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Kinetic characterization of acetate utilization and response of microbial population in super fast membrane bioreactor

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ABSTRACT

The study investigated the functional relationships between changes in microbial community induced by different sludge ages (SRT) selected for super fast MBR operation on variable process kinetics, fate of soluble microbial products (SMPs) and system performance. Acetate, a simple and separately identifiable compound, was selected as the sole organic carbon source. MBR operation was monitored at steady-state at extremely low SRT levels of 2.0, 1.0 and 0.5 d and a hydraulic retention time of 1.0 h. Batch experiments were conducted for kinetic evaluation of MBR performance by model evaluation of oxygen uptake rate, polyhydroxybutyric acid and COD profiles. Bacterial DGGE profiles indicated that SRT exerted shifts in the composition of microbial community. Model evaluation of experimental data also confirmed molecular analyses, indicating variable growth kinetics for utilization of acetate and identified high and variable endogenous respiration as a function of SRT. Changes in the microbial community and process kinetics did not affect MBR performance, providing complete depletion of available acetate. Effluent COD remained below 17 mg/L and entirely composed of SMPs. Particle size analysis revealed a bimodal distribution of the wide spectrum of SMPs above 13 nm and below 2 nm. Effective filtration size of the membrane was reduced to 8 nm due to cake filtration effect. The retained fraction of SMPs was in the range of 1–2 mg/L, but accumulated in the reactor volume, same way as biomass. Therefore, the real merit of super fast MBR was the very low levels of SMP generation (14–18 mg COD/L), rather than the effective capture of accumulated COD due to cake filtration.

1. Introduction

Super fast membrane bioreactor (MBR), involving operation with a sludge age equal to or below 2.0 d [1], includes all the attributes as a novel process scheme that would be qualified for reshaping and replacing conventional biological treatment, relying either on gravity settling or on membrane separation. When properly understood and implemented, it may be designed to remove soluble COD to the extent that is required by effluent limitations. At the same time, it may provide energy recovery utilizing the enhanced/optimized energy potential of the biosolids incorporating generated active biomass and particulate organic matter of influent origin adsorbed onto microbial flocs. It should be noted that the COD content of domestic wastewater mostly consists of complex, particulate and slowly hydrolysable fractions in nature [2–5]. Partial treatment by super fast MBR would also achieve a drastic reduction in energy requirement for aeration, while preserving the energy of the remaining/untreated COD fraction.

In the previous stage of the study, the performance limits of the super fast MBR were tested on a substrate mixture representing the soluble readily biodegradable COD fraction of domestic wastewater [1]. At extremely short sludge ages in the range of 0.5–2.0 d, the super fast MBR system remained stable and secured complete removal of 200 mg COD/L of the available substrate in the influent, under different operating conditions. Sludge age, even in the narrow range, was observed to induce significant changes in the microbial culture, based on molecular studies. Major differences in the soluble residual COD between permeate and reactor volume suggested entrapment of microbial products with larger particle sizes than the membrane [6,7]. This work was quite different from previous studies on high rate MBRs mostly limited with accounts for effective system operation [8–10]. While the reported results

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were significant, it was felt that additional information would still be essential for the accurate understanding of the behavior and performance of super fast MBR to better establish it as a novel and energy efficient biological wastewater treatment scheme.

In this context, the objective of this part of the study was primarily defined to answer the following questions: (i) Would a similar shift in the microbial composition be expected for a simple substrate such as acetate, available as the sole organic carbon source? (ii) Would the microbial shift significantly affect the kinetics of different biochemical processes - i.e. microbial growth, substrate storage, endogenous respiration – observed as part of substrate utilization? (iii) Would variable kinetics, if applicable, exert any negative effect on system stability and performance? (iv) Would the choice of a separately measurable substrate provide a better insight on the generation and magnitude of soluble microbial products (SMPs)? (v) Would the functional relationship between effective filtration size, system performance and the fate of SMPs be better understood by means of particle size distribution (PSD) analysis? It is expected that acceptable scientific explanations to these issues through this study will improve the basis for a better interpretation and manipulation of this technology for its adaptation into practice.

Two factors play an equally important role for the sustainable performance of MBRs: (i) biodegradation potential of the microbial culture, and (ii) filtration capacity of the membrane. While the microbial activity for substrate utilization can always be controlled, effluent filtration is often impaired due to fouling problems [11–14], mostly connected to SMPs. Despite extensive research effort on the subject, the nature and adverse impact of SMPs have not been fully elucidated [15–17]. Also, the magnitude of SMPs could not be correctly estimated, mainly because the complex nature of organics in wastewaters characterized by the same overall parameters such as COD, often mask SMPs and they are likely to include the same compounds as carbohydrates also identified as soluble residual COD [18–20]. The selection of acetate was of vital importance in this respect, as parallel soluble COD and acetate measurements provided an accurate account of substrate biodegradation and the level of residual COD generation/ accumulation along the course of related biochemical reactions.

Particle size distribution (PSD) analysis of residual COD was also utilized for evaluating the fate of SMPs and for establishing the functional relationship between effluent quality, effective filtration size and SMP accumulation in the reactor. Size distribution introduces another dimension to a single measurement for characterizing SMPs, especially when it needs to be evaluated in comparison with the effective filtration size of the membrane. Conventional characterization usually gives a single COD value and this is obviously not sufficient to define different organic matter for appropriate management. In this respect, PSD analysis becomes a useful evaluation instrument for identifying different COD fractions. PSD has long been recognized as a valuable experimental asset for characterization and it is implemented for a wide range of different wastewaters [21–23]. Current research efforts also focus on particle size information for the conceptual understanding of biodegradation [24,25].

2. Materials and methods

2.1. Experimental set-up and operation of MBR system

The study was carried out by operating a lab-scale side-stream MBR with an aerobic bioreactor volume of 3 L coupled with Inge Multibore® 1.5 (Inge GmbH, Germany) membrane module, with an inside diameter of 1.5 mm, an outer diameter of 6.0 mm and a length of 35 cm (Fig. 1) incorporating polyethersulfone (PESM) membrane fiber with a nominal pore size of 20 nm and total membrane surface area of 0.1 m^2. It is true that membranes with higher pore size of around 0.2 μm would retain microorganisms. However, selection of appropriate pore size for membrane should also consider fouling and clogging mechanisms along with physical retention. For systems operated at low sludge ages likely to sustain dispersed growth along with microbial flocs, microorganisms tend to adhere to the pores and cause severe reduction in the projected flux rates. The same mechanism is not often observed with membranes with lower pore sizes, such as the one used in the study, where the retained biomass layer is more easily removed through backwashing. In fact, the selection of the appropriate type of membrane for this study was made on the basis of a set of preliminary experiments testing materials with different pores sizes and the selected membrane with a nominal pore size of 20 nm was found more suitable for the envisaged MBR operation.

The membranes were operated at max. flux of 30 L/m^2 h and the trans-membrane pressure (TMP) was kept below 2 bar. Data acquisition and control of the system were maintained with a pH/ temperature probe and a dissolved oxygen probe connected to a multimeter (Hach-LANGE sc1000, Germany) and three pressure sensors at the inlet, outlet and permeate side of the membrane ultimately connected to a PC. The operation routine consisted of 1-min backwash every 19-min filtration and cleaning once every day by employing 15 min contact with a pH = 12 NaOH solution followed by 1 cycle of normal operation and 15 min contact with a pH = 2.5 H_2SO_4 solution. Each experimental run was initiated with

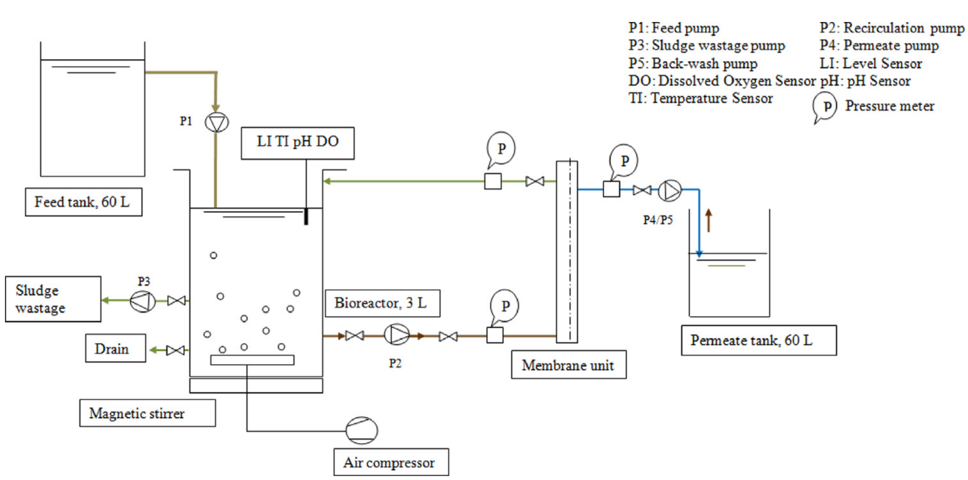

Fig. 1. Process flow scheme of the lab-scale MBR.