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Enzyme augmentation of an anaerobic membrane bioreactor treating sewage containing organic particulates

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ABSTRACT

Hydrolytic enzymes offer the potential for enhancing the hydrolysis of organic particulates, which tends to be rate limiting in the anaerobic treatment of particulate containing wastewaters. In this study, the effects of enzyme augmentation on the biological performance of a laboratory submerged anaerobic membrane bioreactor (AnMBR) were investigated. A hydrolytic enzyme blend containing proteases, amylases and lipases was added to the bioreactor daily at doses ranging from 0.9 to 18 mL/g of influent COD to enhance the hydrolysis of organic particulates and soluble macromolecules. Enhanced enzymatic hydrolysis resulted in the reduction of total and volatile suspended solids by approximately 19% and 22%, respectively, on the average. Overall COD removal efficiency was unaffected while the average biogas production increased from 0.27 to 0.34 L/g of influent COD. Additionally, the concentrations of bound extracellular polymeric substances (EPS) and soluble microbial products (SMP) decreased and increased respectively, suggesting the enzymatic hydrolysis of EPS to SMP. Low enzymatic activities were detected throughout the entire study, probably due to the instability of free enzymes in the bioreactor environment. Nevertheless, membrane retention of exogenous enzymes within the AnMBR is an inherent feature, as evidenced by size exclusion chromatography.

1. Introduction

Anaerobic sewage treatment possesses desirable attributes such as energy generation, low sludge production, low nutrient requirement, and elimination of expenses associated with the provision of oxygen. However, a major disadvantage compared to its aerobic counterpart is a poorer effluent quality requiring additional downstream polishing to meet discharge standards. This shortcoming can be partially circumvented by employing anaerobic membrane bioreactors (AnMBRs) in which suspended solids are completely retained by micro- or ultra-filtration membranes, thereby producing solids-free effluents even under high hydraulic throughputs. Apart from active biomass, these solids include particulate materials originating from the influent and from cell decay. The former is dependent on the influent solids concentration, while the latter is considerable at large solids retention times (SRTs).

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Nomenclature

b	Endogenous decay coefficient (d^{-1})
X_v	Volatile suspended solids (mg/L)
c_p	COD-to-mass ratio of S_p (–)
X_a	Active biomass (mg/L)
f_d	Biodegradable fraction of X_a (–)
Y	True yield (g VSS/g COD)
k_h	Hydrolysis rate constant (d^{-1})
θ	Hydraulic retention time (d)
S	Soluble organics (mg COD/L)
θ_x	Solids retention time (d)
S_p	Organic particulates (mg COD/L)

Solids typically exert 30–70% of the total chemical oxygen demand (COD) in raw sewage (Prashanth et al., 2006), and may even be as high as 85% (Tarek et al., 2001). In an anaerobic environment, the hydrolysis rate of suspended solids is low (0.3–0.7 d^{-1}), about half that of aerobic hydrolysis (Henze et al., 1997), leading to the observation that anaerobic hydrolysis tends to be rate limiting in sewage treatment (Seghezzo et al., 2005).

If screened raw sewage can be treated directly and efficiently using AnMBRs, primary sedimentation and separate sludge digestion could be obviated, thereby allowing sewage treatment processes to be streamlined. Although AnMBR appears feasible for raw sewage treatment (Liao et al., 2006), solids accumulation, especially at high SRTs, may impede its implementation. Prashanth et al. (2006) investigated the biochemical methane potential of synthetic wastewater containing varying proportions of particulate and soluble organics. A declining methane production rate with increasing particulate concentration was observed. Therefore, the potential inhibition of methanogens at higher particulate concentrations may impose a practical limit on the maximum allowable solids load. COD removal efficiencies would also be detrimentally affected due to lower specific methanogenic activities (Martinez-Sosa et al., 2011). Declines in non-methanogenic activities could also be expected. The consequence of process instability and a lack of reactor resilience has been observed in AnMBRs, and both were attributed to the accumulation of organic solids (Jeison et al., 2008).

Membrane performance could also be negatively affected by excessive solids accumulation owing to the interrelated factors of higher cake resistance, reduction in the effectiveness of biogas scrubbing, and a higher sludge viscosity (Martinez-Sosa et al., 2011; Robles et al., 2012). All these translate to higher operating expenses. Furthermore, Jeison et al. (2008) observed not only a low critical flux when treating wastewater with a high particulate content, the stability of the filtration process was also affected, manifested by abrupt fluctuations in membrane resistance. In addition, biogas scouring was unable to effectively control severe cake formation caused by particulate deposition.

Supplementing hydrolytic enzymes to AnMBRs may reduce solids accumulation and enhance biomethane conversion. A mixture of protease, amylase, and lipase can conceivably enhance the hydrolysis of particulates in raw sewage, which typically comprises of 40–60% proteins, 25–50% carbohydrates, and 8–12% lipids (Asano, 2007). Moreover, enzyme augmentation and membrane filtration likely complement each other as the gel layer formed on membrane surfaces could prevent enzyme washout and the impairment of effluent quality. Previous enzyme augmentation studies on lipid-rich wastewaters indicated that higher COD removal efficiencies and biogas production rates could be achieved by supplementing lipases (Leal et al., 2006; Mendes et al., 2006). In municipal sludge digestion, the addition of proteases and amylases enhanced the rate of sludge solubilisation (Yang et al., 2010). Recently, Turkdogan-Aydinol et al. (2011) applied crude enzymes containing proteases, amylases and lipases to mesophilic upflow anaerobic sludge blanket (UASB) reactors treating high-strength raw sewage (993 ± 259 mg COD/L). Higher COD removal efficiencies (73 ± 8%) were reported with an enzyme dose of 2 mL/g of influent COD compared to that without augmentation (64 ± 5%). Higher process stability was also displayed in the former. However, no such studies have been carried out in AnMBRs treating medium-strength sewage, wherein organic particulates undergo concomitant digestion.

The objective of this study was to investigate the effects of enzyme augmentation on the biological performance of a laboratory-scale AnMBR fed with synthetic sewage containing organic particulates. COD removal efficiency, volatile fatty acids (VFA), solids concentration, and biogas production were monitored as performance indicators. The potential retention of exogenous enzymes by fouling layers was also monitored using size exclusion chromatography (SEC) and enzyme activity assays. Coupled with other physicochemical parameters including bound extracellular polymeric substances (EPS), soluble microbial products (SMP), and particle sizes, substrate-enzyme interactions within the AnMBR were identified and elucidated. As the biodegradation of exogenous enzymes was expected, their anaerobic biodegradability was assessed by biochemical methane potential (BMP) assays.

2. Materials and methods

2.1. AnMBR setup and operation

The study was performed in a 8.6 L laboratory-scale submerged AnMBR (Fig. 1) with a working volume of 5 L. Two vertical baffles were installed to create upcomer and downcomer regions. Two triangular blocks were also fixated at the corners of the reactor bottom to minimise dead zones. Flat sheet polyvinylidene fluoride microfiltration membrane (HVLP, Millipore, USA) with a 0.45 μm nominal pore size and 0.05 m^2 effective membrane area was housed in a customised module (Ying Kwang, Singapore) and placed vertically between the baffles. Biogas was recirculated at a rate of approximately 1.5 L/min using a gas pump (EW-07520-47, Cole Parmer, USA) and coarse bubbles were supplied via two tube diffusers at the bottom. Synthetic raw sewage (550 ± 50 mg COD/L) was introduced semi-continuously at a 1.17 h interval using a peristaltic pump (EW-07520-57, Cole Parmer, USA) to maintain a volumetric loading rate of 1.12 kg COD/m^3/d. The soluble fraction of the wastewater was prepared according to the OECD guideline for synthetic sewage (OECD 303A) and diluted twice