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Landfill leachate pollutant removal performance of a novel biofilter packed with mixture medium

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ABSTRACT

Landfill leachate pollutants were treated in a biofilter filled with a mixture of aged refuse and slag, and the performance was compared with those reactors filled solely with either medium. Cultural counting method showed that bioreactor filled with slag had the highest amount of nitrifying bacteria, while polymerase chain reaction–denaturing gradient gel electrophoresis method showed that reactor filled with both media had the highest bacterial community diversity. Particle size distributions measurement showed that slag contained less fine particles than aged refuse, which provided better permeability. The reactor containing both media exhibited a high efficiency in removal of pollutants, and a higher resistance to shock loading and low temperature compared with single-medium reactors. It also overcame both the poor permeability of aged refuse filling and the low bacteria diversity of slag. The study shows that a mixture of aged refuse and slag as a new biofilter medium for leachate pollutant removal is technically viable.

1. Introduction

Landfill leachate is complex wastewater generated from sanitary landfill. A combination of physical, chemical and microbial process is involved in converting the solid waste into liquid form. Leachate contains a considerable amount of organic compounds, nutrients (nitrogen, phosphorus), minerals and heavy metals. As a result of variable leachate composition from different landfills, leachate treatment methods have not been unified so far (Dorota and Ewa, 2008). Landfill leachate treatment usually involves a multistage system of chemical, physical and biological processes (Alessandro and Stefano, 2008), and its treatment cost is higher than that of municipal and industrial wastewater (Kjeldsen et al., 2002; Renou et al., 2008).

Biofilter, an effective way to remove pollutants, ammonia nitrogen in particular, in landfill leachate, has received considerable study. Medium, as the major component of a biofilter, should not only be beneficial to pollutants removal, but also be clog resistant and available at a low cost (Jokela et al., 2002; Zhao et al., 2002; He et al., 2006). Currently, the well-decomposed waste through years in the landfill (aged refuse) is commonly used as a bioreactor/biofilter packing medium for the treatment of leachate. The efficiency in pollutants removal is mainly from its physicochemical and microbiological properties (Zhao et al., 2007), and the biofilter has already been found to be practical and operational in treating landfill leachate in previous reports (Jiang et al., 2007). There is, however, room for improvement in shock load performance and clog resistance. Solid waste discharged from steel refineries and power plants (slag) performs well in adsorbing contaminants in wastewater, in which it finds its wide use (Shilton et al., 2006; Yang et al., 2009; Pratta et al., 2009). Although treatment of municipal wastewater with it in aerated biofilter and constructed wetland has been reported (Lan et al., 2007; Korkusuz et al., 2007), little work has been done on its use in the treatment of leachate.

A bioreactor's microbial population is responsible for the decomposition of leachate pollutants. To gain biological insights of the process, microflora has been investigated using culture-dependent methods (Eichner et al., 1999; Muyzer 1999). As a molecular biological method currently used for analysing change in microbial demographics in an environmental sample, polymerase chain reaction-denaturing gradient gel electrophoresis (PCR–DGGE) is extensively used in analysis of sediment, activated sludge and manure slurry samples (Hanajima et al., 2009; Xie and Yang, 2009; Zeng et al., 2009). However, few studies have used this method to study microbial diversity in the context of biological treatment of leachate.

In this study, a mixture of aged refuse and slag has been used to build a biofilter and its performance was compared with reactors concurrently built and solely filled with aged refuse or slag. The

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purposes of this paper are: (1) compare pollutants removal efficiencies of the biofilters, (2) compare permeability and clog resistance properties by analyzing surface properties of the packing medium and particle size, (3) analyse microbial communities on packing material's biofilm in the biofilters, including bacterial diversity, using conventional microbiological and PCR–DGGE methods, (4) reveal the relation between packing materials and pollutants removal efficiency, and discuss the prospect of practical application of the newly developed mixed biofilter as the first part treatment of the landfill leachate.

2. Methods

2.1. Bioreactor system

Aged refuse about 10 years old was excavated from a landfill cell in the Shanghai Laogang Disposal Plant. Plastic bags and massive inorganic waste (diameter $\Phi > 100$ mm) were removed on site, and the rest coarsely shredded by hand in the lab ($\Phi < 50$ mm). Slag was collected from a power plant (major components (%): SiO_2 55; Al_2O_3 27; Fe_2O_3 5; CaO 3; K_2O 3; TiO_2 1). The characteristics of aged refuse and slag are listed in Table 1.

Three simulated, all made of PVC plastic columns with an inner diameter of 30 cm and height of 150 cm, were used for the experiments. These columns were operated as the bioreactor landfill with leachate treatment. R1 is the reactor filled with a mixture of aged refuse and slag at a v/v ratio of 2:1, while R2 and R3 were filled solely with either aged refuse or slag, respectively (Fig. 1). The rationale for the 2:1 mixture ratio was that higher percentage of age refuse might clog the reactor and higher percentage of slag might prolong the microorganism's growth time in the medium.

Table 1
Characteristics of aged refuse and slag in this experiment.

	Density (g/cm^3)	Porosity (%)	Organic carbon content (%)	Water content (%)	Heterotrophic bacteria count (cfu/g·d.w.)
Aged refuse	1.60–1.76	0.28	8.0	12.0	10^5–10^6
Slag	1.69–1.87	0.32	1.6	10.0	10^2–10^3

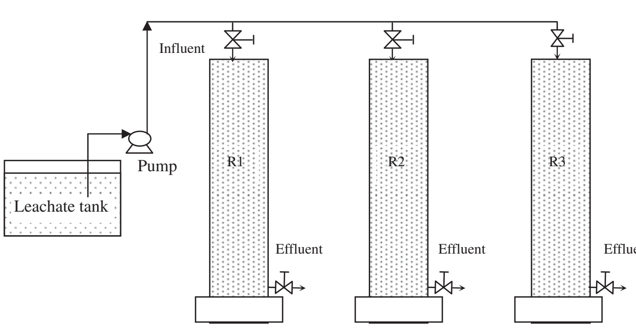

Fig. 1. Schematic diagram of bioreactors.

The initial packing density of the medium was approximately 1200 kg/m^3. A grave layer, about 5 cm thick, was placed below and above the medium layer of each column for leachate drainage and recycled leachate distribution. The biofilter reactors were placed in a sealed and thermostat-controlled room.

The leachate used was taken from the regulating pool of the Shanghai Laogang Disposal Plant. The composition of the influent leachate is given in Table 2, and the metal concentrations in influent were lower than the National Emission Standard (GB8978-1996) except the copper was a bit higher than the standard level.

The experiment was divided into three stages. In the initial stage, spanning the first 9 weeks, aged leachate with a chemical oxygen demand (COD) about 2000 mg/L was used (Berge et al.,2006). The temperature was controlled at 30 °C, hydraulic loading was 20 L/m^3 d, and retention time was 10–14 days. Acclimation took place during this stage (weeks 1–9).

In the second stage, which was from weeks 10–19, fresh leachate was added to raise COD to 5000–8000 mg/L and temperature was lowered to 20 °C. The hydraulic loadings in R2 and R3 were unchanged but that in R1 was raised to 40 L/m^3 d. The retention time was shortened to 5–7 days. In this hydraulic load raising stage, the effects of lowered temperature and increased load on treatment efficiency were examined.

In stage III, spanning from week 20 to 27, the temperature was further lowered to 10 °C and hydraulic loading was unchanged. The efficiency of pollutant removal in reactors at low temperatures was examined.

2.2. Sampling and analytical methods

Leachate samples were collected every week from the effluent port of each reactor and concentrations of COD_{Cr}, five day biological oxygen demand (BOD_5), ammonia nitrogen (NH_4^+–N), oxidation nitrogen (NO_x^-–N) and total nitrogen (TN) were determined according to the standard methods (APHA-AWWA-WEF, 1998). Oxidation–reduction potential (ORP) and pH values were measured with a digital meter pHS-25 (Shanghai Leici Instrument Co., China). Solid samples were taken from the middle port of each reactor at the 9th, the 15th and the 20th weeks.

2.3. Scanning electron microscopy (SEM) observation

Light microscopy and SEM were performed to identify the biofilm. Aged refuse and slag samples were collected from R2 and R3 after 9 weeks of operation, fixed with 2.5% glutaraldehyde in saline phosphate buffer for 2 h at 4 °C and post-fixed with 1% osmium tetroxide in the same buffer for 1 h. Samples were dehydrated and coated with a 25 nm layer of gold–palladium mixture and examined with the SEM (JSM-5610LV) at 5000–10,000× magnification.

2.4. Microorganism counting

From each column, 1 g of solid samples at different stages were collected and each sample was put into a 99 mL flask with distilled water, then vortexed 30 min and swirled under sonication for 2 min. The cell numbers of bacteria were determined by serial dilution. The culture medium of heterotrophic bacteria was Lurina-

Table 2
Influent composition at different stages (in mg/L except pH and ORP).

Stage	COD_{Cr}	BOD_5	NH_4^+–N	NO_x–N[a]	TN	pH	ORP mv
I	~2000	250–300	1700–2000	~10	~2000	~8.0	~−300
II and III	5000–8000	1300–2000	1500–2800	~10	2000–3000	~8.2	~−340

[a] Including NO_2^-–N and NO_3^-–N.