Effect of upflow velocity on the ultrafiltration resistance of UASB Effluents

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Abstract

Present work investigates the effect of upflow velocity on both biological removal efficiency and physicochemical characteristics of the effluent in a laboratory scale upflow anaerobic sludge blanket (UASB) reactor treating synthetic municipal wastewater. For this purpose, upflow velocities of 1.2 m/h, 0.6 m/h and 1.2 m/h were applied in four successive stages over a total operation period of 159 days. Filterability tests were carried out during each stage in order to assess the effect of upflow velocity on membrane performance. The results indicate that the increase in total chemical oxygen demand (COD) and turbidity at high upflow velocities were attributed to the washout of colloidal particles from the system. Moreover, particle size distribution (PSD) of the effluent showed a significant variation between different upflow velocities. Because of the observed PSD differences that obviously play an important role in membrane fouling, it was hypothesized that upflow velocity would be a critical parameter for the filterability of effluents in membrane coupled UASB reactors. This hypothesis was confirmed by the finding that the filterability of the effluent during the operation at 0.6 m/h was higher than that during the operation at 1.2 m/h.

Keywords

Anaerobic membrane bioreactor; municipal wastewater; filterability; upflow anaerobic sludge blanket reactor; upflow velocity; wastewater treatment

INTRODUCTION

Recently, research on anaerobic membrane bioreactors (AnMBRs) including membrane coupled UASB reactors has received considerable interest and their potential for the treatment of municipal wastewaters has been investigated in several studies (Kataoka et al., 1992; Zhang et al., 2011). In a membrane coupled UASB reactor the sludge bed in the lower part of the UASB reactor is used as a biofilter prior to membrane filtration by entrapping most of the particulate matter via adsorption and subsequent biodegradation. The membrane unit can be either located in the top part of the UASB reactor or in a subsequent unit. In the proposed reactor configuration, the membrane is only exposed to the sludge bed supernatant or to the UASB effluent and thus effluent quality plays a major role in stable operation of the membrane coupled system (Martin-Garcia et al., 2011). One of the most important indicators of effluent quality in this configuration is effluent filterability, which determines the potential loss of filtration performance (Janssen, 2011). Studies on AnMBRs present high variability in bulk liquid filterability because filterability is related to many factors including the properties of the feed water, membrane material, cake layer build up, operational conditions such as shear rate, sludge retention time, temperature, cross flow velocity. Obviously, for membrane coupled UASB systems the efficiency of solids entrapment determines the amount and properties of solids leaving the UASB with the effluent, being subjected to membrane filtration. In this context, upflow velocity in membrane coupled UASB reactors seems to be the critical parameter determining the reactor efficiency and effluent fouling propensity (Mahmoud et al., 2003).

Several researchers investigated the effect of UASB upflow velocity on the biological process performance and solids retention capacity (e.g. Chernicharo and Cardoso, 1999). However, regarding membrane coupled UASB systems there is almost no information in the literature about the effect of upflow velocity on effluent filterability, a parameter that is closely related to the membrane fouling potential of the effluent. Hence, in our present work we researched the impact of UASB upflow velocity on both bio-chemical and physicochemical parameters during treatment of synthetic municipal wastewater. The specific aim of our work is to assess effluent filterability at defined upflow velocities in order to ensure adequate operation of membrane coupled UASB systems. The information obtained from this study will be used for optimizing the hydraulic conditions in membrane coupled UASB systems in order to achieve a stable effluent quality and to minimize the membrane fouling potential of the effluent.

MATERIAL AND METHODS

A laboratory scale UASB reactor (Figure 1) with an effective volume of 7 L was used in the experimental studies. During the experiments, pH was in the range of 6.8 to 7.1. The temperature of the jacketed reactor was controlled at 25±2 ºC by a thermostatic water bath (Tamson Instruments). The experimental system was connected to a computer running LabView software in order to control all pumps and collect pH, temperature and biogas flow data. The reactor was seeded with flocculent anaerobic sludge obtained from a pilot scale UASB reactor treating black water (Sneek). Synthetic municipal wastewater was used as feed. The COD, soluble COD and TSS concentrations of this synthetic wastewater were about 530 mg/L, 159 and 230 mg/L, respectively.

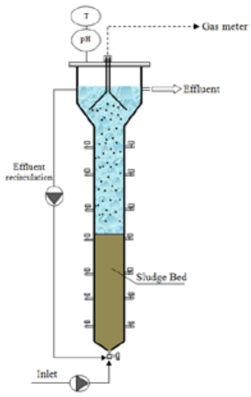

Figure 1. Schematic diagram of the UASB reactor

COD and TSS were measured according to Standard Methods (APHA, 2005). The samples for soluble COD measurement were filtered through a 0.45 micrometer fiberglass filter (Whatman, Spartan 30). The turbidity and pH were measured by HACH 2100N Turbidimeter and by a WTW multi720 pH meter, respectively. The PSD of the effluent was assessed by a Mastersizer 2000 (Malvern Instruments, Hydro 2000 MU) that has a detection range of 0.02-2000 µm. The methane content in the biogas was measured using a Varian 3800 gas chromatograph equipped with a flame ionization detector. The statistical calculation was carried out by using Minitab 16 software (Minitab Inc., USA). The Specific Ultrafiltration Resistance (SUR) test, developed at Delft University of Technology (Roorda 2004), was used to test the filterability of the effluent. A detailed schematic diagram of the experimental set-up can be found in the study of Janssen (2011).

RESULTS AND DISCUSSION

Total and soluble COD concentrations in the effluent at different upflow velocities are shown in Figure 2. After a 40 day acclimation period operating the UASB at 0.6 m/h, the measuring period was started at day 0 with an increased upflow velocity of 1.2 m/h. After the decrease of the upflow velocity from 1.2 m/h to 0.6 m/h at day 34, a gradual decrease was observed in total COD concentration to the range of 130-160 mg/L. Average total COD removal efficiencies of 60% and 66% were obtained at upflow velocities of 1.2 m/h and 0.6 m/h, respectively. However, soluble COD concentrations were found to be similar at both upflow velocities. At day 88 the upflow velocity was restored to 1.2 m/h in order to confirm whether the effect of upflow velocity on total COD concentration is reproducible. During this period, an increase in total effluent COD concentration was observed again, similar to the first period of 1.2 m/h. The observed increase in total COD concentration at an upflow velocity of 1.2 m/h may be attributed either to the release of colloidal and suspended particles from the sludge bed or the decrease in bioconversion. Almost stable biogas production (data not shown) throughout the whole study in spite of the variations in total COD removal efficiency indicates that changes in upflow velocity merely impacts release of colloidal and suspended particles rather than biodegradation.

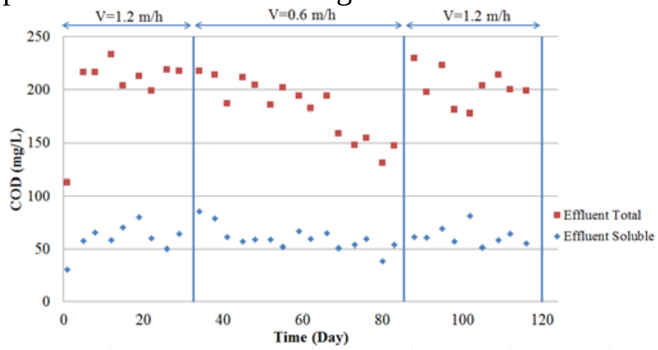

Figure 2. Total and soluble COD concentrations in the effluent

In order to verify this assumption, TSS and turbidity were measured in both the supernatant and effluent of the UASB reactor (data not shown). There was no significant change ($p=0.087$) in effluent TSS concentrations as a result of changes in upflow velocity. However, the average turbidities were found to be 55±10 NTU and 35±10 NTU at the upflow velocities of 1.2 m/h and 0.6 m/h, respectively. Variations observed in effluent turbidity at different upflow velocities seem contradictory with TSS results which do not show significant differences between each upflow velocity. Likely, this is attributable to the washout of colloidal particles from the system instead of suspended particles, since turbidity is an indicator of both suspended and colloidal particles. Following the results of PSD analyses (data not shown), a more homogenous effluent in terms of PSD with more unevenly distributed peaks was obtained at the upflow velocity of 0.6 m/h, whereas PSD at 1.2 m/h was more heterogeneous, meaning more and lower peaks. Moreover, at an upflow velocity of 1.2 m/h, there was a shift to the left part (i.e. smaller particles) and an apparent decrease in the D(0.5) was observed, whereas at an upflow velocity of 0.6 m/h peaks shifted to the right (i.e. larger particles) and an increase in D(0.5) was observed. From these results, it can be concluded that at the high upflow velocity, even small sized particles could be washed out and effluent having an average D(0.5) value of 4.9 µm was obtained, whereas an average particle size of 108 µm was measured after the operation period of 0.6 m/h.

In order to investigate the relationship between filterability and effluent characteristics at different upflow velocities, the SUR of samples obtained at different upflow velocities was measured (Figure 3). Filterability deterioration at higher upflow velocity was related to the presence of colloidal material and a heterogeneous particle size distribution during the operation at 1.2 m/h. This means that at the upflow velocity of 0.6 m/h the average filterability of the UASB effluent was better and more appropriate for membrane filtration in comparison to the effluent obtained at 1.2 m/h.

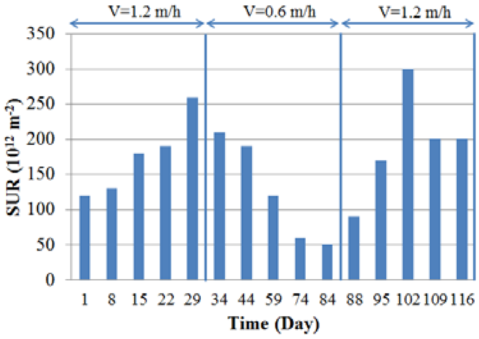

Figure 3. SUR values at different upflow velocities

CONCLUSION

Upflow velocity is an important parameter that affects the characteristics of the effluent especially with respect to physical characteristics and particle size distribution. An upflow velocity of 1.2 m/h was less appropriate than 0.6 m/h, because operation at the high upflow velocity caused washout of colloidal particles and an apparent shift towards smaller particles. The high upflow velocity would therefore result in a more intense contact of small particles with a membrane when coupling the UASB reactor with a membrane filtration unit. The results of the effluent characterization were confirmed by the filterability tests in which a better filterability was obtained with the upflow velocity of 0.6 m/h in comparison to 1.2 m/h. Therefore, it was concluded that selection of a modest upflow velocity plays a major role in controlling the membrane fouling potential of the effluent, which is one of the most important challenges for the operation of membrane coupled UASB reactors.

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