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Influence of sludge retention time at constant food to microorganisms ratio on membrane bioreactor performances under stable and unstable state conditions

Maud Villain *, Benoît Marrot

Aix-Marseille Université, CNRS, M2P2 UMR 7340, 13545 Aix en Provence, France

HIGHLIGHTS

- ▶ Effect of SRT (20 and 50 d) at constant F/M ratio on MBR performances was assessed.
- ▶ Autotrophs and heterotrophs showed higher exogenous activities at SRT of 50 d.
- ▶ Higher soluble microbial products (SMP) release was observed at SRT of 50 d.
- ▶ SMP were composed at 49% of polysaccharides at SRT of 50 d.

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ABSTRACT

Food to microorganisms ratio (F/M) and sludge retention time (SRT) are known to affect in different ways biomass growth, bioactivities and foulants characteristics. Thus the aim of this study was to dissociate the effects of SRT from those of F/M ratio on lab-scale membrane bioreactors performances during stable and unstable state. Two acclimations were stabilized at a SRT of either 20 or 50 d with a constant F/M ratio of 0.2 $kg_{COD}\ kg_{MLVSS}^{-1}\ d^{-1}$. During stable state, a higher N–NH_4^+ removal rate (78%) was obtained at SRT of 50 d as an easier autotroph development was observed. Soluble microbial products (SMPs) release was double at 50 d with a majority of polysaccharides (49% of total SMP). The unstable conditions consisted in F/M ratio changes and operation without air and nutrient. Autotrophs were highly affected by the tested disturbances and SMP retention on membrane surface exhibited consistent changes during the performed stresses.

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1. Introduction

The growth rate of membrane bioreactor (MBR) is higher (almost 10.9% per annum) compared to other advanced wastewater treatment technologies and more than any other membrane technologies (Drews, 2010). The MBR system has drawn a lot of attention because of the numerous advantages over the conventional wastewater treatment plant (WWTP), such as a smaller footprint, process flexibility and complete retention of the biomass. As sludge retention time (SRT) affects in the same time biomass characteristics (*e.g.* sludge structure and biomass activity) (Han et al., 2005), membrane biofouling (Grelier et al., 2006) and outlet effluent quality, SRT is considered as one of the target operating factors to control (Meng et al., 2009). Thus, in the past ten years the rate of publications on the SRT in MBR and its influence on bioactivities of microorganisms (Han et al., 2005; Huang et al., 2001), sludge structure (Laera et al., 2007), dissolved organic matter as well as ammonium removal efficiencies (Hocaoglu et al., 2011) and membrane fouling (Van den Broeck et al., 2012) has increased continuously.

In aerobic bioprocesses there are heterotrophic and autotrophic bacteria which prevail. Because the oxidation of inorganic material does not yield as much energy as the oxidation of organic carbon sources, autotrophs have a much slower growth rate than heterotrophs. Thus, it is preferable to work at a high sludge rate to achieve a high ammonium removal rate.

As far as membrane biofouling is concerned, the extracellular polymeric substances (EPS) in either bound or soluble form are currently considered as the predominant cause of fouling in MBRs (Le-Clech et al., 2006; Meng et al., 2009). Bound EPS consist of proteins, polysaccharides and humic substances, which are the main components, and lipids, nucleic and uronic acids in fewer proportions (Wingender et al., 1999). They are located at the cell surface or outside. Soluble microbial products (SMPs) can be defined as the pool of organic compounds that are released into the solution from

* Corresponding author. Tel.: +33 4 42 90 85 03; fax: +33 4 42 90 85 15.
E-mail address: maud.villain@etu.univ-cezanne.fr (M. Villain).

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substrate metabolism (usually with biomass growth) and biomass decay (Barker and Stuckey, 1999). Laspidou and Rittmann (2002) proposed a unified theory to define the complex interrelations between bound EPS and SMP. They subdivided SMP into two categories: substrate-associated products (UAP), which are produced directly during substrate metabolism and biomass-associated products (BAP) which are formed from biomass, presumably as part of decay. Cells use electrons from the electron-donor substrate to build active biomass and they produce bound EPS and UAP in the process. Part of the bound EPS can be hydrolyzed to BAP. Some SMP can be used by active biomass as recycled electron donors; and some can be adsorbed by the biomass flocs and then become bound EPS. No consensus has been found about the influence of SRT on membrane biofouling. Many studies found that bound EPS content decreased and consequently membrane fouling whereas SRT increased from 10 to 60 d (Ahmed et al., 2007; Massé et al., 2006). However, a too long SRT (above 60 d) was also found and resulted in excessive membrane fouling. Lee et al. (2003) noticed that the overall fouling resistance increased when SRT increased from 20 to 40 and 60 d. These reported results indicate that in order to control bound EPS concentration and thus membrane fouling with high removal efficiencies, the optimum SRT of MBRs should be controlled between 20 and 50 d (Meng et al., 2009). Several studies however reported that bound EPS had little correlation with membrane fouling. Instead, SMP have a great impact on the membrane fouling as due to the membrane rejection, SMP are more easily accumulated in MBRs (Drews et al., 2008; Jang et al., 2007). In most of the studies SMP concentration decreased together with increasing SRT (Lee et al., 2003; Liang et al., 2007). Therefore, SRT does not need to be too long.

However in a large part of these researches, because biomass requires at least 2 or 3 months to be stabilized in MBR process, only one acclimation is realized (Huang et al., 2001; Massé et al., 2006; Hocaoglu et al., 2011). SRT is progressively increased with a reduction of sludge extraction. Thus a biomass concentration augmentation is observed. Accordingly as feedwater characteristics are let constant, food to microorganisms (F/M) ratio progressively decreases with increasing SRT and microbial bioactivities reduce still maintaining high removal rates of COD and ammonium.

Thus, as F/M ratio is known to directly affect biomass growth, biomass activity (Johir et al., 2011) and EPS production (Laspidou and Rittmann, 2002), it is clearly useful to perform a study at different SRTs with a constant F/M ratio to dissociate both effects of SRT and F/M ratio on foulants characteristics, bioactivities and removal rates.

Furthermore, in wastewater treatment processes it is not rare to operate in unstable conditions due to diurnal, seasonal and irregular variations in substrate strength and flow rate. The unstable operational condition often causes serious deterioration of sludge flocs, microbial activities and treatment performance (Sponza, 2003). The EPS abundance of the sludge can be sensitive to the environmental variations, such as changes in organic loading rate, aerobic or anaerobic conditions (Sheng et al., 2010). In case of stress conditions, EPS release was reported to directly affect the quality of outlet effluent (Jang et al., 2007). However, the links between autotrophic and heterotrophic activities with EPS production and removal rates under unstable conditions at different SRTs have not been well characterized. The effects of EPS released on membrane rejection at different SRTs during unstable MBR operation also need to be investigated.

The present work was first carried out to dissociate the effects of SRT on biomass activity (*e.g.* autotrophs and heterotrophs), removal rates, SMP release and membrane biofouling from the effects of F/M ratio on the same parameters. Therefore, two entire acclimations in MBR were realized and SRT was stabilized directly at either 20 or 50 d with a constant F/M ratio. The biological activity was followed from respirometry tests focusing on the distinction between autotrophs and heterotrophs. The objectives of the second part of this study were to determine the effects of three different operational stresses (F/M ratio increase, F/M ratio decrease, 24 h without air and nutrient) on the evolution of biomass activities, treatment performances, SMP release and their membrane rejection for both biomass acclimated at SRT of 20 and 50 d.

2. Methods

2.1. The MBR setup

The external MBR (Polymem, France) was composed of a 18 L bioreactor equipped with a cooling coil to maintain biomass at approximately 25 °C (Fig. 1). The membrane system used was a tubular ceramic membrane (ultrafiltration, Novasep-Orelis, France) made with ZrO_2–TiO_2 was characterized by a 150 kDa cut off and a 0.02 m^2 filtration area. Crossflow filtration was operated with a centrifugal pump which recycled sludge back to the membrane. The influent was provided to the bioreactor with a feed pump connected to a level regulator. The membranes used for the whole experiments had the same initial water permeability of 110 L h^{-1} m^{-2} bar^{-1}.

During both acclimations in the external MBR, the mixed liquor volatile suspended solid (MLVSS) was stabilized around 8 g L^{-1} and the crossflow velocity was held constant at 4 m s^{-1}, based on the results of a previous study performed in the same type of bioreactor to limit membrane biofouling (Clouzot et al., 2011). The constant flow rate operating mode was used. The permeate flux was 0.75 L h^{-1} which fixed a hydraulic retention time (HRT) of 24 h. The increase in transmembrane pressure (TMP) was monitored with manometer sets at the inlet and outlet of the membrane module.

2.2. Biomass acclimations to the MBR process

Both acclimations were realized with AS sampled from the same municipal wastewater treatment plant (Aix en Provence, France, 175,000 inhabitant equivalent, 35,000 m^3 d^{-1}, organic load 0.12 kg_{BOD5} $kg_{MLVSS}{}^{-1}$ d^{-1}). The initial Mixed Liquor Suspended Solids (MLSS) concentration ranged from 3 to 4 g L^{-1} and the amount of MLVSS varied from 75% to 80%. Samples were taken from the recirculating loop between the aerated tanks and the secondary clarifiers and then transported to the laboratory with no aeration (30 min). The AS was concentrated around 8 g_{MLSS} L^{-1} in the MBR. A balanced synthetic sewage influent (C/N/P ratio = 100/10/2) was prepared with mass ratios of 2.1 $C_6H_{12}O_6$, 1.0 $(NH_4)_2SO_4$, 0.2 KH_2PO_4, 0.4 $NaHCO_3$, 0.1 $MgSO_4$ and 0.02 $CaCl_2$. The food-to-mass ratio (F/M) was maintained around 0.2 kg_{COD} $kg_{MLVSS}{}^{-1}$ d^{-1} with adjustment of the nutrient concentrations in the feed to the MLVSS contents. Oxygenation cycles of 2 h with air and 1 h without air were programmed to allow nitrification and denitrification reactions. The pH was maintained constant at 7 by an automatic regulator with $NaHCO_3$ solution (60 g L^{-1}).

The SRT was fixed at 20 days in the first acclimation (Run I) and at 50 days in the second one (Run II) due to a control of the amount of waste sludge. The amount of waste sludge is inversely proportional to the desired sludge age (Eq. (1)):

$$V_{waste} = V_R/SRT \tag{1}$$

With V_{waste}: the volume of waste sludge per waste event (L), V_R: the total volume of MBR (L), SRT: the desired sludge retention time (d).

AS was wasted every day from the drain of the bioreactor. In order to reduce the effect of discontinuous sludge wasting on sludge

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