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Research article

Effect of sparging rate on permeate quality in a submerged anaerobic membrane bioreactor (SAMBR) treating leachate from the organic fraction of municipal solid waste (OFMSW)

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A B S T R A C T

This paper focuses on the treatment of leachate from the organic fraction of municipal solid waste (OFMSW) in a submerged anaerobic membrane bioreactor (SAMBR). Operation of the SAMBR for this type of high strength wastewater was shown to be feasible at 5 days hydraulic retention time (HRT), 10 L min^{-1} (LPM) biogas sparging rate and membrane fluxes in the range of 3–7 L m^{-2} hr^{-1} (LMH). Under these conditions, more than 90% COD removal was achieved during 4 months of operation without chemical cleaning the membrane. When the sparging rate was reduced to 2 LPM, the transmembrane pressure increased dramatically and the bulk soluble COD concentration increased due to a thicker fouling layer, while permeate soluble COD remained constant. Permeate soluble COD concentration increased by 20% when the sparging rate increased to 10 LPM.

1. Introduction

The main advantages of membrane bioreactors (MBR) include rapid start-up and a higher loading rate than classical technologies (Stephenson et al., 2000), combining in one unit the removal of COD, solids and nutrients, thus resulting in a small footprint and a very high quality permeate with no suspended solids. Anaerobic MBRs have the added advantage of producing energy in the form of biogas, and generating very little excess sludge, thereby reducing the burden of sludge disposal. In a submerged anaerobic membrane bioreactor (SAMBR) the membrane is submerged within the reactor, and membrane cleaning is accomplished by recirculating the biogas; the coarse bubbles produced underneath the membrane scour it and reduce biofouling to manageable levels, i.e. low transmembrane pressure (TMP) drops. Several researchers have observed fouling minimization by gas sparging (Hong et al., 2002; Li et al., 2005) and other turbulence promoting techniques such as gas/liquid slug flow (Mercier-Bonin et al., 2001) or polymeric particles (Imasaka et al., 1989).

In sidestream membrane bioreactors the membrane module is external to the bioreactor. Sidestream membranes usually operate at higher crossflow velocities (1–5 m s^{-1}), transmembrane pressures (TMP = 2–7 bars) and permeate flux (70–100 LMH) compared to the SAMBR, but they generate more shear (Berube et al., 2006). This can lead to more cell lysis and extracellular polymer production, which also causes biofouling; sidestream operation in a MBR can lead to a 50% decrease in sludge activity after circulating the sludge 20 times, and a 90% loss within 100 cycles (Brockmann and Seyfried, 1997). Despite being costly (Al-Malack, 2006), the main advantage of crossflow filtration is the limitation of cake build-up at the membrane surface due to the shear stress caused by the tangential flow. In a sidestream configuration it has been shown by several researchers that a higher crossflow velocity has a beneficial influence on the flux as it increases the critical flux and reduce cake formation (Chen et al., 1997; Defrance and Jaffrin, 1999) by decreasing the resistance associated with the polarization layer (Choo and Lee, 1998): concentration polarisation (CP) is the tendency of solutes to accumulate on the membrane surface within a concentration boundary layer, and this liquid film is stagnant since the liquid velocity at the membrane itself is zero. This implies that the only mode of transport is diffusion, and the solute concentration near the membrane increases exponentially with increasing flux.

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Furthermore, due to CP, permeation of the reactor solutes and colloids through the membrane decreases depending on the thickness of the layer; however, this thickness decreases when turbulence in the reactor is increased. At high fluxes, significant flux decline is observed for any membrane/wastewater combination (Amy, 2008), and this can be attributed to a thicker CP layer, manifesting itself in the aggregation of soluble microbial products (SMPs), humic substances, organic colloids and suspended matter, and calcium carbonate precipitates (Boussu et al., 2006; Mahvi and Razavi, 2005).

The submerged configuration is usually preferred because of low operating costs, gentle mixing and high COD removal efficiency. With a synthetic low strength wastewater feed for an anaerobic submerged membrane bioreactor, Hu (2004) showed that biogas should be sparged as soon as there is a flux applied through a Kubota membrane with a 0.4 micron pore size. Otherwise, if the flux is too high, the cake will consolidate and gas sparging will be inefficient to remove the cake once it has formed. He also showed that the TMP was minimal (0.1 bar) with the highest gas flowrate (15 LPM). It turned out that this flowrate caused a cake to form with bigger particles than at lower flowrates, indicating that the smallest particles produced at lower flowrates were responsible for the fouling and thus the increase in TMP. However, gas sparging is only effective up to a limit, i.e. there are some forms of fouling that are resistant to gas sparging (Hong et al., 2002; Hu, 2004; Li et al., 2005).

Stephenson et al. (2000) stated that most studies in the literature showed that the concentration of soluble COD was consistently two or three times higher in the reactor than that observed in the effluent due to the rejection of soluble organics (COD) by the membrane. Akram and Stuckey (2008) reported ratios of COD reactor/COD permeate as high as 12 in SAMBR and that ratio was 1–5 when activated carbon was added. Considerably lower COD concentrations in the permeate compared to the bulk are due to filtration by the fouling layer and narrowed pores (Choi and Ng, 2008; Hu, 2004). Furthermore, the membrane rejects most of the high molecular weight and slowly degradable compounds (Trzcinski and Stuckey, 2009a).

This indicated that a large amount of dissolved COD was retained by the thin polarization layer on the membrane surface, thus enhancing the effluent quality substantially. Interestingly, several researchers found that the cake layer acted as a “dynamic” membrane on top of the actual membrane, and also led to a greater rejection of volatile fatty acids (Choo and Lee, 1996b; Hu, 2004) and viruses (Fox and Stuckey, 2015a). These authors observed that virus rejection increased at low sparging rate due to membrane fouling which demonstrated that fouling can also be beneficial for effluent quality. This has important practical applications as the costs associated with tertiary treatment (activated carbon, sand filters and chlorination/ozonation) could significantly decrease if the SAMBR permeate quality can be fine-tuned using the sparging rate, but there is a lack of information regarding its feasibility and its impact on maintainable flux. Based on the available information in the literature it was hypothesized that effluent quality could be improved further due to concentration polarization and membrane rejection, i.e. by reducing the sparging rate, the cake layer should become thicker and permeate quality should improve. The aim of this paper was, therefore, to study the effect of sparging rate on effluent quality and membrane flux.

2. Materials and methods

2.1. High-strength leachate wastewater

The leachate used in this study was produced in a continuous bench scale hydrolytic reactor (20 L) fed real components of municipal solid waste: 41.3% kitchen wastes, 10.8% garden wastes and 47.9% paper wastes on a wet basis according to a previous study (Trzcinski and Stuckey, 2009b). The leachate had the following properties: pH: 6.7–7.7, soluble chemical oxygen demand (SCOD-filtered through a 0.45 microns Sartorius filter): 530–2840 mg/L (average: 1410 mg/L), total chemical oxygen demand (TCOD): 1.3–11.8 g/L (average: 7.3 g/L), volatile fatty acids: 30–980 mg/L as COD (average: 390 mg/L), ammonia-nitrogen: 7–140 mg N/L (average: 44 mg N/L), phosphorus: 3.9–24 mg P/L as orthophosphates (average: 11 mg/L).

2.2. Reactors and start-up

Two submerged anaerobic membrane bioreactors (SAMBRs) were fed in parallel with the OFMSW leachate at 5 days hydraulic retention time (HRT) and 300 days solid retention time (SRT). The two SAMBRs were 3 L reactors fitted with a Kubota polyethylene flat sheet membrane with 0.1 m^2 of total surface and a pore size of 0.4 microns. A detailed description of the reactor can be found elsewhere (Trzcinski and Stuckey, 2009b). One pump was used to set a constant flux, and some of the permeate was recycled back to the SAMBR with a separate pump in order to control the HRT. Both SAMBRs were maintained at 35 ± 1 °C. The biogas sparging rate was initially set at 5 L min^{-1} (LPM) to minimize cake formation on the membrane until steady-state in terms of SCOD concentration was achieved.

SAMBR1 was inoculated with 0.5 L of seed from a SAMBR fed on the same leachate at 5 days HRT. The volume was adjusted to 3 L with the anaerobic biomedium defined in Owen et al. (1979) so that the initial mixed liquor total suspended solids (MLTSS) and mixed liquor volatile suspended solids (MLVSS) were 3.3 and 2.5 g/L, respectively. SAMBR2 was inoculated with biomass from a 4 L chemostat batch-fed (once a week) on a 8 g COD/L synthetic feed (Nachaiyasit and Stuckey, 1995) to assess the effect of culture on COD removal. The supernatant was discarded and the settled solids were used to inoculate SAMBR2. The volume was adjusted to 3 L with the anaerobic biomedium defined in Owen et al. (1979) so that the initial MLTSS and MLVSS were 2.6 and 1.78 g/L, respectively.

2.3. Analytical and statistical methods

The measurement of pH (Jenway 3020 pH Meter) was accurate to within ±0.02 units. The mixed liquor total suspended solids (MLTSS), volatile suspended solids (MLVSS), soluble chemical oxygen demand (SCOD-filtered through a 0.45 microns Sartorius filter) and total chemical oxygen demand (TCOD) were measured as described in standard methods (APHA, 1999). Their coefficient of variation (COV) for ten identical samples was ±4%, 3.1%, 2.6% and 9.9%, respectively. Volatile fatty acids (VFAs) were measured using a Shimadzu gas chromatograph with a flame-ionized detector and a SGE capillary column (12 m × 0.53 mm ID-BP21 0.5 μm). The COV was ±3% for ten identical samples. Ammonia-nitrogen was measured using the nesslerization method by reading absorbance at 425 nm, and the COV was equal to ±6.6% for 10 identical samples. The measurement of orthophosphates was carried out according to the vanadomolybdophosphoric acid colourimetric method described in standard methods (APHA, 1999). The absorbance was read on a spectrophotometer at 470 nm, and the coefficient of variance for ten identical samples was ±0.6%.