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Degradation of municipal solid waste in simulated landfill bioreactors under aerobic conditions

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ABSTRACT

In this study the municipal solid waste degradation processes in simulated landfill bioreactors under aerobic and anaerobic conditions is investigated. The effect of waste aeration on the dynamics of the aerobic degradation processes in lysimeters as well as during anaerobic processes after completion of aeration is presented. The results are compared with the anaerobic degradation process to determine the stabilization stage of waste in both experimental modes. The experiments in aerobic lysimeters were carried out at small aeration rate ($4.41 \cdot 10^{-3}$ l min^{-1} kg^{-1}) and for two recirculation rates (24.9 and 1.58 l m^{-3} d^{-1}). The change of leachate and formed gases composition showed that the application of even a small aeration rate favored the degradation of organic matter. The amount of CO_2 and CH_4 released from anaerobic lysimeter was about 5 times lower than that from the aerobic lysimeters. Better stabilization of the waste was obtained in the aerobic lysimeter with small recirculation, from which the amount of CO_2 produced was larger by about 19% in comparison with that from the aerobic lysimeter with large leachate recirculation.

1. Introduction

Municipal waste includes organic matter which, as a result of decomposition, may pose a threat to the environment. In an anaerobic landfill, biogas produced from organic matter can be used for energy production for a period of 10–20 years. This period is followed by a slow methane production, which can last for several decades (Ritzkowski and Stegmann, 2003). Full biological stabilization of an anaerobic landfill can be reached even after 100 years (Rich et al., 2008).

To reduce the negative impact of anaerobic landfills on the environment, intensive studies have been carried out on aerobic landfills because organic matter decomposition under aerobic conditions is faster than under anaerobic ones (Hantsch et al., 2003). During the decomposition of organic matter by heterotrophic microorganisms under aerobic conditions mostly carbon dioxide is produced (Mertoglu et al., 2006). Waste aeration leads to a reduction of pollutant loads in the leachate characterized by biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) (Bilgili et al., 2006, 2007; Borglin et al., 2004; Cossu et al., 2003; Erses et al., 2008; Hashisho and El-Fadel, 2014; Read et al., 2001; Ritzkowski and Stegmann, 2005). Additionally, the volume of leachate decreases during aeration because of water evaporation caused by elevated temperature within the waste (Read et al., 2001). Other benefits resulting from the use of aerobic decomposition of organic matter includes reduced odor emissions, enhanced waste settling rates and decreased production of methane.

The main disadvantage of organic matter decomposition under aerobic conditions is high energy consumption connected with waste aeration. Optimum conditions for the decomposition of organic matter and minimization of energy consumption can be reached by an appropriate selection of operating parameters such as the rate of aeration and leachate recirculation (Rich et al., 2008).

The strategy of reduction of biodegradable wastes which are to be deposited (EU Directive no. 99/31 of 26 April 1999) would cause a decline of methane production in anaerobic landfills. A decrease of organic matter content in municipal wastes will elicit a faster stabilization of wastes in the aerobic landfill and a reduction of energy consumption used for waste aeration. Recently, an interest in aerobic landfills has increased and investigations have been carried out at both laboratory and field scales. Aerobic landfills were investigated in bioreactors (lysimeters) by Bilgili et al. (2006, 2007), Borglin et al. (2004), Cossu et al. (2003), El-Fadel et al. (2013), Erses et al. (2008) and Stessel and Murphy (1992). Studies on aerobic landfill were carried out at various rates of aeration and leachate recirculation.

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Organic matter decomposition in the aerobic landfills was studied by Read et al. (2001) and Jacobs et al. (2003). Read et al. (2001) observed that waste aeration induced faster stabilization of the waste load, enhancement of landfill settling, reduced methane production, decrease of the amount of leachate and significant reduction of pollutants in the leachate. In the studies carried out by Jacobs et al. (2003), a significant reduction in odor emission during waste aeration was observed.

Waste aeration is also employed to stabilize old municipal landfills. Recovery of landfill gas in such cases is not economical because of insufficient gas production. The aerobic stabilization of old municipal landfills was investigated by Hantsch et al. (2003), Prantl et al. (2006), Raga and Cossu (2014), Ritzkowski et al. (2006) and Zieleniewska-Jastrzebska et al. (2007). The researchers observed a positive effect of aerobic conditions on the stabilization of old municipal landfills.

The stabilization of the waste can be characterized by a number of parameters such as: respiration activity (AT_4), gas production coefficient (GB_{21}), ratio C/N, respiratory quotient (RQ), BOD_5, COD, and BOD_5/COD ratio. Also, changes in the gas and leachate composition after aeration completion are used to determine the stabilization of waste. In the literature, there are short descriptions of the processes which occur in waste after the completion of aeration (Prantl et al., 2006; Slezak et al., 2010a).

The aim of this study was to carry out experimental simulations of the processes observed in the municipal landfills under both anaerobic and aerobic conditions. In the aerobic landfill, the effect of leachate recirculation rate on organic matter degradation was investigated. Based on the results obtained, processes under aerobic and anaerobic conditions were compared. Additionally, when the waste aeration had been completed, the composition of leachate and biogas was measured in order to determine the level of waste stabilization.

2. Materials and methods

The experimental simulation of a landfill was carried out in three lysimeters (A1, A2, AN) of the working volume 15 l. The lysimeters consisted of a PVC cylinder of 0.15 m in inner diameter and 1.15 m in height; under the lysimeter there was a collection vessel for recycled leachate. A detailed description of the lysimeters with a control and measuring system is given by Slezak et al. (2010b). In lysimeters A1 and A2 an aerobic landfill was investigated. Both lysimeters were continuously aerated with the same aeration rate ($4.41 \cdot 10^{-3}$ l min^{-1} kg^{-1}), and the daily leachate recirculation rate was 24.9 and 1.58 l m^{-3} d^{-1}, respectively. The aeration rate was smaller than those used previously in experiments in order to check whether small amounts of supplied air would be sufficient. In the research of Bilgili et al. (2006, 2007), Borglin et al. (2004), Cossu et al. (2003) and Erses et al. (2008) the aeration rate was in the range 0.012–0.22 l min^{-1} kg^{-1} and the applied leachate recirculation rates ranged from 0.35 to 144 l m^{-3} d^{-1} (Table 1). The rate of leachate recirculation in lysimeter A2 was similar to the values used in the work of Erses et al. (2008). While in lysimeter A1 approx. 16 times higher recirculation rate was used, which allowed to conduct research at a large flow of leachate and low aeration rate. An even greater recirculation rate was applied by Borglin et al. (2004) in laboratory studies of the aerobic landfill.

Aeration of the aerobic lysimeters commenced on the 8th day after loading the lysimeters and was continued for 196 days. The duration of aeration was chosen based on previously conducted research (Slezak et al., 2012). Additionally, in the aerobic lysimeters, gas and leachate composition was monitored for 43 days after terminating aeration. The rate of leachate recirculation in the lysimeter prior to and after aeration commencement was the same as after the end of the aeration. Simulation of the anaerobic landfill in lysimeter AN was carried out for 247 days (239 days from when the lysimeters started to be aerated). In the lysimeter AN, the rate of leachate recirculation was 9.08 l m^{-3} d^{-1}.

Table 1
Operating parameters of an aerobic landfill simulation.

	Leachate recirculation rate (l m^{-3} d^{-1})	Aeration rate (l min^{-1} kg^{-1})	Lysimeter volume (l)	Duration of aeration (d)
Bilgili et al. (2006, 2007)	0.35	0.084 0.086	390	250
Borglin et al. (2004)	144	0.039	200	400
Cossu et al. (2003)	7	0.22 0.012	25	120
Erses et al. (2008)	1.5	0.023	96	374
This work	1.58 – lysimeter A2 24.9 – lysimeter A1	$4.41 \cdot 10^{-3}$	15	196

The municipal solid model waste was composed of organic waste (28%), paper (19%), plastics (12%), textiles (4%), compost (27%) and inorganic matter (10%) (Slezak et al., 2010b). The content of carbon and nitrogen in the waste amounted to 32.3% and 0.51% by weight, respectively. Each lysimeter was loaded with 5.0 kg of wet municipal solid model waste with a moisture content of 32.0% by weight. The compost added to the lysimeters served as an inoculum for aerobic and anaerobic processes. Total dry mass (DM) of model wastes in the lysimeter was 3.4 kg. To ensure appropriate moisture content in the waste and leachate to be recirculated, at the start of the experiment 5.0 l of distilled water was added to each lysimeter. The water content in the waste after water addition was 53.4% by weight.

In order to better understand the simulated process of experimental municipal landfills in the lysimeters, wastes, leachate and gas were analyzed. The analysis of the composition of gas and leachate in the lysimeters started on the 8th day after lysimeter load and was continued for 239 days. In the first three weeks of the processes, samples for analysis were taken every 5 days on average, on subsequent days samples were taken every 17 days. Once the aeration of aerobic lysimeters was completed, the frequency of sampling the leachate and gas was increased because of intensive changes of these parameters. The leachate was analyzed every 14 days, and the gas every 7 days on average.

In the sampled leachate, the following indices were analyzed: chemical oxygen demand by the dichromate method, total organic carbon (using analyzer (IL 550 TOC-TN, Hach-Lange) and ammonium nitrogen by the distillation method in the Büchi device. In the gas leaving the lysimeters, the concentration of oxygen (O_2), methane (CH_4) and carbon dioxide (CO_2) was measured using a gas content analyzer LMS GAS DATA, and the gas flow rate was assessed using a Ritter flow-meter. Dry matter of the model waste was determined by a gravimetric method. The elemental composition of waste expressed as carbon and nitrogen content was determined by means of an elemental analyzer NA 2500 (CE Instruments). All analytical procedures were performed in accordance with Standard Methods (APHA, 1998). The rate of oxygen consumption was calculated according to the formula (1):

$$S = \frac{32}{22.4} P \left(\frac{21 - c}{100} \right) \qquad (1)$$