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Municipal waste stabilization in a reactor with an integrated active and passive aeration system

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ABSTRACT

To test whether an integrated passive and active aeration system could be an effective solution for aerobic decomposition of municipal waste in technical conditions, a full-scale composting reactor was designed. The waste was actively aerated for 5 d, passively aerated for 35 d, and then actively aerated for 5 d, and the entire composting process was monitored. During the 45-day observation period, changes in the fractional, morphological and physico-chemical characteristics of the waste at the top of the reactor differed from those in the center of the reactor. The fractional and morphological analysis made during the entire process of stabilization, showed the total reduction of organic matter measured of 82 wt% and 86 wt% at the respective depths. The reduction of organic matter calculated using the results of Lost of Ignition (LOI) and Total Organic Carbon (TOC) showed, respectively, 40.51–46.62% organic matter loss at the top and 45.33–53.39% in the center of the reactor. At the end of the process, moisture content, LOI and TOC at the top were 3.29%, 6.10% and 4.13% higher, respectively, than in the center. The results showed that application of passive aeration in larger scale simultaneously allows the thermophilic levels to be maintained during municipal solid waste composting process while not inhibiting microbial activity in the reactor.

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1. Introduction

Active aeration is typical in mechanical–biological treatment (MBT) systems based on aerobic stabilization and biodrying. At larger scales (full to industrial), however, one-way aeration of municipal waste without mixing the waste creates a temperature gradient, which leads to a lack of homogeneity in the moisture and energy content of the final product (Sugni et al., 2005). Another problem is how to adjust the process of aeration. In the process of aerobic stabilization, air–gas conditions, temperature, and hydration are optimized in order to enhance the mineralization of organic matter. However, with the progressive mineralization of organic matter, calorific value of stabilized waste decreases (Adani et al., 2002). Thus, at industrial scale, to obtain a product of high biological stability and high calorific value might be problematic.

For this reason, various attempts have been made in recent years to improve techniques for aerating organic waste. Bari and Koenig (2001) used internal recirculation of air in a single reactor system and reuse of spent air in a two-reactor system in series for composting a mixture of presorted food waste, wastepaper and sawdust. Sugni et al. (2005) tested at laboratory scale periodic inversion of a reactor to change the direction of aeration during biodrying of municipal waste. As a result, the authors limited the conditions causing poor homogenization of the biodrying product which resulted from the presence of a temperature and moisture gradient. Xiao et al. (2009) used an incubator for rapid biodegradation of organic municipal waste and maintained the thermophilic temperature in a compost pile by changing aeration frequency. The authors compared the compost quality of five different processes. They concluded that rapidly heating the composting waste to 50 °C and maintaining that temperature during the whole composting process could apparently shorten the composting cycle without degradation of compost quality. Interestingly, Zhang et al. (2008a,b) found that when conventional aerobic biodrying was modified by combining it with a hydrolytic stage with low-frequency ventilation, the moisture content of the waste was reduced by 78.5% w/w.

A simple alternative for waste aeration may be passive aeration. Effectiveness of passive aeration is fairly well recognized (Ogunwande and Osunade, 2011; Karnchanawong and Suriyanon, 2011). However, most studies have been conducted using agricultural waste. Patni et al. (2001) found that passive aeration is cheaper to operate, while also being of comparable efficacy to active aeration. In the production of poultry manure fertilizer, passive aeration can also lead to lower nitrogen losses. Similar

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conclusions were reached by Jiang et al. (2015), who compared passive aeration with different forced aeration rates during composting of pig feces and corn stalks. The authors showed that forced aeration accelerated the maturating process, but did not improve the quality of the end product. Mason et al. (2004), at pilot-scale, successfully composted high-moisture bovine manure using sawdust or paper as amendments and woodchips as the bulking agent. The use of a passive aeration system allowed thermophilic temperature to be reached within 3 days of pile formation and maintained for up to 54 days. Zhan et al. (1992) obtained temperatures in the range of 60–88 °C after three days of composting poultry manure with peat.

Relatively few studies have focused on the use of passive aeration for the stabilization of municipal solid waste. Our previous work (Kasinski and Wojnowska-Baryla, 2014) showed that over 25 days, a passively aerated reactor enables effective stabilization of organic fraction of municipal solid waste (OFMSW) in laboratory conditions. However, during the early stages of tests in full-scale it was found that 25 days was too short for effective composting, so the time would be increased to 35 days. A further complication noted in the previous research (although not mentioned in the cited paper) was that despite high stability of waste, passive aeration alone resulted in odor problems and higher moisture content of waste. Therefore, the question was posed as to whether a combined aeration system would be capable of bringing the advantages of both methods together; the lower odor problems and lower waste moisture content of active aeration, as well as the effective and cheap stabilization offered by passive aeration. A forced aeration system was added to the reactor and the 35 day period of passive aeration would now be preceded by a 5 day deodorization period (active aeration) and followed by a 5 day drying period (active aeration). The time for deodorization was based on a study by Smet et al. (1999), who showed that the emission of volatile organic compounds during the aerobic composting occurs mainly during the first week.

The aim of the present study was to analyze the effectiveness of aerobic stabilization of municipal waste in a large scale passively aerated reactor supplemented by two short active aeration modes. The scope of the investigation included the following: (a) monitoring the physico-chemical, fractional and morphological changes of the waste at two depths in the reactor during the process of municipal waste biodegradation; (b) monitoring and measuring the volume and physico-chemical characteristics of the leachate generated during the process; (c) evaluating the effectiveness of the process by calculating the loss of organic matter based on the physico-chemical characteristics of waste before and after stabilization.

2. Materials and methods

The test was performed in closed technology hall of the Department of Municipal Waste Management of Olsztyn, Poland, which ensured the stable values of the air temperature (around 20 °C). The reactor, with an integrated active and passive aeration system, was specifically designed for this experiment by Waste Biosolutions Ltd., Poland. As such it is considered "full scale" but, should the results be positive, it may be considered as a pilot model for further research or application. It was made of steel with a thickness of 5 mm and protected by anticorrosion paint. The working volume of the reactor was about 30.55 m^3. A galvanized-steel grating with a size of 20 × 20 mm was mounted at a height of 0.3 m from the bottom.

The waste mass was aerated by two fans, with a total capacity of 0.72 kW and a total air flow rate of 4920 m^3/h. The working pressure of a single fan could reach 360 Pa. Passive aeration was enabled by eight dampers located in the side walls of the reactor. The dampers closed automatically during active aeration and opened during passive aeration. In the side wall of the reactor, the temperature electrodes were mounted in six holes at a depth of 0.4 m and 1.25 m. In the bottom of the reactor, a valve for leachate collection was installed. For the study, the <80 mm waste fraction of 400 kg/m^3 bulk density was chosen, which was separated by a rotary screen. The reactor was filled with 10.44 Mg of waste. The initial height of the waste mass was around 2 m. The reactor was closed by a semi-permeable Gore-Tex® membrane, which filtered the processing air (odors) and ensured the outflow of steam.

The aerobic stabilization of municipal waste was carried out in three stages. As the study was primarily concerned with passive aeration, it was desirable to bring the active stages down to a minimum. Although based on Smet et al.'s findings (Smet et al. (1999)) our own research showed that 5 days was sufficient for our purposes. Odor levels were measured using an Olfactometer TO8 (Ecoma) and were found to be sufficiently low. However, due to the lack of any methodic guidelines on the use of this instrument or measured readings we have not included any data. Stage I, designed to deodorize waste, consisted of 5 days of active aeration with an air flow rate of 350 m^3/h (33.5 L/h/kg of initial waste mass). Stage II was 35 days of passive stabilization with opened dampers. This stage was the main period of measurement and analysis. Stage III, designed to reduce the moisture content of the waste, was not initially time-specific but eventually comprised of the last 5 days of the process (by which time the waste was sufficiently dried). The stage was carried out with active aeration at an air flow rate of 1700 m^3/h.

During aerobic stabilization of the <80 mm municipal waste fraction, the temperature was monitored daily in the places marked in Fig. 1. The three measurements made at a given depth were averaged. During the process, the daily production of leachate was measured and then directly taken (without storing) for further laboratory analysis. In the leachate the following characteristics were determined: organic compounds (COD) (ISO 6060:2006), biodegradable organics (BOD_5), Kjeldahl nitrogen (PN-EN 25663:2001) and ammonia nitrogen by distillation with titration (ISO 5664:2002). Additionally, chloride concentration was determined by titration (ISO 9297:1994). Finally, electrolytic conductivity (BS EN 27888:1999) and pH (BS-C-04642-7:1999) were determined. In accordance with Bari and Koenig (2001), no replicate tests were performed due to the large scale at which the experiment was carried out, the long duration of the experiment and the wide range of measurements and analytical methods that were used. At 5-day intervals, the fractional, morphological, chemical, physical, and biological (AT4) changes in the stabilizing waste were monitored. It was decided to carry out monitoring at two different depths. These corresponded with the top (down to 0.4 m) and the center of the reactor (at a depth of 1.25 m). These depths were chosen due to estimated highest (center) and lowest levels of stabilization (top) in the reactor. To ensure quality and representative sampling, the quartering method was used. Firstly, primary samples of 250 L were randomly collected at each aforementioned depth with an AMS drill of 2 L cylinder volume (totaling 125 samples from random points). Each of the primary samples was mixed, shaped into the form of a cuboid and divided into four parts. Two opposing parts of the cuboid were returned to the reactor, the two remaining parts were re-quartered. The process of quartering was repeated to obtain a laboratory sample of about 15 dm^3. The samples were then immediately taken for laboratory analyses. This was especially important when measuring the actual value of AT4 as this could change during storage. The fractional composition was determined by sieve analysis (PN-93/Z-15006), separating the fractions of <10 mm, 10–20 mm, 20–40 mm, 40–60 mm and 60–80 mm, in which nine morphological components were

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