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Research article

Treatment of landfill leachate in municipal wastewater treatment plants and impacts on effluent ammonium concentrations

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ABSTRACT

Landfill leachate is the result of water percolating through waste deposits that have undergone aerobic and anaerobic microbial decomposition. In recent years, increasingly stringent wastewater discharge requirements have raised questions regarding the efficacy of co-treatment of leachate in municipal wastewater treatment plants (WWTPs). This study aimed to (1) examine the co-treatment of leachate with a 5-day biochemical oxygen demand (BOD_5): chemical oxygen demand (COD) ratio less than or slightly greater than 0.26 (intermediate age leachate) in municipal WWTPs (2) quantify the maximum hydraulic and mass (expressed as mass nitrogen or COD) loading of landfill leachate (as a percentage of the total influent loading rate) above which the performance of a WWTP may be inhibited, and (3) quantify the impact of a range of hydraulic loading rates (HLRs) of young and intermediate age leachate, loaded on a volumetric basis at 0 (study control), 2, 4 and 10% (volume landfill leachate influent as a percentage of influent municipal wastewater), on the effluent ammonium concentrations. The leachate loading regimes examined were found to be appropriate for effective treatment of intermediate age landfill leachate in the WWTPs examined, but co-treatment may not be suitable in WWTPs with low ammonium-nitrogen (NH_4-N) and total nitrogen (TN) emission limit values (ELVs). In addition, intermediate leachate, loaded at volumetric rates of up to 4% or 50% of total WWTP NH_4-N loading, did not significantly inhibit the nitrification processes, while young leachate, loaded at volumetric rates greater of than 2% (equivalent to 90% of total WWTP NH_4-N loading), resulted in a significant decrease in nitrification. The results show that current hydraulic loading-based acceptance criteria recommendations should be considered in the context of leachate NH_4-N composition. The results also indicate that co-treatment of old leachate in municipal WWTPs may represent the most sustainable solution for ongoing leachate treatment in the cases examined.

1. Introduction

Landfill leachate is the result of water percolating through waste deposits that have undergone aerobic and anaerobic microbial decomposition (Chofqi et al., 2004; Gupta et al., 2014; Mukherjee et al., 2014). Its composition is a function of the type of waste in the landfill, landfill age, climate conditions, and hydrogeology of the landfill site (Chofqi et al., 2004; Slack et al., 2005). A landfill site will produce leachate throughout its working life and also for several hundred years after it is decommissioned (Wang, 2013). The control of a landfill site, and appropriate treatment of the leachate it produces, is paramount in the protection of the surrounding environment, as leachate contamination of groundwater, rivers, lakes and soils has the potential to negatively affect local habitats, resources and human health (Ağdağ and Sponza, 2005; Marshall, 2009).

The European Union (EU) Landfill Council Directive 1999/31/EC (EC, 2001) and subsequent waste management legislation (EC, 2008) have resulted in major changes in the waste management sector in Europe over the last 30 years. The Landfill Directive sets targets that (1) reduce the percentage of waste that can be consigned to landfill for each member state (2) decrease the quantity of

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biodegradable municipal waste sent to a landfill, and (3) places responsibility on landfill owners to budget for the aftercare of a landfill site for a minimum of 30 years after operation has ceased. Prior to the implementation of this Directive, landfilling across the EU was unregulated and poorly planned (EC, 2007). The Directive has resulted in dramatic improvements in the manner in which landfills, and specifically landfill leachate, is managed (McCarthy et al., 2010; Brennan et al., 2015). While there has been a decline in landfilling in recent years, leachate generation is a legacy problem, and the treatment of leachate is the major management issue facing landfill operators (Zhang et al., 2009; Brennan et al., 2015). Many landfills are not located close to suitable receiving waters (Knox et al., 2015). Therefore, the most sustainable option may be to transfer leachate to wastewater treatment plants (WWTPs) for final treatment.

Leachate contains high levels of 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammonium-nitrogen (NH_4-N), chloride (Cl), sodium (Na), potassium (K), nitrogen (N), boron (B), solvents, phenols, hardness and metals, including iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), cobalt (Co), chromium (Cr), nickel (Ni), cadmium (Cd) and lead (Pb) (Tatsi and Zouboulis, 2002; Chofqi et al., 2004; Ağdağ and Sponza, 2005; Marzougui and Ben Mammou, 2006). Young leachate (generated in operational landfills or landfills closed for less than five years (Renou et al., 2008)) is highly biodegradable and exhibits COD and NH_4-N concentrations of up to 80,000 and 3100 mg L^{-1}, respectively, and BOD_5:COD ratios of up to 0.7 (Stegmann et al., 2005). As a result, biological treatment methods are reasonably efficient in the removal of COD, NH_4 and metals (Kurniawan et al., 2006). Conversely, older (stabilised) leachate is less biodegradable and contains methanogenic leachate with BOD_5:COD ratios < 0.2 (Stegmann et al., 2005), and therefore is not as efficiently treated using biological methods. In the current paper, landfills are defined as young (operational/closed less than five years), intermediate (closed more than five year but less than 10), and old (closed more than ten years) (after Renou et al., 2008).

To date, there has been limited work regarding the impacts of co-treatment of landfill leachate and municipal wastewater in WWTPs (Renou et al., 2008), and studies have been largely limited to laboratory-scale batch experiments (Diamadopoulos et al., 1997; Çeçen and Aktaş, 2004; Capodici et al., 2014; Wu et al., 2015; Mojiri et al., 2014). These studies have generally concluded that WWTP removal efficiency is not adversely affected, provided the total hydraulic loading of leachate does not exceed 10% of the total municipal wastewater entering the WWTP. However, at these volumetric loading rates effluent NH_4-N and total nitrogen (TN) may be significantly impacted due to their relatively high concentrations in landfill leachate (Diamadopoulos et al., 1997; Ye et al., 2014; Ferraz et al., 2014). The lack of recent studies examining co-treatment of leachate in operational municipal WWTPs is a concern for WWTP managers, as wastewater effluent is subject to increasingly stringent legislation in the EU. There is a concern that recommendations based on laboratory studies and, not site-specific data, may result in failures to achieve compliance.

Studies have demonstrated that co-treatment of young leachate with municipal wastewater does not adversely affect WWTP performance (Diamadopoulos et al., 1997; Kalka, 2012; Ye et al., 2014); however, the effect of old landfill leachate (BOD_5:COD < 0.01; Renou et al., 2008) has not been widely examined with the exception of Del Borghi et al. (2003), who concluded that old leachate should mixed with young leachate before treatment. The current study (1) examines the co-treatment of leachate with a BOD_5: COD ratio less than or slightly greater than 0.26 (intermediate age leachate) in municipal WWTPs and attempts to quantify the maximum hydraulic and mass (expressed as mass nitrogen or COD) loading of landfill leachate (as a percentage of the total influent loading rate) above which the performance of a WWTP may be inhibited and (2) quantifies the impact of a range of volumetric loading rates (VLRs) of young and intermediate age leachate, loaded on a volumetric basis at 0, 2, 4 and 10% (expressed as volume landfill leachate treated in the WWTP as a percentage of the total influent wastewater to the WWTP), on NH_4-N removal. The study is thus focused on the identifying the optimum leachate loading strategy adoptable which will minimize the adverse effects of landfill leachate presence in the WWTP and ensure effective treatment of wastewater and leachate.

2. Materials and methods

2.1. Study sites

Three activated sludge WWTPs, two of which were representative of WWTPs co-treating leachate in Ireland and another which had not received landfill leachate in over one year and hereafter referred to as Sites 1, 2 and 3, were selected for use in this study. Landfill leachate (LL) accepted at Site 1 and 2 (intermediate) and a young landfill leachate from another landfill (young) were identified and hereafter referred to as LL 1, 2 and 3.

2.2. WWTP monitoring

Sites 1 and 2 were selected and monitored to determine the impact of leachate loading regime on WWTP performance. Their operational information is given in Table 1. Both WWTPs received leachate (Table 2) at average VLRs, of 1.2 and 2.3%. Leachate loading regimes examined during the study were: (1) drip-feed (2) no-leachate addition and (3) shock loading (i.e. relatively large leachate volumes added to the WWTP in a brief pulse). Drip-feed and no-leachate scenarios were examined at Site 1, whereas shock loading was examined at both Site 1 and 2 (Table 3). Refrigerated automatic wastewater samplers (Aqua Cell, UK) were used to collect grab samples at eight-hour intervals at the head of the works prior to primary settlement and at effluent discharge points (effluent wastewater samples) of Sites 1 and 2. Influent and effluent flows were recorded using on-site flow recording equipment. For operational reasons, it was not practical to monitor each loading regime for a time period longer than the sludge age of the WWTP, and this must be taken into account when interpreting differences between leachate loading regimes.

2.3. Analysis of wastewater and landfill leachate

Samples were analysed for BOD_5, COD, CODs, filtered total nitrogen (TN_f), filtered total inorganic carbon (TIC_f), filtered total organic carbon (TOC_f), ortho-phosphorus (PO_4-P), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), alkalinity, sulphate, chloride, NH_4-N and suspended solids (SS). All analyses were conducted in accordance with the standards method for the examination of water and wastewater (APHA, 2012). Conductivity and pH were determined using a SAC950 sample changer and a Titralab 870. Total metal concentrations for Cu, Cd, Cr, As, Pb, Hg, and Ni were determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Agilent 7500a Technologies Inc. USA) following microwave digestion (CEM Discover SPD Microwave Digester) using Trace Metal Grade Nitric Acid (Fisher, UK).

2.4. Nitrification inhibition batch experiments

Laboratory batch experiments, conducted to supplement the results of the WWTP study, examined the impact of various landfill