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Research article

Removal of organic matter and ammonium from landfill leachate through different scenarios: Operational cost evaluation in a full-scale case study of a Flemish landfill

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Several scenarios are available to landfilling facilities to effectively treat leachate at the lowest possible cost. In this study, the performance of various leachate treatment sequences to remove COD and nitrogen from a leachate stream and the associated cost are presented. The results show that, to achieve 100% nitrogen removal, autotrophic nitrogen removal (ANR) or a combination of ANR and nitrification – denitrification (N-dN) is more cost effective than using only the N-dN process (0.58 €/m^3) without changing the leachate polishing costs associated with granular activated carbon (GAC). Treatment of N-dN effluent by ozonation or coagulation led to the reduction of the COD concentration by 10% and 59% respectively before GAC adsorption. This reduced GAC costs and subsequently reduced the overall treatment costs by 7% (ozonation) and 22% (coagulation). On the contrary, using Fenton oxidation to reduce the COD concentration of N-dN effluent by 63% increased the overall leachate treatment costs by 3%. Leachate treatment sequences employing ANR for nitrogen removal followed by ozonation or Fenton or coagulation for COD removal and final polishing with GAC are on average 33% cheaper than a sequence with N-dN + GAC only. When ANR is the preceding step and GAC the final step, choice of AOP i.e., ozonation or Fenton did not affect the total treatment costs which amounted to 1.43 (ozonation) and 1.42 €/m^3 (Fenton). In all the investigated leachate treatment trains, the sequence with ANR + coagulation + GAC is the most cost effective at 0.94 €/m^3.

1. Introduction

Landfilling remains the primary disposal method for municipal solid waste in developed and developing countries (Tizaoui et al., 2007). As a result of ground water intrusion, rainfall percolation and moisture present in the waste, deposits of toxic waste waters called landfill leachate are generated. Release of this leachate into the environment without proper treatment poses considerable risks to human and ecosystem health. The European Union council directive of 1999/31/EC requires landfill operators to undertake proper leachate treatment during the entire life cycle of a landfill to prevent any possible negative effects to the environment (Council of the European Union, 1999). In Flanders (the Northern part of Belgium), this EU directive is reflected in Flemish environmental regulations VLAREM II (www.emis.vito.be).

Several conventional as well as advanced treatment processes have been tested and are used to treat leachate (Gao et al., 2015b). To meet the strict quality standards for the direct discharge of leachate into surface water, it is widely accepted that a combination of chemical (coagulation-flocculation, advanced oxidation processes (AOPs), physical (adsorption, membrane filtration, air stripping) and biological steps are to be used (Gao et al., 2015b). Often, the potential techniques for treatment of landfill leachate are

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evaluated based on their ability to reduce the pollutant load. This is clearly seen in different review papers (Gao et al., 2015b; Kurniawan et al., 2006b; Renou et al., 2008). Other important factors used to evaluate the suitability of a technique for treatment of landfill leachate include available operational experience, energy requirements, process reliability and related environmental impacts (Van Hulle et al., 2010). Regardless of the aforementioned criteria, the most crucial factor used in selection of the best available techniques is cost (Van Hulle et al., 2010). This is because operation and maintenance of a leachate treatment sequence accounts for 40–60% of total investments costs (IPPC, 2007). This constitutes 50–67% of total landfilling costs (IPPC, 2007). Therefore, the importance of an economic assessment of proposed leachate trains cannot be over emphasized.

On a large scale, landfill leachate treatment costs are directly affected by environmental concerns (Fig. 1) (Bisung et al., 2015). The environmental concerns are in turn driven by the available technology and its efficiencies, operating conditions and environmental discharge standards. These three factors directly affect the quality of landfill leachate discharged into the environment and impose a cost to the treatment of landfill leachate.

In view of their economy, several treatment plants incorporate a biological step as initial treatment step (Behzad et al., 2011; Gao et al., 2015b). Indeed, a survey of 166 leachate treatment plants by Alvarez-Vazquez et al. (2004) showed that 72% of the schemes had a biological method such as aerobic lagooning, activated sludge, and up-flow anaerobic sludge blanket. These biological processes make use of the nitrification-denitrification (N-dN) mechanism for nitrogen removal. Micro-organisms involved in N-dN processes are readily hampered by high concentrations of ammonium nitrogen (500–2000 mg/L) (Kjeldsen et al., 2002) present in leachate. For instance after a long hydraulic residence time of 20 days, only 20% ammonium nitrogen could be removed during N-dN in a sequencing batch biofilter granular reactor (Di Iaconi et al., 2006). Besides, additional carbon sources are required to aid the nitrification-denitrification process (Chys et al., 2015a). As an alternative biological method, leachate treatment

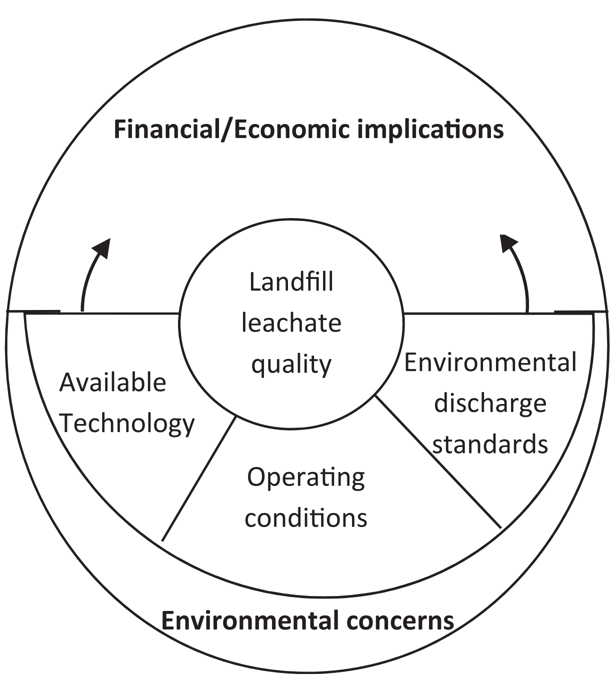

Fig. 1. The factors directly affecting landfill leachate quality and their relationship with environmental concerns and costs.

facilities are now employing full autotrophic nitrogen removal (ANR) processes (Gao et al., 2015a). Depending on the operating conditions, ANR processes can achieve up to 90% nitrogen removal (Anfruns et al., 2013). Moreover, compared to nitrification-denitrification methods, ANR is known to consume 60% less oxygen and 40% less or no organic carbon (Van Hulle et al., 2010) and is therefore characterized by less operational costs. On the other hand, operational problems and long start up periods of ANR processes (Van Hulle et al., 2010) have led to the use of chemical techniques such as struvite precipitation. Ozturk et al. (2003) showed that 90% of ammonium nitrogen can be removed from landfill leachate with an influent ammonium nitrogen concentration of 2240 mg/L. The related cost amounts to 4.45 €/m^3 despite considering the economic value of the struvite.

For removal of non-biodegradable (organic) matter present in the effluent of biological techniques, generally activated carbon adsorption is used. However, this also results in high costs as a large amount of activated carbon is necessary to remove the recalcitrant COD in the leachate. Difficulties and high costs associated with regeneration of used activated carbon further limit its application in landfill leachate treatment. Advanced oxidation processes (AOPs) are reported as the most effective method in degradation of recalcitrant organic matter, and hence pose a possible alternative to activated carbon (Anfruns et al., 2013; Kurniawan et al., 2006a). Anfruns et al. (2013) reported up to 98% COD and 87% total nitrogen removal when an Anammox process is coupled with photo-Fenton in treatment of landfill leachate. However, the chemical and energy requirements for AOPs are very high with respect to the total operating costs (Table 1). In the combined treatment of landfill leachate using sequencing batch reactor (SBR), coagulation – flocculation, Fenton and up-flow biological aerated filters, 30% of the total treatment costs were attributed to reagents for the Fenton step (Li et al., 2009). Reagents for the photo-Fenton step in the study of Anfruns et al. (2013) cost 6.61 €/m^3, which is 92% of the total operating costs. A parallel configuration with ozonation used 4.04 €/m^3 for ozone production from a total operating cost of 7.72 €/m^3 (Anfruns et al., 2013). Efforts to lower the energy costs of AOPs, have focused on natural solar energy as a cheaper and sustainable alternative energy source (De Torres-Socías et al., 2015; Rocha et al., 2011; Silva et al., 2016). Based on UV radiation distribution in certain geographical locations, the sole use of solar radiation is not feasible as the land requirements for installing compound parabolic collectors (CPCs) is impractical (43,173 m^2) where land is scarce and expensive (Silva et al., 2016). Furthermore, CPCs are expensive (349 €/m^2) and constitute a cost of at least 24% of the total unitary (€/m^3) operating costs (De Torres-Socías et al., 2015). Table 1 gives a summary of the costs implications for adopting different technologies for COD removal (unless otherwise stated) from landfill leachate.

The importance of cost in treatment of landfill leachate is clearly seen in Gupta and Singh (2007). In this study, a cheap treatment sequence (1.12 €/m^3) with a methane phase bed reactor, leachate recycling unit and soil column is recommended for use as opposed to one with an activated carbon (2.8 €/m^3) as the final polishing step; which is however more effective in COD, BOD_5 and suspended solids removal. This illustrates the need to balance economic and technical performance criteria that often is required in practice.

Conditions such as seasonal variations in leachate quality, which might become even more pronounced as a result of climatological changes, can have a significant impact on leachate treatment costs. For instance, the chemical oxygen demand concentration in leachate increases on average from 4539 to 9004 mg/L (Kawai et al., 2012). This in turn increases the chemical demand in case of chemical treatment and consequently increases the operational costs. Also the implementation of more stringent environmental

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