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Application of landfill treatment approaches for stabilization of municipal solid waste

Stephanie C. Bolyard [a,*], Debra R. Reinhart [b]

[a] University of Central Florida, Civil, Environmental, and Construction Engineering, 12800 Pegasus Drive, ENG I Room 340, Orlando, FL 32816, United States
[b] University of Central Florida, Office of Research and Commercialization, 4365 Andromeda Loop N., MH 243, Orlando, FL 32816, United States

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ABSTRACT

This research sought to compare the effectiveness of three landfill enhanced treatment approaches aimed at removing releasable carbon and nitrogen after anaerobic landfilling including flushing with clean water (FB 1), leachate recirculation with ex-situ treatment (FB 2), and leachate recirculation with ex-situ treatment and in-situ aeration (FB 3). After extensive treatment of the waste in the FB scenarios, the overall solids and biodegradable fraction were reduced relative to the mature anaerobically treated waste. In terms of the overall degradation, aeration did not provide any advantage over flushing and anaerobic treatment. Flushing was the most effective approach at removing biodegradable components (i.e. cellulose and hemicellulose). Leachate quality improved for all FBs but through different mechanisms. A significant reduction in ammonia–nitrogen occurred in FB 1 and 3 due to flushing and aeration, respectively. The reduction of chemical oxygen demand (COD) in FB 1 was primarily due to flushing. Conversely, the reduction in COD in FBs 2 and 3 was due to oxidation and precipitation during Fenton's Reagent treatment. A mass balance on carbon and nitrogen revealed that a significant fraction still remained in the waste despite the additional treatment provided. Carbon was primarily converted biologically to CH_4 and CO_2 in the FBs or removed during treatment using Fenton's Reagent. The nitrogen removal occurred through leaching or biological conversion. These results show that under extensive treatment the waste and leachate characteristics did meet published stability values. The minimum stability values achieved were through flushing although FB 2 and 3 were able to improve leachate quality and solid waste characteristics but not to the same extent as FB 1.

1. Introduction

Municipal solid waste (MSW) generation reached 1.3 billion tonnes per year globally in 2010 and is projected to increase to 2.2 billion tonnes by 2025 (Hoornweg and Bhada-Tat, 2012). The projected increase in waste generation poses a significant challenge to disposing of this waste in a controlled and sustainable manner. Landfilling is still the primary method for waste disposal in both developed and developing countries despite the push to divert waste from landfills by recycling, mechanical and biological treatment, and thermal conversion. There were approximately 1908 operating landfills in the United States (U.S.) in 2011 and the number of mature landfills entering long-term care in the near future will increase (EPA, 2013).

After a landfill has been operated for an extended period of time and the concentration of anaerobically biodegradable organic compounds in the leachate are largely removed, leachate may contain inorganic contaminants and refractory organic by-products that potentially threaten the environment and human health. These contaminants include ammonia–nitrogen, pharmaceutical, personal care products, and heavy metals (Barlaz et al., 2002; Kjeldsen et al., 2002). Knowledge of the extent of waste stabilization and leachate quality is important when trying to determine when it is safe to release a landfill from long-term care. The extent of waste degradation is a major driver in evaluating when a landfill has reached completion and what the remaining pollution potential may be.

Modern landfills are designed and constructed with engineered containment systems that protect the environment. U.S. regulations require that, after a landfill is closed the cell is capped to avoid additional moisture intrusion (RCRA Subtitle D). Once capping is completed, waste degradation will slow or cease all together due to a lack of adequate moisture to sustain microbial degradation (Ritzkowski et al., 2006; Scharff, 2014). Although reducing leachate generation is advantageous for landfill owners/operators this design approach is not a sustainable practice; without sufficient moisture, complete stabilization of the

* Corresponding author.
E-mail address: Stephanie.Bolyard@ucf.edu (S.C. Bolyard).

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waste will not occur. Human health and the environment will only be protected as long as the designed containment systems remains intact (Scharff, 2014). If there is a breakdown in the integrity of the containment system long after a site has been released from post-closure care (PCC), moisture can be introduced, reinitiating the degradation process, and consequently leachate or gas emissions (Allen, 2001; Scharff, 2010; Tchobanoglous and Kreith, 2002). Therefore, to minimize the long-term environmental impact of landfills, enhanced emission reduction methods are needed prior to a breach of the containment system. It has been suggested that the introduction of liquid (e.g., flushing) and aeration are the best ways to safely reduce or end PCC (Ritzkowski et al., 2006; Stegmann et al., 2003). Flushing has been shown to remove releasable carbon and nitrogen but requires a large volume of water. Two alternative treatment processes have been suggested to reduce the water requirement and leachate requiring treatment as well as costs associated with the conventional means of flushing. Combining in-situ aeration with ex-situ chemical oxidation can provide the opportunity to remove recalcitrant carbon and biologically convert ammonia–N to nitrate or nitrogen gas.

A laboratory evaluation of three landfill enhanced treatment approaches aimed at removing releasable carbon and nitrogen species after anaerobic landfilling was conducted. The three landfill completion approaches include (1) flushing with clean water, (2) leachate recirculation with ex-situ treatment, and (3) leachate recirculation with ex-situ treatment and in-situ aeration. The latter scenario is referred to as Stabilization through Treatment, Aeration, and Bioreactor Leaching (STABL). This study aims to compare the effectiveness of the three approaches and to evaluate the technical and economic applications of landfill completion technologies.

2. Materials and methods

The feasibility of removing carbon and nitrogen to complete the treatment of landfilled waste was evaluated by operating laboratory-scale flushing bioreactors (FBs) under three different completion approaches depicted in Fig. 1.

2.1. Laboratory-scale anaerobic bioreactor operation

Synthetic waste was generated from new and post-consumer products. Synthetic waste was used to minimize variability in reactor operation that could result from using "real" waste and also to better define and understand the reactor inputs. A detailed breakdown of the initial waste composition can be found in the Supplemental Information (Table SI-1) which is based on waste generated in the U.S. Each waste component was individually weighed, then combined on a plastic tarp. After mixing, liquid was added to achieve a moisture content of 50% by weight. To ensure there was adequate buffering capacity and to avoid the reactors becoming acid-stuck, sodium bicarbonate was added to the distilled (DI) water for a final concentration of 3.4 g/L $NaHCO_3$. In addition to distilled water, anaerobically digested sludge, collected from a local wastewater facility, were added to provide a source of anaerobic organisms and decrease start-up time. Buffered DI water was initially added every three days to each reactor to generate a sufficient volume of leachate to be recirculated. Once a sufficient amount of leachate was generated, it was drained and recirculated every three days. This synthetic waste was degraded under anaerobic conditions in laboratory-scale anaerobic bioreactors (Bolyard and Reinhart, 2013) until a source of mature waste was achieved. The waste was deemed mature once the leachate five-day biochemical oxygen demand/chemical oxygen demand (BOD_5/COD) was less than 0.10.

2.2. Flushing bioreactor design and operation

Eighteen FBs were operated under three different scenarios (1) flushing with clean water (FB 1), (2) recirculation of leachate, external leachate oxidation using Fenton's Reagent, with no internal oxidation (FB 2), and (3) recirculation of leachate, external leachate oxidation using Fenton's Reagent, and internal aeration (FB 3). These scenarios are depicted in Fig. 1. The FBs were constructed from 20-l high-density polyethylene containers and were modified for leachate drainage and recirculation (FBs 1–3), and air addition of 0.17 m^3/h (FB 3 only), as shown in Fig. SI-1 of the Supplemental Information. An aquarium air compressor was used to inject air into FB 3 for continuous aeration. Air movement was countercurrent to leachate injection through a vertical perforated pipe, which was positioned approximately halfway into the waste mass to maximize nitrogen removal through both nitrification (aerobic upper zone) and denitrification processes (anoxic lower zone). Gas was not collected from the FBs.

Each FB was filled, without compaction, with approximately 4 kg of mature waste (wet weight) for a final density of

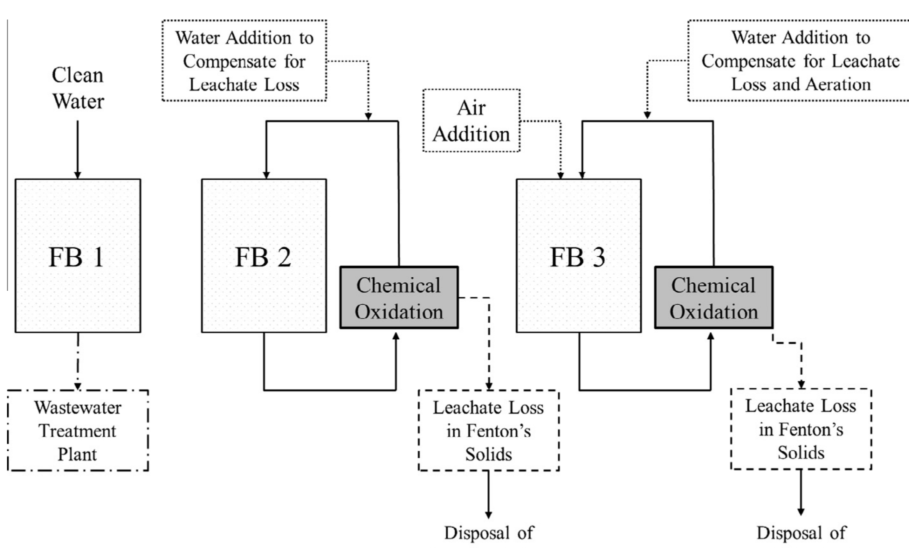

Fig. 1. Detailed flushing bioreactor operation.