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Biomass characterization by dielectric monitoring of viability and oxygen uptake rate measurements in a novel membrane bioreactor

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HIGHLIGHTS

- The impact of OLR on viability and activity of activated sludge sometimes is different.
- SMP release in the bioreactor depends on the viability of activated sludge.
- Novel method based on capacitance was introduced for viability of activated sludge.
- Determination of activated sludge quality is important for efficient operation of MBR.

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ABSTRACT

The application of permittivity and oxygen uptake rate (OUR) as biological process control parameters in a wastewater treatment system was evaluated. Experiments were carried out in a novel airlift oxidation ditch membrane bioreactor under different organic loading rates (OLR). Permittivity as representative of activated sludge viability was measured by a capacitive on-line sensor. OUR was also measured as a representative for respirometric activity. Results showed that the biomass concentration increases with OLR and all biomass related measurements and simulators such as MLSS, permittivity, OUR, ASM1 and ASM3 almost follow the same increasing trends. The viability of biomass decreased when the OLR was reduced from 5 to 4 kg COD m^{-3} d^{-1}. During decreasing of OLR, biomass related parameters generally decreased but not in a similar manner. Also, protein concentration in the system during OLR decreasing changed inversely with the activated sludge viability.

1. Introduction

The membrane bioreactor (MBR) has been widely used to treat both municipal and industrial wastewater (Judd, 2008). The activated sludge present in the MBR is a mixed culture with a great variety of microbial species which are highly specialized for the removal of an individual class of pollutants from the wastewater (Munz et al., 2008; Fenu et al., 2010; Laera et al., 2011). Control of the MBR process is a rather complicated task since the biological performance can be affected by wastewater quality, membrane selectivity and operating conditions such as solids retention time (SRT), hydraulic retention time (HRT), food-to-microorganism (F/M) ratio, and membrane permeate flux (Sofia et al., 2004; Hagman et al., 2008). The performance of treatment process depends on the microbial quantity and quality. Therefore, application of an appropriate method for monitoring these microbial key parameters is crucial to maintain effective treatment of wastewater (Lim et al., 2002; Chu et al., 2009; Clouzot et al., 2011).

Organic loading rate (OLR) is among the wastewater parameters that alter the microbial metabolism and activity of activated sludge (Chen et al., 1980). It can also have adverse effects on the global COD removal efficiency (Shin et al., 2011) due to release of large amounts of soluble microbial products (SMP) (Feng et al., 2008; Zhou et al., 2009). SMPs are defined as the pool of organic compounds that are released into the solution from heterotrophic substrate metabolism and biomass death (Laspidou and Rittmann, 2002). SMP may inhibit the nitrification process and may affect the flocculation, viscosity and other sludge physical characters (Ichihashi et al., 2006; Zhou et al., 2009; Azami et al., 2012). In aerobic biological treatment, the secretion of SMP depends on the operating parameters such as; sludge retention time (Liang et al., 2007), hydraulic retention time (Langenhoff et al., 2000) and

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organic loading rate (Jang et al., 2007). High OLR and COD usually result in significant accumulation of SMP that is the source of some problems in treatment plants. However, the majority of researches have been conducted at low and medium OLR and the effect on system's viability has not been considered. There is a lack of information regarding changes in activated sludge during transient organic loading rates.

As mentioned, the efficiency of a biological wastewater treatment process depends on the active biomass that can be affected by the influent nature and composition. The use of on-line sensors providing information on the key process parameters is helpful for effective wastewater treatment. On-line measurement of some parameters such as; pH, DO and temperature is conventional but application of on-line sensors which are able to determine the biomass activity and viability could be more important. Data collected from such sensors would also allow the fine-tuning of mathematical models and application of appropriate process control strategies (Guwy et al., 1998). The biomass in activated sludge is normally expressed as concentration of mixed liquor suspended solids (MLSS) or mixed liquor volatile suspended solids (MLVSS). Since they contain, besides active microorganisms, all other particulate matters and cell debris, such parameters cannot be adequate representative for viable and active biomass. Some authors (Jørgensen et al., 1992; Henze et al., 1995; Garcia-Ochoa et al., 2010; Rodríguez et al., 2011; Torrents et al., 2012) proposed a simple method to evaluate the biomass activity through the respirometric activity measurement by calculating oxygen uptake rate (OUR). Others tried to obtain biomass related information through mass balance and simulations based on the activated sludge models (Lobos et al., 2009) or by applying fluorescence in situ hybridization (FISH) technique (Manser et al., 2005). There is, therefore, a major requirement for accurate measurement and control of the viable and active biomass within bioreactor, both at laboratory and industrial scales. Dielectric permittivity is another technique of biomass measurement that has also been applied for monitoring the changes in viability and physiological states of several microorganisms (Sarrafzadeh et al., 2005; Tibayrenc et al., 2011). This technique is based on the ability of biological cells to accumulate charges when exposed to an electrical field. The dead cells, whose plasma membrane is permeabilized, cell debris and non biological particles are not polarizable and therefore not detected. This technique was used in this work to evaluate its usefulness for monitoring biomass of a lab scale hybrid MBR in comparison with other biomass measurements. Experiments were carried out in a new bioreactor presented in our previous work (Pajoum shariati et al., 2013) and called airlift oxidation ditch membrane bioreactor (AOXMBR). The impact of OLR on the performance of this bioreactor has been studied and a special attention has given to the influence of organic loading changes on microbial viability and activity at high cell density.

2. Methods

2.1. Experimental setup and operating conditions

The setup shown in Fig. 1 is a 65 L membrane bioreactor with the shape of an oxidation ditch. It is equipped with a submerged flat sheet membrane module (Microdyn-Nadir GmbH, Germany) and air injection systems placed just below the membrane module between two baffles acting as airlift. The aeration in the designed system not only supplies O_2 for activated sludge but also provides the driving forces for the complete mixing and circulation of the suspension inside the bioreactors and membrane scoring. The pressure gauge was installed in order to monitor the variation of the trans-membrane pressure between the membrane and the effluent peristaltic pump. A peristaltic pump was also used to provide the synthetic wastewater prepared with different COD concentrations.

The experiments lasted 70 d during which the organic loading rates were changed from 0 to 5 kg COD m^{-3} d^{-1} in a constant HRT of 12 h (Table 1). The influent was a synthetic sewage mainly composed of glucose, NH_4NO_3 and $(NH_4)_2HPO_4$ in a ratio of COD/N/P (100/5/1). The experiments were carried out at ambient temperature with a pH between 7 and 7.5. Table 1 summarizes the operational conditions.

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). Supernatant and permeate were analysed for polysaccharide and protein, which are regarded as important parts of SMP materials. The protein content was determined according to the method of Lowry et al. (1951). Polysaccharides were determined according to the method of Dubois et al. (1956). To measure the respirometric activity of cells, the activated sludge was transferred into water-sealed bottles (300 mL) where the DO was monitored using a DO sensor (WTW 340i, Germany) allowing oxygen uptake rate (OUR) calculations. The specific oxygen uptake rate (SOUR) was obtained by dividing OUR by the Mixed Liquor Volatile Suspended Solids (MLVSS) concentration.

Absolute permittivity increment and conductivity, which are expressed in pico-Farads/cm (pF/cm) and milli-Simens/cm (mS/

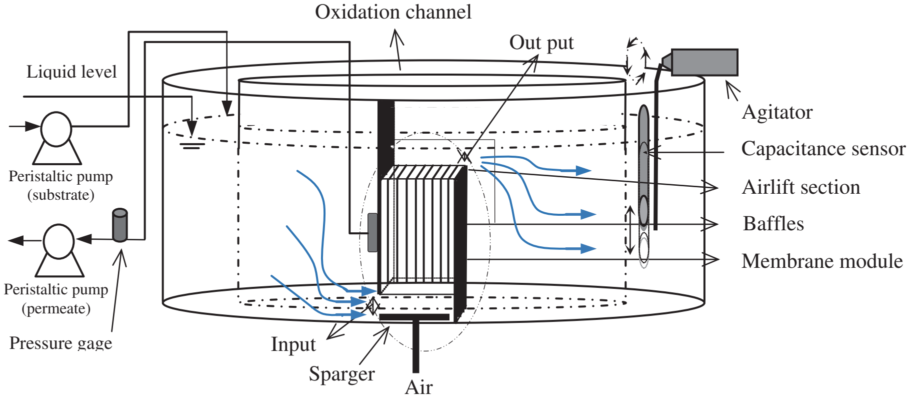

Fig. 1. Schematic diagram of the airlift oxidation ditch membrane bioreactor system (AOXMBR). Aeration in the airlift section provides the circulation force in oxidation ditch too.