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Hollow fiber vs. flat sheet MBR for the treatment of high strength stabilized landfill leachate

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ABSTRACT

The Membrane Bioreactor (MBR) technology is increasingly becoming a prominent process in the treatment of high-strength wastewater such as leachate resulting from the decomposition of waste in landfills. This study presents a performance comparative assessment of flat sheet and hollow fiber membranes in bioreactors for the treatment of relatively stable landfill leachate with the objective of defining guidelines for pilot/full scale plants. For this purpose, a laboratory scale MBR system was constructed and operated to treat a leachate with Chemical Oxygen Demand (COD) (3900–7800 mg/L), Biochemical Oxygen Demand (BOD_5) (~440–1537 mg/L), Total Phosphorus (TP) (~10–59 mg/L), Phosphate (PO_4^{3-}) (5–58 mg/L), Total Nitrogen (TN) (1500–5200 mg/L), and ammonium (NH_4^+) (1770–4410 mg/L). Both membranes achieved comparable BOD (92.2% vs. 93.2%) and TP (79.4% vs. 78.5%) removals. Higher PO_4^{3-} removal efficiency or percentage (87.3% vs. 81.3%) and slightly higher, but not statistically significant, COD removal efficiency were obtained with the hollow fiber membrane (71.4% vs. 68.5%). On the other hand, the flat sheet membrane achieved significantly higher TN and NH_4^+ removal efficiencies (61.2% vs. 49.4% and 63.4% vs. 47.8%, respectively), which may be attributed to the less frequent addition of NaOCl compared to the hollow fiber system.

1. Introduction

While at the bottom of the desirable hierarchy, landfilling, in many countries, continues to be a common element and often the only option adopted from the integrated system due to economic considerations. In landfills, leachate generation remains an inevitable consequence of the decomposition of the waste and the percolation of water through decomposing waste. Landfill leachate is invariably laden with various contaminants, whose characteristics are dependent on landfill age, precipitation, seasonal weather variation, and waste composition amongst other factors (Renou et al., 2008; Kulikowska and Klimiuk, 2008). Due to its complex and variable composition, leachate is difficult to treat (Tatsi and Zouboulis, 2002). Failing to properly treat the leachate is known to pollute the receiving environment (Kurniawan et al., 2006; El-Fadel et al., 1997). Thus, treating landfill leachate is increasingly subject to stringent environmental requirements to protect ground and surface water resources (Renou et al., 2008). Commonly adopted leachate management options include discharge into sewer systems for subsequent treatment with municipal wastewater (Çeçen and Çakiroğlu, 2001), recirculation (Rodríguez et al., 2004), evaporation followed by sludge disposal, and on-site treatment (Bodzek et al., 2006). In the latter context, various biological and physical/chemical technologies have been developed. Physical/chemical methods are usually adopted as pre/-post treatment or to remove specific pollutants (Renou et al., 2008). On the other hand, biological methods, which encompass several suspended and attached growth methods under either aerobic or anaerobic conditions, are often applied to treat the bulk of the biodegradable fraction in the leachate.

The Membrane Bioreactor (MBR) technology, a combination of membrane separation and biodegradation processes, is increasingly being recognized as the process treatment of choice for the treatment of high-strength wastewater, containing complex and recalcitrant compounds (Sutherland, 2010; Bilad et al., 2011). An MBR can be considered as a Conventional Activated Sludge (CAS) system with efficient membrane filtration that holds small particles (size <0.1 μm) (Santos et al., 2010). The main advantages of MBRs include the ability to replace the second stage of conventional wastewater treatment (i.e. gravity settling), produce a better quality effluent, and reduce reactor volume and footprint. Furthermore, an MBR is usually operated at a higher Mixed Liquor Volatile Suspended Solids (MLVSS), with values ranging between 8000 and 12,000 mg/L, as compared to the 2000–3000 mg/L range typically

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reported in conventional activated sludge systems (Sutherland, 2010; Cornel and Krause, 2006; Alvarez-Vazquez et al., 2004).

With increasingly stringent discharge standards, conventional treatment methods (biological or physico-chemical) are seldom adequate to meet the standards. In combining biological degradation and physical separation, the MBR technology has shown satisfactory results in treating old/stabilized landfill leachate (Alvarez-Vazquez et al., 2004). In the context of leachate treatment, the MBR has been shown to have high BOD removal rates (90–99%), irrespective of experimental conditions and leachate maturity. In contrast, the efficiency of MBR in removing Chemical Oxygen Demand (COD) is known to vary widely from as low as 25% (Jakopović et al., 2008) to as high as 90% (Chen and Liu, 2006; Puszczało et al., 2010; Aloui et al., 2009).

While the literature on the use of MBR in wastewater treatment is relatively rich, studies examining the impact of various membrane types in an MBR system on the treatment efficiency of high strength stabilized landfill leachate are limited. A large proportion of the literature studies on leachate treatment by MBRs have employed HF membrane modules with a fewer number adopting the FS membrane modules (Cui et al., 2003; Le-Clech et al., 2006). Furthermore, data on phosphorus removal achieved by MBR treating stabilized leachate is scarce, with no data on removal achieved by flat sheet MBRs. In this study, the two most common membrane types, hollow fibers and flat sheet, were compared by testing them in an MBR system to assess their effectiveness in treating stabilized high strength landfill leachate with the objective of defining guidelines for a pilot/full scale plant. During the process, several parameters, including phosphate and total phosphorus, were monitored at different locations of the experimental setup.

2. Materials and methods

2.1. Experimental setup

The experimental setup (Fig. 1) consisted of two Plexiglas denitrification tanks (D) with stirrer mixers (C) to prevent settlement of solids and two aerobic Plexiglas tanks (E, L), one of which was equipped with a Flat Sheet (FS) membrane (Kubota, 203), while the other was fitted with a Hollow Fiber (HF) membrane (ZW 10). A blower (M) with a rotameter (Omega-FL-3663C) to regulate the airflow from a central air compressor was attached to each membrane to provide aeration and help in scrubbing the membrane and eliminate-minimize potential fouling. In addition, two pressure sensors (F) (Omega DPG 1000ADA or DAR) connected to a digital display were used to trace variations in membrane pressure. Peristaltic pumps (Master Flex 07528-10 and 7550-22) (I, K), with variable speed and reverse operation modes, were used for the permeate suction and recirculation. Both systems were fed with landfill leachate from a common storage tank connected to the denitrification tanks by means of a multi-channel peristaltic pump (A, B). The systems were connected to a drain (H) to allow sludge wastage and hence control of the Solid Retention Time (SRT). FS and HF membrane modules were chosen in this study because they are the two most commonly used membrane types (Stephenson et al., 2000). Both membrane modules exhibit advantages and disadvantages (Cui et al., 2003; Le-Clech et al., 2006): FS modules are less prone to fouling and relatively easy to control but are more expensive than HF modules which are more prone to fouling but can withstand vigorous backwashing.

2.2. Operation and control

The influent leachate was collected weekly from an operational sanitary landfill in Naameh–Lebanon and transported to the laboratory for characterization and usage in the reactors. The landfill is part of an integrated regional solid waste management system and receives over 2000 tons per day of municipal waste composed of a large fraction of organic food waste with high moisture content.

The experiment was initiated by filling the reactors with leachate, opening the aeration valves in the aerobic tanks, and turning on the mixers in the anoxic tanks at low speeds (≈150 rpm). The flow rate was increased gradually until a Hydraulic Retention Time (HRT) of 100 h (4.2 days) was achieved. A sludge retention time of 30 days was selected based on previous data from full scale MBR plants treating old landfill leachate (Alvarez-Vazquez et al., 2004), where an SRT of 30 days achieved superior treatment performance (Hasar et al., 2009a,b).

Foaming in the membrane tanks was controlled using an anti-foaming agent (Sigma A6426-from Sigma Aldrich) (few drops almost twice per week in the first month, every two weeks afterwards). The HF membrane was cleaned twice a week using sodium hypochlorite (NaOCl) solution, while the FS membrane was cleaned by gentle scraping of solids.

The manufacturer of the flat sheet membrane recommended chemical cleaning for the membrane modules once every six months only. In contrast, the hollow fiber membrane modules needed weekly cleaning through backwashing with NaOCl solution. The cleaning process is equivalent to a repeated backpulse field operating condition (aimed to dislodge fouling material) whereby the membrane is backwashed with NaOCl solution after reversing the direction of the flow through the pump. This Cleaning In Place (CIP) of the HF membrane is conducted to avoid removing the membrane module from the aerobic tank.

2.3. Analytical methods

Throughout the experimental program (127 days), samples were collected twice a week from the feed tank and permeate and once per week from all tanks. Samples were analyzed for several indicators including pH, Biochemical Oxygen Demand (BOD_5), Total Nitrogen (TN), ammonium (NH_4^+), COD, Total Phosphorus (TP), and phosphate (PO_4^{3-}) according to Standard Methods of the American Public Heath Association (APHA) (APHA, 2005). The pH was measured using a Thermo Scientific Orion 3 STAR pH Benchtop meter, the DO for BOD determination was measured using a WTW Oxi 538 Oximeter, while other parameters were quantified using spectro-photometric analysis that was performed using a HACH DR/2010 Spectrophotometer. Collected data were then analyzed using R 3.03 statistical software (R Core Team, 2014). Differences between the two MBR systems with respect to the achieved removal efficiencies of various parameters were quantified. Statistical comparison was conducted by running paired *t*-tests, when the data were normally distributed, and the paired Wilcoxn Signed Rank test, when the normality assumption was violated. The confidence level was set to 95% (a significance level of 0.05).

3. Results and discussion

Leachate characterization (Table 1) showed high levels of TN (1500–5200 mg N/L), pH values ranging between 8.08 and 8.87, and a low BOD_5/COD ratio (0.07–0.22), all reflecting a stabilized leachate (Aloui et al., 2009; Jakopović et al., 2008; Trebouet et al., 1999). However, ammonium and TP levels (1770–4410 mg/L and 10.5–59 mg/L, respectively) were high and more typical of a young leachate (1400–10,250 mg/L for ammonium and 1.6–655 mg/L for TP).