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Review

The role of the operating parameters of SBR systems on the SMP production and on membrane fouling reduction

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ABSTRACT

In this work, six identical laboratory SBRs treating simulated wastewater were operated in parallel studying the effect of three food-to-microorganisms ratio (F/M ratio; 0.20, 0.35 and 0.50 kg COD·kg $MLSS^{-1}·d^{-1}$), two hydraulic retention times (HRT; 24 and 16 h) and two values of number of cycles per day (3 and 6). Influence of these operational parameters on the SMPs production and reactor performance, were studied. Results indicated that the highest F/M ratio, HRT and cycles/day produced 72.7% more of SMP. In a second experimental series, biological process yielding the maximal and the minimal SMPs production were replicated and both mixed liquors (ML) and treated effluents were ultrafiltrated. The flux decay in the conditions of minimum and maximum SMPs production were 52% and 72%, when the SBRs effluents were ultrafiltrated while no significant differences in the ultrafiltration of ML were found. In terms of permeability recovery, this was lower for the case of the ML (73% and 49% of initial permeability recovered for effluent and ML ultrafiltration, respectively).

1. Introduction

The ultrafiltration (UF) membrane technology is used as a tertiary treatment in order to produce high effluent quality. This technique is used to treat the secondary effluents after biological treatment to reduce the total solids, biological or chemical oxygen demand (Acero et al., 2010; Norton-Brandão et al., 2013; Tchobanoglous et al., 1998) and other pollutants like pharmaceutical substances (Garcia-Ivars et al., 2017; Secondes et al., 2014). On the other side, UF is also used in membrane bioreactors (MBR) in order to separate the treated wastewater from the mixed liquor. These processes produce water that can be reuse in the agriculture or for other purposes like urban and industrial uses, aquifer recharge, etc. contributing to environmental sustainability.

However, one of the disadvantages of the UF that avoid a wider implementation in the wastewater treatment plants (WWTP) is membrane fouling. The main fouling mechanisms in the UF membranes are the pore blocking (due to small colloids deposition) and cake layer formation (due to build-up of particles on the membrane surface). Additionally, solutes adsorption onto the membrane increases the fouling process (Boerlage et al., 2002; Mousa and Al-Hitmi, 2007). On the other hand, in recent years it has been reported that the filtration resistance caused by chemical potential mechanism is the cause of the primary fouling of the membrane. This fouling mechanism, based on the Flory-Huggins theory, was proposed by Chen et al. (2016). It was also confirmed using alginate solution to mimic the polysaccharides of the extracellular polymeric substances in MBRs (Zhang et al., 2018). These authors also highlighted the important role of the calcium ions on the membrane fouling.

In the secondary effluent the main foulant substances are the soluble organic matter. Many researchers report that SMPs are the predominant components of the soluble organic matter (Gkotsis et al., 2015; Schiener et al., 1994). The main SMPs components are carbohydrates, proteins and humic substances (Barker and Stuckey, 1999). They are generated by three mechanisms: biomass growth, substrate metabolism and biomass decay and cell lysis (Laspidou and Rittmann, 2002). Thus, the mechanisms of microbial survival, under different substrates or operational conditions, influences on the SMPs amounts generated during the biological treatment (Wang and Zhang, 2010).

Concerning to the MBRs, there are more substances than in the UF process of secondary effluents that contribute to the membrane fouling like sludge fractions as suspended solids, colloids and dissolved solutes (Defrance et al., 2000; Fan et al., 2006) including the extracellular polymeric substances (EPS), which can be accumulated on the cellular walls of the microorganisms or dissolved in the reactor as SMPs (Hodgson et al., 1993; Jefferson et al., 2004).

The role of SMPs in membrane fouling is unclear. There are researchers that reported a positive correlation between SMPs

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productions and membrane fouling (Lee et al., 2004; Rosenberger et al., 2006), while others did not observe this relationship (Drews et al., 2008). On the other hand, there are not consensuses into researchers community about optimal operational conditions like F/M ratio (Ghangrekar et al., 2005; Prashanth et al., 2006).

In this work six SBRs worked under different operational conditions. Three different F/M ratio (0.20, 0.35 and 0.50 kg DQO·kg SSLM^{-1}·d^{-1}), two HRT (24 h and 16 h) and two operational cycles per day (3 and 6 cycles/day) were tested. All of these values are typical in SBRs operation. The first objective was to study the relationship between these conditions and the biological reactors performance and their SMPs productions. This information allowed obtaining the operational conditions that minimized and maximized the SMPs productions. The second objective of this work was the study of the UF membrane fouling working under the extreme operational conditions obtained in the first experimental step. In this way, it was evaluated the membrane fouling due to SMPs and due to sludge flocs. For this purpose, it was assessed by filtrating both ML (operation similar a MBR system) and effluent SBR (simulating a tertiary treatment of secondary effluent).

2. Materials and methods

2.1. Biological reactors

2.1.1. First experimental step: relationship between operational conditions, SBRs performance and SMPs production

In this part, the objective was to assess the relationship between the SMPs concentrations produced during the municipal wastewater biological treatment and the operational conditions of the SBRs. For this purpose six identical SBRs were operated with synthetic wastewater (SWW), which simulates municipal wastewater, under operational conditions reported in Table 1. SBRs start-up was performed with sludge taken from a MWWTP located in Valencia (Spain).

The main components of each reactor consisted of a mechanical stirrer, two peristaltic pumps and a compressor that supplied air into the SBR through two air diffusers located on the reactor bottom. The system "On and Off" used in these equipments consisted of time programmers connected to the electrical network. Characteristics of each cycle are presented in Table 1.

The SBRs (named SBR-n, where n values were between 1 and 6) were operated during 31 days. The reaction volumes of all SBRs were 6 L. As it can be shown in Table 1 different feed/draw volumes and COD concentrations of feed solution were used in order to achieve the required HRT and cycles/day in the SBRs operation. In all the SBRs a concentration of 2500 mg L^{-1} of mixed liquor suspended solids (MLSS) was maintained. Periodically sludge withdrawals were carried out to maintain this value.

These configurations allowed studying the influence of F/M ratio comparing the performances and the SMPs concentrations of SBR-1, SBR-2 and SBR-3. Additionally, two different HRT and two operating cycles/day were evaluated, comparing SBR-1, SBR-4, SBR-5 and SBR-6. Finally, the operational conditions that minimized and maximized the SMPs productions were obtained.

Table 1
Operational SBRs conditions.

Reactor	Operating parameters			
	F/M (kg COD·kg MLSS^{-1}·d^{-1})	HRT (h)	Cycles/day	$V_{feed/draw}$ (L)
SBR-1	0.20	24	3	2
SBR-2	0.35			
SBR-3	0.50			
SBR-4	0.20	24	6	1
SBR-5	0.20	16	6	1.5
SBR-6	0.20	16	3	3

	3 Cycles/day	6 Cycles/day
Cycle characteristics		
Filling + Aerobic reaction	6 h	3 h
Sedimentation	90 min	45 min
Draw	25 min	13 min
Idle	5 min	2 min

2.1.2. Second experimental step: evaluation of UF membrane fouling

In this part, the objective was to study the effect of SMPs concentration on the UF membrane fouling. For this purpose effluent and mixed liquor (ML) of two different SBRs were used as feeds for the UF membrane. These SBRs worked under the operational conditions obtained in the first experiment, which minimized and maximized the SMPs productions. When effluent and ML were UF the membrane operated like a tertiary treatment or a MBR system, respectively.

In this way, two additional SBRs were operated during 25 days according to mentioned objective. The UF experiments were carried out twice in each reactor (in the second and third week, named UF1 and UF2). In order to be valid the replication tests, it was previously proved that SMPs concentration was the same in both feeds. Each experiment was performed in two days: in the first one effluent was collected to perform the UF experiments and in the second day ML was tested. This ML was returned to SBR after the experiment to maintain the efficiency of the biological treatment until to perform the second test.

The UF module, which allowed locating a flat sheet membrane, was a Rayflow from Orelis (France). Filtration was done in cross-flow mode. UP150 P membrane from Microdyn Nadir (Germany) was used to carry out the experiments. The active layer material of the membrane was polyethersulfone with a molecular weight cut-off of 150 kDa. Its flow rate according to data supplier is ≥ 285 L m^{-2}·h^{-1} (with clean water, 2 bar, 20 °C and cross-flow operation). The effective area was 100 cm^2.

In all the experiments the cross-flow velocity was 2 m s^{-1} (feed flow rate = 300 L h^{-1}) and temperature was 25 °C. The steps followed in each experiment were: membrane compaction at transmembrane pressure (TMP) of 3 bars during 2 h, initial membrane permeability (with deionised water and three TMP; 1, 2 and 3 bar), membrane fouling (with secondary effluent or ML and TMP = 1 bar), membrane rinsing (30 min with deionised water without applying TMP) and final permeability under the same conditions as the initial one. During the membrane fouling, the retentate and the permeate streams were recycled to the feed tank to work at constant concentration and membrane flux was measured periodically. All the fouling tests were performed until stationary permeate flux value was reached (around 105 min).

2.2. Synthetic wastewater

A synthetic wastewater (SWW) with peptone, meat extract and K_2HPO_4 (supplied by Panreac) diluted in tap water (mimicking municipal wastewater) was prepared for feeding the SBRs. Peptone and meat extract concentrations (in equal amount) were calculated to achieve the COD (Eq. (1)) to maintain the required F/M ratio.

$$F/\,M = \frac{COD \bullet V_{feed|draw}}{V_R \bullet MLSS} \tag{1}$$

where V_R = 6 L, MLSS = 2500 mg L^{-1}, F/M was the value in Table 1 specified for each reactor and $V_{feed|draw}$ was calculated according HRT and cycles/day also specified in Table 1.

K_2HPO_4 concentration was calculated in each case to have a relationship between COD and phosphorous (COD:P) of 100:1. Table 2 shows the four different compositions of synthetic wastewaters used.