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Effects of exogenous aerobic bacteria on methane production and biodegradation of municipal solid waste in bioreactors

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ABSTRACT

Landfill is the most common and efficient ways of municipal solid waste (MSW) disposal and the landfill biogas, mostly methane, is currently utilized to generate electricity and heat. The aim of this work is to study the effects and the role of exogenous aerobic bacteria mixture (EABM) on methane production and biodegradation of MSW in bioreactors. The results showed that the addition of EABM could effectively enhance hydrolysis and acidogenesis processes of MSW degradation, resulting in 63.95% reduction of volatile solid (VS), the highest methane production rate (89.83 L kg^{-1} organic matter) ever recorded and a threefold increase in accumulative methane production (362.9 L) than the control (127.1 L). In addition, it is demonstrated that white-rot fungi (WRF) might further promote the methane production through highly decomposing lignin, but the lower pH value in leachate and longer acidogenesis duration may cause methane production reduced. The data demonstrated that methane production and biodegradation of MSW in bioreactors could be significantly enhanced by EABM via enhanced hydrolysis and acidogenesis processes, and the results are of great economic importance for the future design and management of landfill.

1. Introduction

In the past century, as the world's population grew to be more concentrated in urban areas and affluent, waste production has risen tenfold (Hoornweg et al., 2013). Global municipal solid waste (MSW) production reached 1.3 billion tons per year in 2010 and it is expected to increase to 2.2 billion tons per year by 2025 (Hoornweg and Bhada-Tata, 2012). Disposal of MSW is of growing importance and the landfill technology is the most common and efficient way to achieve this objective. 54% of all solid waste produced in the United States was transported to landfill in 2010 (US EPA, 2012). While in 2011, 77% of all solid waste produced in China went to landfills (National Bureau of Statistics, 2012). However, the landfill gas (LFG) produced by microorganisms within a landfill, mostly methane and carbon dioxide, could contribute to the greenhouse effect if it released into the air directly. Alternatively, methane can be collected and used as an excellent fuel to generate electricity and heat. By the year of 2012, there are approximately 50 MSW to energy facilities in operation in China, with an installed capacity of 100 MW, but maintenance is costly (Zheng et al., 2014). Therefore, it is of great economic and social importance to effectively manage landfill to support maximum methane production within limited time.

The landfill gas is produced via chemical and biological reactions of microorganisms with the waste, and the production rate is depended on the waste composition, landfill geometry, and microbial populations. Currently, numerous studies have focused on the effects of various physical and chemical operational parameters to enhancing methane production and biodegradation of MSW. It has been reported that leachate recirculation, recirculation volume, waste shredding, waste compaction, control of moisture content and temperature, pH adjustment, aeration and addition of sludge, nutrient and gravel can be used to enhance biological degradation of the waste in bioreactors (Reinhart et al., 2002; Valencia et al., 2009; Warith, 2002). However, there are limitations to existing technology in field application and the conditions of landfills are difficult to modify after construction.

In recent years, there has been increasing interest in studying the effect of microorganisms on substrate degradation and

Abbreviations: EABM, exogenous aerobic bacteria mixture; WRF, white-rot fungi; LFG, landfill gas.

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methane production in landfill (Divya et al., 2015). It has been reported that in the landfill, the degradation of solid waste results from various physical, chemical and biological reactions occurring simultaneously with interactive relations (Barlaz, 1997), and bacteria play a crucial role among those complicated reactions (Sawamura et al., 2010). The process for organic waste decomposition generally takes place in four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Rich et al., 2008). The organic wastes such as protein and lipids are firstly hydrolyzed by aerobic microorganisms to monosaccharides, amino acids and fatty acids and then these hydrolysis products were broken down into H_2, CO_2 and organic acids (Sang et al., 2012). Finally, methanogenic microorganisms convert these products into methane in anaerobic condition. Therefore, the optimization of microbial population in landfill is regarded as rational method to enhance the solid waste degradation. For instance, researchers have observed increased methane production when dungs containing highly active microbial communities are introduced in food waste as an additive (Dhamodharan et al., 2015; Eze and Agbo, 2010). Some enzymes like lignin peroxidases, polyphenol oxidases, manganese dependent peroxidases, and laccases were used as additives to lignin-rich MSW to enhance methane production (Jayasinghe et al., 2012; Schroyen et al., 2014; Shah et al., 2015).

Methane generation of MSW begins with the degradation of organic matter, thus we investigated whether methane production can be enhanced by promoting the degradation of the organic matter. Therefore, some aerobic bacterial strains with high protein and lipid enzyme activity were isolated and added in MSW to promote methane production. Lignin can be only partly degraded to monomeric compounds by hydrolysis and is mostly degraded by attack on the C–C bonds. It was shown that the side chain and aromatic rings of lignin model compounds were oxidatively cleaved via aryl cation radical and phenoxy radical intermediates in reactions mediated by lignin peroxydase (Lip)/H_2O_2, and laccase (LA)/O_2 mediator (Higuchi, 2006). And therefore increase the methane production (Liu et al., 2014; Shah et al., 2015; Taherzadeh and Karimi, 2008). We expected the addition of WRF would help to enhance the methane production of MSW in bioreactors.

The aim of this work is to study the effects and the role of EABM and WRF on the biodegradation and methane production of MSW in laboratory-scale bioreactors, and then provide a practical method for the design and management of landfills. The results showed that the EABM can promote the degradation of organic matter, enhance the hydrolysis and acidogenesis process, accelerate the acetogenesis and methanogenesis, and increase the cumulative methane production almost three times more than the control. The results obtained are of great importance for the future design and maintenance of landfill.

2. Materials and methods

2.1. Materials

Preparation of aerobic bacterial mixture: Five aerobic bacteria strains with high protein and lipid enzyme activity were screened and isolated from MSW in previous work and identified as *Bacillus cereus*, *B. subtilis*, *Staphylococcus saprophyticus*, *Staphylococcus xylosus* and *Pantoea agglomerans* (data unpublished). A white-rot fungal (WRF) strain *Phanerochaete chrysosporium* was stored at 4 °C in our lab. All bacteria strains were grown in medium composed of agricultural byproduct (soybean meal 2.4%, starch 1.6% and fish meal 1%, pH 7.0) at 30 °C, 200 rpm overnight, and WRF was cultured in the potato medium at 30 °C, 200 rpm for 72 h. The aerobic bacterial mixture composed of five strains was obtained by mixing the five individual bacterial liquid cultures at the ratio of 1:1:1:1:1. WRF mycelia pellets were harvested directly from culture by centrifugation (3000 rpm, 15 min).

The collected MSW from a landfill site in Huangjinkou, Wuhan were sorted as food residual, paper and leaves, plastic, cloths, metal, glass and stone by weight. The artificial MSW used in this study was prepared according to the method described in previous studies (Ağdağ and Sponza, 2005; Chiemchaisri et al., 2002; Šan and Onay, 2001), with 69% food residual, 14% paper and leaves, 2% plastic, 8% cloth, 2% metal, 3% glass and 2% stone. In order to accelerate waste degradation and to facilitate compaction, solid waste was shredded to diameter of 5 cm and well mixed (Jayasinghe et al., 2011).

2.2. Experiment setup

The bioreactors were made up of acrylic material with 8 mm thickness, internal diameter of 0.2 m and height of 0.66 m (Fig. 1). Each bioreactor consisted of leachate collection, sampling, recirculation, and gas collection and MSW sampling pot. Every bioreactor was filled with 10 kg gravel stones at the bottom (about 10 cm height), above that was 10 kg MSW (about 45 cm) with 2 kg soil layer (about 5 cm) covered on the top (Table 1). An opening was created to each bioreactor on one side for sampling (Fig. 1). All bioreactors were kept and operated in a laboratory at room temperature. Leachate was collected at the bottom of the bioreactor for sampling and was recirculated back to the bioreactor through the pipe by pumping.

2.3. Experiment procedure

The control bioreactors R1 and R2 were sprayed and well mixed with 1 kg water and 1 kg culture medium, respectively. The EABM was added at the ratio of 1.0, 1.0, 0.5 and 0.25 kg per 10 kg of MSW in R3, R4, R5 and R6, respectively (Table 1), and additional WRF was supplemented in R4 for evaluating its effect on lignin decomposition. The water content of each sample was adjusted by spraying water accordingly to maintain the same moisture content during the experiment in all bioreactors. The bioreactor experiments lasted 55 days until no methane production could be recorded.

2.4. Sampling and analytical methods

Biogas was collected every day, leachate and MSW samples were collected and measured every two days for pH, COD, BOD_5,

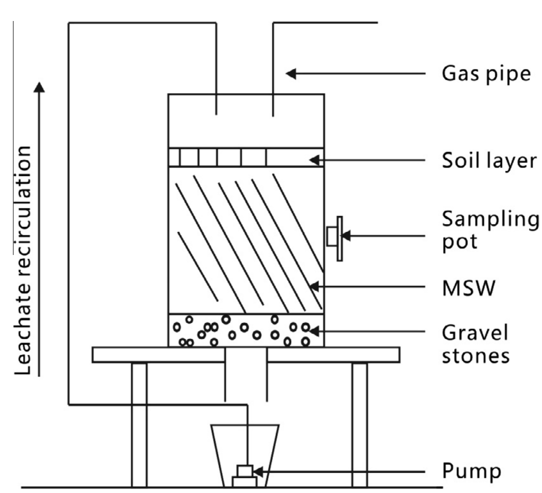

Fig. 1. Scheme of bioreactors.