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A systematic study on the effect of substrate acidification degree and acidogenic biomass on sludge filterability

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ABSTRACT

The influence of substrate acidification on sludge filtration characteristics was systematically investigated by using short term filtration tests. Four reactors were operated with raw and acidified whey permeate in order to evaluate the effect of acidogens on sludge filterability. The results showed that feeding non-acidified substrate promoted the growth of acidogens which in return decreased the median particle size of the sludge and adversely influenced specific resistance to filtration (SRF). In addition to the presence of acidogens, the food to mass (F:M) ratio was found as an important operation parameter on sludge filterability. Various filterability indicators, such as capillary suction time (CST), SRF and supernatant filterability, tended to became worse at increased F:M ratios. The decreased filterability at high F:M ratio was attributed to the accumulation of soluble microbial products (SMP) in the reactors. Interestingly, impact of acidogens on short term critical flux tests was not significant, but this may be a consequence of the experimental set-up.

1. Introduction

The anaerobic digestion process can be regarded as an intertwined collaboration of different microorganisms with specific functionalities. So far, high rate anaerobic reactors that rely on granulation for biomass retention have been successfully applied for the treatment of various types of wastewaters (van Lier, 2008). Short hydraulic retention times applied in these reactors exerts a selection mechanism which promotes microbial aggregation, eventually resulting in anaerobic sludge granules, and the wash out of microorganisms incapable of forming these granules. However, some wastewater types are known as notorious for treatment in granular sludge bed reactors due to the problems with granule formation and biomass retention (Dereli et al., 2012). Membranes, as a physical barrier for particulate matter, present an ultimate solution for biomass retention problems in anaerobic

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reactors. Thus, anaerobic membrane bioreactors (AnMBRs) have received an ever growing interest, especially for the treatment of wastewaters with extreme characteristics. AnMBRs ensure the retention of slow growing anaerobic bacteria inside the reactor and provide excellent effluent quality free of suspended solids. However, membrane fouling, indicated by the reduction in permeate flux or increase in filtration resistance, due to e.g. clogging of the membrane pores, limits the wide spread application of AnMBRs (Liao et al., 2006).

Membrane fouling is a very complex process, which depends on multiple factors such as reactor and membrane operating conditions, substrate and sludge characteristics and membrane properties. Although extensive research has been carried out on these parameters, the influence of substrate characteristics has generally been overlooked and rarely investigated (Gao et al., 2013). The substrate characteristics can indirectly influence the biomass filterability, organic and inorganic fouling. Substrate composition not only alters the dominant microorganisms in the reactors, but also affects the concentration and composition of extracellular polymeric substances (EPS) and soluble microbial products (SMP), which were associated to membrane fouling (Le-Clech et al., 2006). McAdam et al. (2007) showed that the substrate composition had an effect on floc mechanical strength and thus, influenced the sludge filterability in MBRs fed with acetate and ethanol as the sole carbon source. Gao et al. (2013) reported significantly different filtration resistances in MBRs treating different types of industrial wastewater under aerobic and anaerobic operating conditions. They concluded that the colloidal fraction and particle size distribution (PSD) of the incoming wastewater can partially influence the PSD of bulk and cake sludge in MBR systems, thus inevitably affecting filtration performance. Arabi and Nakhla (2008) systematically investigated the effect of the protein to carbohydrate ratio in the feed wastewater on the filtration performance of MBRs. High protein content in the feed stimulated the excretion of both the proteineous and carbohydrate type SMP. They observed an increased rate of fouling and attributed this to SMP accumulation and occurrence of small-sized flocs at higher protein to carbohydrate ratio in the feed.

Only a few studies reported about the influence of substrate characteristics on the filtration performance and fouling in AnMBRs. In an attempt to investigate the effect of wastewater acidification degree on sludge filterability, Jeison and van Lier (2007) operated two identical AnMBRs fed with a volatile fatty acids mixture (VFA) and a VFA/glucose mixture. They observed a higher degree of fouling in VFA/glucose AnMBR and attributed this to extensive growth of acidogenic biomass as individual cells on glucose. Therefore, they asserted that the acidification degree of substrate can strongly influence the physical properties of the sludge and determine the applicable flux and fouling rate. Jeison et al. (2009) further confirmed that the single cells present in the supernatant of an AnMBR treating non-acidified substrate were mainly acidogenic biomass. Thus, they concluded that a small fraction of sludge can determine the rheology, particle size distribution and filtration behavior of the whole sludge. On the other hand, although Torres et al. (2011) reaffirmed that the supernatant fraction of the sludge played an important role in filterability, they could not validate selective enrichment of single cell acidogenic bacteria in the supernatant of AnMBR sludge. Thus, the impact of acidogenic biomass on sludge filterability remains unclear and needs further investigations. Moreover, recent studies showed that the microbial diversity of the bulk sludge and cake layer depositing on the membrane can be significantly different (Calderón et al., 2011; Lin et al., 2011). This indicates that some species have a higher affinity to attach and colonize on the membrane surface, and may play an important role in membrane fouling.

Based on the studies cited above, this research focuses on the influence of acidogenic biomass on sludge filterability. We aim to bring a systematic insight to the influence of substrate acidification degree on sludge filtration characteristics by presenting results obtained from anaerobic reactors fed with acidified and non-acidified whey.

2. Materials and methods

2.1. Reactor setup and operation

Four lab-scale reactors, each consisting of 2 L effective volume, were operated (Fig. 1). In order to maintain mesophilic conditions (37 ± 1 °C), warm water was recirculated through double wall water jacket of the reactors. pH was controlled with stand alone pH controllers and dosing pumps for acid or caustic. The reactors were continuously mixed with a stirrer motor. To simulate the shear effect in cross-flow AnMBRs the sludge was continuously recirculated with a peristaltic pump at a flow rate of 12 L h^{-1} (~6 volume turnovers per hour). The biogas was measured with wet tipping gas meters and daily biogas production was recorded online. Methane composition of the biogas was checked daily by washing 10 mL of biogas in a graduated glass column filled with 1 M NaOH solution.

Three reactors (R-2, R-3 and R-4) were operated under methanogenic conditions by controlling the pH between 7 and 8, and one reactor (R-1) was operated under acidogenic conditions at pH 5.5. All reactors, except R-1 were operated as continuous stirred tank reactors (CSTRs). R-1 was operated as a timer controlled sequencing batch reactor (SBR) with 19 h continuous 'feed & react', 4 h settle and 1 h decant phases. All reactors except R-1 were inoculated with mechanically disintegrated granular sludge from a full scale expanded granular sludge bed (EGSB) reactor treating lactose based industrial wastewater. R-1 was started up without any seed and acidogenic biomass grew rapidly within a few days. Solids retention time (SRT) was controlled by daily extracting a certain volume of sludge from the reactors.

2.2. Experimental methods

2.2.1. Analytical methods

Analyses were performed on the wasted sludge to check the biological performance of the reactors. Chemical oxygen demand (COD), soluble COD, total phosphorus (TP) and phosphate were measured with Hach-Lange kits. Standards Methods (APHA, 1998) were used for the determination of total solids (TS), total suspended solids (TSS), total Kjeldahl