nevertheless, the deposit of material on the membrane affects the membrane rejection. In fact, this effect is only observed after a membrane chemical cleaning (92 d and 106 d) where the rejection of polysaccharide decreased from 42% (before cleaning) to 17% (just after cleaning). This phenomenon is only observed for polysaccharide and a short filtration time (1 day). This phenomenon underline the ability of (i) the dynamic membrane for increasing the membrane rejection and (ii) the polysaccharide molecules to foul the membrane as their particle size are close to the membrane pore size.

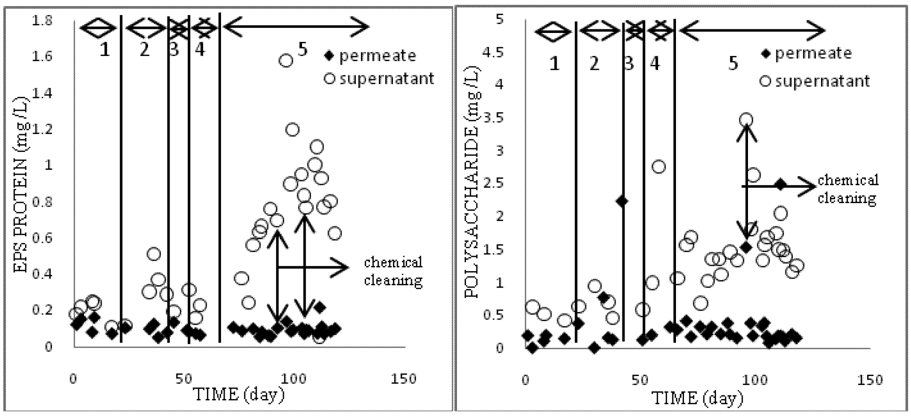

Figure 3: Soluble Protein and polysaccharide versus time.

3.3. Comparison of sludge morphology

Fig. 4 shows that the mean floc diameter decreased from 78 to 38 µm, from day 10 to day 120, whereas the MLSS concentration changed from 8 to 16 g.L^{-1}. The decrease in floc size as time increased can be correlated to the increasing of the soluble protein and polysaccharide concentrations (Fig. 4). This illustrates again the advantage of working at moderate MLSS around 10-12 g.L^{-1}in AOXMBR, which prevents the dispersion of the entire biomass as has been observed in systems with high shear stress (Kim et al., 2001).

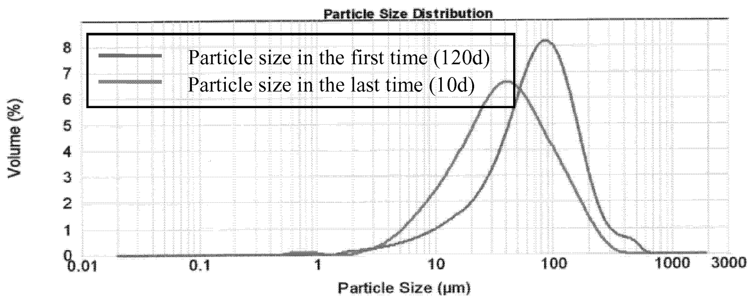

Figure 4: Particle size distribution of activated sludge in the AOXMBR in the first and last day of experiment.

3.4. Membrane fouling

The rate of change in Transmembrane Pressure (TMP) is an important factor to evaluate the system performance in AOXMBRs because at a constant permeate flow rate, TMP is directly related to the rate of membrane fouling. The value of TMP was close to 300 mbar after 92 days but, in the second period, with the same HRT of 24h, this value was reached after only 15 day. This phenomenon was due to the increase of soluble protein in the reactor and change in the bacterial floc size.

4. Conclusion

The present study was focused on the performance of a novel membrane bioreactor (AOXMBR), and the impact of high SRT on sludge characteristics and membrane fouling. The results showed that high SRT induced high MLSS concentration and increase soluble protein concentration in and decreased floc size, both of them affect membrane fouling.

Considering the differences of SMPs composition (protein, polysaccharide) and floc size, it is still difficult to conclude whether protein concentration or small floc size were the main cause of membrane fouling. Moreover, biofilm and mixed liquor were largely composed of soluble portions. Also, no sludge was observed on the membrane surface which appeared still more or less clean (no black or brown deposits were detected). It is concluded that soluble protein and floc size could be a major cause of membrane fouling.

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