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Oxygen demand for the stabilization of the organic fraction of municipal solid waste in passively aerated bioreactors

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A B S T R A C T

Conventional aerobic waste treatment technologies require the use of aeration devices that actively transport air through the stabilized waste mass, which greatly increases operating costs. In addition, improperly operated active aeration systems, may have the adverse effect of cooling the stabilized biomass. Because active aeration can be a limiting factor for the stabilization process, passive aeration can be equally effective and less expensive. Unfortunately, there are few reports documenting the use of passive aeration systems in municipal waste stabilization. There have been doubts raised as to whether a passive aeration system provides enough oxygen to the organic matter mineralization processes. In this paper, the effectiveness of aeration during aerobic stabilization of four different organic fractions of municipal waste in a reactor with an integrated passive ventilation system and leachate recirculation was analyzed. For the study, four fractions separated by a rotary screen were chosen. Despite the high temperatures in the reactor, the air flow rate was below 0.016 m^3/h. Using Darcy's equation, theoretical values of the air flow rate were estimated, depending on the intensity of microbial metabolism and the amount of oxygen required for the oxidation of organic compounds. Calculations showed that the volume of supplied air exceeded the microorganisms demand for oxidation and endogenous activity by 1.7–2.88-fold.

1. Introduction

The landfilling of untreated organic municipal waste is associated with excessive emission of landfill gas and odors, as well as stronger leachates with organic loads up to 123,000 mg BOD5/L (Bone et al., 2003). Hence, it is necessary to initially stabilize municipal waste, in order to hygienize and mineralize the organic matter in it. The implementation of aerobic stabilization of municipal wastes is technologically and economically justified. In comparison with two-phased conventional composting technologies, the short digestion period with aerobic stabilization allows an increase in operational efficacy.

Conventional aerobic waste treatment technologies use active aeration. In addition to the installation of the ventilation system, forced aeration of waste requires the use of aeration devices that provide active air transport through the stabilized waste mass, which greatly increases operating costs. In addition, improperly operated active aeration systems may have the adverse effect of cooling the stabilized biomass. Bari and Koenig (2001) showed that the use of unidirectional active aeration generates a vertical temperature gradient in the reactor, which reduces the efficiency of waste stabilization. Another technological problem of forced aeration systems is the occurrence of a moisture gradient and, consequently, a reduction of the homogenization degree of the resulting product. Sugni et al. (2005) suggest that this may be due to the fact that the air flowing through the lower layers of the waste reaches a point of saturation of water vapor, and therefore does not have the ability to absorb additional moisture when passing through the upper layers. The gradients of temperature and of humidity result from the fact that the higher water content in waste causes limited dissipation of heat, resulting in the rise of waste temperature. In order to eliminate problems of unequal drying of the waste fractions, alternative aeration techniques are used. Sugni et al. (2005) suggest periodically changing the aeration direction to reduce temperature and moisture gradients that impede homogenization of the biodrying product. In turn, Bari and Koenig (2001) suggest internal recirculation of air in a single-reactor system or reuse of spent air in a two-reactor system in series.

Because cooling by active aeration can be a limiting factor for the stabilization process, passive aeration can be equally effective and less expensive. According to Barrington et al. (2003), the concept of passive aeration was introduced by McGarry and Strainforth (1978). Since then, the high efficiency of this technical solution has been repeatedly documented. In most cases, however, studies have been conducted using agricultural waste. Mathur

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et al. (1990) successfully used passive aeration for composting livestock waste with peat, reaching a temperature of 55 °C in 4 days. Zhan et al. (1992) obtained temperatures in the range of 60–65 °C after three days of composting poultry manure with peat. Patni et al. (2001) found that passive aeration is cheaper to operate, but comparable in effectiveness to active aeration, which in the production of poultry manure fertilizer can lead to a reduction in nitrogen losses. However, there is little data on the use of passive aeration systems in the stabilization of municipal waste.

Passive aeration requires installation of the ventilation system under or inside the stabilized waste, in order to increase air convection resulting from the temperature difference between the composted material and the environment (Sartaj et al., 1997). Proper design of the ventilation system responsible for air transport, has a decisive influence on the efficiency of passive aeration. Doubts have been raised as to whether a passive aeration system provides enough oxygen for the processes of organic matter mineralization. An overview of the literature data indicates that passive aeration is very useful for biological treatment processes. There are few reports documenting the use of the system in the stabilization of mixed municipal waste. Theoretically, such a solution would increase the efficiency of municipal waste biostabilization while reducing costs. Hence, for technological reasons, monitoring passive air flow in the process of aerobic stabilization of municipal waste is interesting.

The aim of the present study was to analyze the effectiveness of aeration during aerobic stabilization of municipal waste in a reactor with an integrated passive ventilation system and leachate recirculation. The scope of research includes: (a) monitoring the 25-day process of municipal waste stabilization in the reactor by measuring the temperature, mass and volume of air inflow; (b) evaluating of physico-chemical properties of selected organic fractions of municipal solid waste before and after 25-days of stabilization; (c) determining the amount of air flowing through the reactor and using a mathematical model to calculate the amount of oxygen required for mineralization of organic matter and (d) evaluating the effectiveness of aeration in the passively ventilated reactor during the stabilization by comparing the results obtained from monitoring with those from mathematical modeling of the process.

2. Materials and methods

2.1. Experimental material and reactor construction

For the study four organic fractions of waste were selected. They were characterized by different granulometric composition and physico-chemical properties; the granules in fraction F1 had a diameter of <40 mm; in fraction F2, a diameter of 40–100 mm; in F3, 20–80 mm; and in F4, <100 mm. These size fractions are typically obtained in Poland via the processes of mechanical sorting during mechanical–biological treatment of municipal waste. Due to the amount of waste needed to fill the reactor, it was not possible to obtain the test material from one batch of waste. Our preliminary, unpublished research has, however, shown that, regardless of the type of analyzed fraction, mechanism of the stabilization process is identical and the differences in the course of the temperature profile resulted from physical properties of the waste. On this basis, it was assumed that the analysis of four different fractions would be more interesting than the analysis of one fraction with four replications. The properties of selected fractions are presented in Table 1.

The stabilization was carried out in a reactor with passive aeration, equipped with devices for the automatic control of temperature and mass, as well as for measuring the amount of incoming air. The bioreactor, made of polyethylene, had a cover lid and aeration piping system. The walls of the reactor, with a thickness of 7 cm, were filled with polyurethane insulating material to reduce the heat loss. The reactor had a volume of 550 L and a height of 105 cm. The reactor was of a tapered structure that narrowed towards the base, with the top measuring 85 × 75 cm, and the bottom base – 75 × 60 cm. Loss of moisture and heat was limited by applying a seal in the cover of the reactor.

The passive aeration system was based on a chimney effect, where the aeration occurs as a result of the temperature difference between the stabilized mass and the environment. Air was supplied to the reactor via an opening with a diameter of 4 cm, and was distributed throughout the waste heap via five perforated stainless steel tubes with an internal diameter of 5.5 cm, positioned in the center of the bioreactor wall. The air outlet was located in the cover lid and was equipped with a condenser to separate the extracted water vapor. At the bottom of the reactor wall a valve for the evacuation of collected leachate was installed.

In order to ensure that the aerobic condition prevailed during the process, the reactor was equipped with six plastic tubes for analyzing the composition of gas inside the mass of stabilized waste (Ø 1 cm). The tubes were inserted into the mass at the depth of 20 cm (points 7a and 7b), 50 cm (points 7c and 7d) and 90 cm (points 7e and 7f). A diagram of the test site is shown in Fig. 1.

2.2. Experimental protocol

The period of aerobic stabilization of the selected waste fractions was set at 25 days. Each of the experimental series (F1–F4) was carried out in two stages. Stage I lasted 15 days and included intensive stabilization with the recirculation of condensed water vapor and collected leachate. The recirculation was carried out once daily by dispersing the liquid on the surface of the waste heap in the reactor. Stage II, lasting 10 days, was a drying stage with no recirculation, as a result of which, microbial activity was not supported.

2.3. Physical and chemical analysis

The progress of waste stabilization was monitored with the following physical and chemical indicators:

- temperature, measured automatically using the PC THERM REM-84 m dual channel temperature sensor with ±0.1 °C accuracy; daily showed as an average of 1440 measurements,
- the mass of aerobically stabilized waste, controlled with ±0.1 kg accuracy by four-sensor platform scales; daily readouts showed as an average of 24 measurements,
- the volume of air supplied to the reactor, measured by the gas flow meter with a minimum flow rate of 0.016 m^3/h,
- gas composition, measured once daily with a GA 2000 PLUS analyzer to determine the content of oxygen, carbon dioxide and methane.

Samples of solid waste, were analyzed to determine:

- moisture content, measured every second day gravimetrically by drying the samples (150 g) at 105 °C to a constant weight (Polish Standard PN-EN 12880:2004),
- the elemental composition of solid waste, determined in 25-day intervals by mineralization of the dried samples with sulfuric acid, potentiometric titration with sodium bromate (total nitrogen), photometry (flame photometry, total potassium) and colorimetry with the reaction mixture of nitric acid + ammonium metavanadate + ammonium molybdate (total phosphorus),
- the share of chlorine, sulfur, and hydrogen, determined in 25-day intervals using macro analyser vario Macro cube CHNS,