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In situ nitrogen removal in phase-separate bioreactor landfill

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Abstract

The feasibility of in situ nitrogen removal in phase-separate bioreactor landfill was investigated. In the experiment, two sets of bioreactor landfill systems, namely conventional two-phase and in situ nitrogen removal bioreactor landfills, were operated. The in situ nitrogen removal bioreactor landfill (NBL) was comprised of a fresh-refuse filled reactor (NBLF), a methanogenic reactor (NBLM) and a nitrifying reactor (NBLN), while the two-phase bioreactor landfill (BL) used as control was comprised of a fresh-refuse filled reactor (BLF) and a methanogenic reactor (BLM). Furthermore, the methanogenic and nitrifying reactors used aged refuse as bulk agents. The results showed that in situ nitrogen removal was viable by phase-separation in the bioreactor landfill. In total 75.8 and 47.5 g of nitrogen were, respectively, removed from the NBL and the BL throughout the experiment. The methanogenic reactor used the aged refuse as medium was highly effective in removing organic matter from the fresh leachate. Furthermore, the aged refuse was also suitable to use as in situ nitrification medium. The degradation of fresh refuse was accelerated by denitrification in the initial stage (namely the initial hydrolyzing stage) despite being delayed by denitrification in a long-term operation.
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1. Introduction

Landfill is one of the most common techniques for the management of municipal solid waste around the world (Lei et al., 2007). However, the degradation of refuse is very slow, which made the stabilization of refuse in the common landfill taking long time. Furthermore, the treatment of leachate produced from the common landfill is difficult and costly due to the immense variety of organic, inorganic, heavy metal contents and C/N ratios throughout the whole life span. Recently, the bioreactor landfill which is based on the recirculation of leachate has been developed. Moreover, the notion has gained acceptance gradually, and bioreactor landfills have been reported to be practical and operational (Jiang et al., 2007).

Although the leachate recirculation could accelerate the stabilization of refuse and hence extend landfill air space, the disadvantages still remained in the bioreactor landfill. One of them is ammonia. The ammonia concentration of leachate often accumulated to a higher level in the bioreactor landfill than the common one because there was no degradation pathway for ammonia in anaerobic system. It has been suggested that ammonia is one of the most significant long-term pollutant problems in landfills and is likely a parameter that will determine when landfill post-closure monitoring may end (Berge et al., 2005). Moreover, the lower C/N ratio in the leachate from the bioreactor landfill also caused more serious challenges to the treatment system (Burton and Watson-Craik, 1998; Barlaz et al., 2002; Price et al., 2003; He et al., 2005; Luostarinen et al., 2006). Removal of ammonia from the leachate is currently practiced ex situ. However, ex situ treatment could be difficult and costly. Therefore, the development of an in situ nitrogen removal technique would be an attractive

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alternative, potentially yielding both economic and environmental advantages.

The landfill layer had no ability to treat the leachate in the initial degradation phase (Wang et al., 2006) and hence leachate recirculation probably caused an "ensiling process" in the bioreactor landfill. Some reports showed the methane production remained inhibited for over 1 year in a landfill moistened by leachate recirculation (O'Keefe and Chynoweth, 2000). Recirculating leachate within the same landfill cell could not correct the imbalance between acidogenesis and methanogenesis that formed in "ensiling process" (Dong et al., 2007). A two-phase treatment, namely an acid formation phase and a methane fermentation phase, was practiced pervasively in the organic fermentation process. Microorganisms in the acid formation phase and methane fermentation phase have different growth rates, optima for the environmental and nutrition. Thus, the optimization of these conditions would improve performance and enhance the solid waste stabilization rate in the first few years in the landfills. There have been some works about the bioreactor landfill based on the phase-separate principle (He et al., 2005, 2006, 2007; He and Shen, 2006). In addition, the nitrogen removal of leachate also could be processed simultaneously when the proper phase-separation was developed in the bioreactor landfill (Onay and Pohland, 1998; He et al., 2005; He and Shen, 2006).

In our investigation, three aspects were mainly taken into account. Firstly, the pollutants in leachate, especially ammonia, could be in situ removed effectively in the bioreactor landfill. The in situ nitrification–denitrification process appeared more promising than the conventionally adopted ex situ processes because of its lower operational cost and lower space requirement. There have been significant amounts of research on the evaluation of the fate of nitrogen in biological treatment processes and landfill leachate. However, only a limited number of them have been conducted on in situ removal of ammonia in the bioreactor landfills (Mertoglu et al., 2006). Secondly, based on the concept of phase-separation, aerobic nitrification (NBLN), anoxic denitrification and hydrolysis (NBLF), methanogenic reactor (NBLM) were, respectively, constructed in the bioreactor landfill. The organic matter in fresh-refuse was hydrolyzed and dissolved into the leachate in the anoxic denitrification and hydrolysis reactor. The resulting leachate was characterized as acidic and a high content of organic matter. The leachate was first fed to the methanogenic reactor for methanogenesis, and then the effluent was fed to the nitrifying reactor for the oxidization of ammonia to nitrate, the resulting effluent was finally recycled into the anoxic denitrification and hydrolysis reactor. Because methanogenesis not only produced enough alkalinity to buffer the acids but also eliminated the threat that heterogenic bacteria posed to nitrifying bacteria in the nitrifying reactor, it was the important to keep the process progressing successfully (especially in the initial phase). Thirdly, the aged refuse was used as a bulk agent in the methanogenic and nitrifying reactors. The aged refuse contains a wide spectrum and large number of microorganisms, which have a strong decomposition capability for refractory organic matter present in some wastewater (Zhao et al., 2007). Furthermore, the effect of leachate recirculation is maximized when a landfill reaches the stable phase (Wang et al., 2006). Additionally, the in situ nitrification of ammonia was more economical and could typically occur in older landfills (Ritzkowski et al., 2006; Berge et al., 2006).

2. Methods

2.1. Experimental designation

In the experiment, two types of phase-separate bioreactor landfills were designated and operated. In situ nitrogen removal bioreactor landfill (NBL) was comprised of methanogenic reactor (NBLM), nitrifying reactor (NBLN) and the fresh-refuse filled reactor (NBLF). The two-phase bioreactor landfill (BL) was used as control, which was comprised of methanogenic reactor (BLM) and the fresh-refuse filled reactor (BLF). The schematic configurations are shown in Fig. 1.

All the reactors were constructed with PVC. The fresh-refuse filled and nitrifying reactors had a diameter of 28.7 cm and length of 100 cm, while the methanogenic reactor had a diameter of 28.7 cm and length of the 65 cm.

2.2. Simulated bioreactor landfill loading and the characteristics of refuse

All the refuse was cut into pieces of 3 cm approximately and mixed before loading. The methanogenic and nitrifying reactors were loaded with 26.5 and 50 kg of aged refuse at a wet density of 940 and 980 kg m^{-3}, respectively. The aged refuse was excavated from Hangzhou landfill in China and had a placement time of 6–7 years, its characteristic followed as: TN, 4191 mg N kg^{-1} dry refuse; VS (w/w), 17.3%; BDM (w/w), 8.2%; pH, 7.59; moisture content, 38.2%.

Both the fresh-refuse filled reactors were packed with 27.4 kg of fresh refuse at a wet density of 680 kg m^{-3}. The fresh-refuse was collected from Caihe transfer station of Hangzhou, whose physical composition of fresh-refuse was (by wet weight, w/w): residues of kitchen, 57.9%; papers, 7.0%, plastics, 5.0%; cellulose textile, 3.0%; glass, 2.6%; woods, 7.7%; brick and soil, 16.8%. The initial characteristics of fresh-refuse were: TN, 12330 mg N kg^{-1} dry refuse; VS (w/w), 60.8%; BDM (w/w), 41.9%. In addition, the moisture content of refuse in the fresh-refuse filled reactor was adjusted to 70% at the beginning of operation.

2.3. Design and operation of the bioreactor landfills

All the reactors were placed in room temperature and semi-continuously operated during the experiment. The

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