



Research article

The influence of perforation of foil reactors on greenhouse gas emission rates during aerobic biostabilization of the undersize fraction of municipal wastes

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ABSTRACT

The opinion, that the use of foil reactors for the aerobic biostabilization of municipal wastes is not a valid method, due to vulnerability to perforation, and risk of uncontrolled release of exhaust gasses, was verified. This study aimed to determine the intensity of greenhouse gas (GHG) emissions to the atmosphere from the surface of foil reactors in relation to the extent of foil surface perforation.

Three scenarios were tested: intact (airtight) foil reactor, perforated foil reactor, and torn foil reactor. Each experimental variant was triplicated, and the duration of each experiment cycle was 5 weeks. Temperature measurements demonstrated a significant decrease in temperature of the biostabilization in the torn reactor. The highest emissions of CO₂, CO and SO₂ were observed at the beginning of the process, and mostly in the torn reactor. During the whole experiment, observed emissions of CO, H₂S, NO, NO₂, and SO₂ were at a very low level which in extreme cases did not exceed 0.25 mg t⁻¹.h⁻¹ (emission of gasses mass unit per waste mass unit per unit time). The lowest average emissions of greenhouse gases were determined in the case of the intact reactor, which shows that maintaining the foil reactors in an airtight condition during the process is extremely important.

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1. Introduction

Transformation of organic matter to produce organic fertilizer (i.e. compost) or by aerobic biostabilization to create a stable material (i.e. waste) both result in the release of heat, carbon dioxide and many deleterious gases to the atmosphere (Epstein, 1997).

The process of composting generates emissions of other substances, including: volatile organic compounds (VOCs), ammonia (NH₃), carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), hydrogen sulphide (H₂S) and methane (CH₄) (Jiang et al., 2011). NH₃, NO and NO₂ are

environmentally harmful gases which exert a strong impact on chemical and physical processes in the atmosphere (Fukumoto et al., 2011). SO₂ is of major concern because it can cause serious health problems, such as cardiovascular diseases, and acidification of some soils and water bodies (Ling-Yun and Jia-Jia, 2016). Both NH₃ and H₂S are major toxic and odorous chemicals responsible for malodour and health problems (Yuan et al., 2015). CO₂ emitted from composting is considered neutral with respect to global warming (Boldirn et al., 2009). As well as a greenhouse gas, CO may be detrimental in the work environment and pose a risk of intoxication and even death to staff (Phillip et al., 2011).

Emission of greenhouse gases from the composting/biostabilization process is strongly determined by waste type and properties, as well as technological parameters of the process. Wastes characterised by low C/N ratio and high moisture content readily generate gases during both storage and composting (Pagans et al., 2009). Wastes with low nutrient content, low porosity and

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high in poorly-biodegradable fraction may inhibit decomposition processes and decrease greenhouse gases emission (Sanchez et al., 2015).

Another important factor that determines process effectiveness is temperature (Mason, 2006). It affects the metabolism and population numbers of microorganisms (Liang et al., 2003), with a direct effect on gaseous emissions. Phillip et al. (2011) confirmed that CO generation during composting was positively correlated with temperature, whereas Hanajima et al. (2010) linked the peak concentrations of NH₃ and sulphur compounds with composting temperature. NO is generated during composting, generally through nitrification and denitrification that are controlled by several factors including moisture content, temperature, organic matter content, as well as nitrate (NO₃) and ammonium (NH₄) contents (del Prado et al., 2006). However, nitrification is inhibited when the temperature is over 40 °C, and at low oxygen concentration <7%. Denitrification can proceed under mesophilic and thermophilic conditions when the process is repressed by O₂ (Beck-Friis et al., 2001). NO and NO₂ are also important as they are the main source of N₂O in composting through the denitrification process (Thomson et al., 2012).

The development of anaerobic conditions in a waste heap leads to increasing contents of methane and H₂S (Scaglia et al., 2011), and to decreasing contents of CO (Hellebrand and Kalk, 2001) and CO₂ (Sommer and Moller, 2000). Appropriate aeration of the waste heap is one of the key parameters affecting the emissions of greenhouse gases (Jiang et al., 2011). Excess aeration may accelerate gaseous escape from the centre of the heap, thereby increasing losses of heat and moisture. Adjustment of this parameter is extremely important in determining the flow of harmful gaseous emissions (Smet et al., 1999).

Equally significant is the choice of an aeration system. The rate of the composting process with forced aeration static pile (FAS) is higher than that with the natural ventilation static pile method (NVS) (Stentiford, 1996). Furthermore, FAS has been defined as a useful method for reducing nitrogen losses by volatilization (Sanchez-Monedero et al., 2001). Rasapoor et al. (2016) showed higher CO₂ emissions for forced aeration than from static aeration and turning method. Another factor affecting the emission potential during composting is bulk density. Unlike composting method, compaction is one of the management strategies used to restrict O₂ supply within the waste material, thus limiting biological activity, preventing temperature increase, and significantly reducing CO₂ and NH₃ emissions compared with conventional solid waste storage (Pardo et al., 2015). Webb et al. (2012) examined the relationship between the bulk density of the pile and NH₃ losses, and found a negative relationship with NH₃ emissions.

In Poland, municipal solid waste (MSW) is managed mainly by mechanical–biological treatment (MBT) and in the past few years, 127 large-scale MBT facilities have been built, treating more than 4.1 Mt waste/y (KPGO, 2016). The main outputs of a typical MBT plant are: refuse derived fuel (RDF), ferrous and non-ferrous metals (FM-NFM) and stabilised organic waste (SOW), produced from the biological treatment of the undersize fraction (<80 mm) of the waste (Di Lonardo et al., 2012). Considering the large scale of MSW treatment in MBT plants, it is important to examine emissions of greenhouse gasses from MBT plants during aerobic biostabilization of the undersize fraction. Although CO₂, CO, H₂S, and NH₃ emissions from composting are reported in the literature, information on NO, NO₂, SO₂ emissions is still insufficient.

Many technologies for municipal waste biostabilization are currently marketed, consisting of reinforced concrete reactors, roofed with plastic or semi-permeable membranes and using systems of forced air circulation and material moistening. Usually, such installations require the stabilised material to be turned

during its transport from one box to another (Adani et al., 2004).

An alternative technology for biostabilization of the undersized fraction of MSW is to use a cheap, disposable, closed tank reactor or foil tunnel (Gašior et al., 2014) with forced aeration, enabling automatic control of the aeration of the stabilised or composted feedstock. The use of foil reactors is controversial because of the risk of perforation of the foil wall by glass or other sharp objects occurring in the waste material. It is essential to determine precisely the emissions of greenhouse gasses from foil reactors and the effect of perforation on emission rates.

This study aimed to determine the intensity of greenhouse gas emissions to atmosphere from the surface of foil reactors during biostabilization of the undersize fraction of MSW, in relation to the extent of foil surface perforation, and temperature rise. It is hypothesised that gas emission rates will increase with increasing perforation of the reactor's foil surface and with increasing temperature.

2. Materials and methods

2.1. Characteristics of waste biostabilization technology in foil reactors

The process of waste biostabilization in foil reactors initially involves mechanical processing of the MSW, which creates an undersize fraction (particle diameter < 80 mm). Waste is introduced into tubular foil reactors via a purpose-designed line press, similar to agricultural machines for packing hay into foil bales. Filled foil reactors are sealed and placed on a concrete surface to begin fermentation (Fig. S1 – Supplementary materials).

Perforated aeration and gas collection pipes are mounted through the entire length of the reactor; the aerating pipe fitted along the base, the collecting pipe along the upper part of the reactor (Fig. 1). Process gas is discharged via the collection pipe to a biofilter (standard container or open biofilter) filled with porous organic material to remove dust, volatile substances and odour.

Aeration of the reactors is achieved with an air blowing ventilator in two stages:

1. dynamic – air-flow via one or more perforated pipes running the entire length of the reactor
2. static – aeration of the feedstock due to pressure generated in the reactor after each blowing cycle.

Typically, foil reactors are 50–75 m in length, up to 3 m diameter, with foil thickness of 0.25 mm, and contain ca. 230 t of wastes. The mean dynamic air flow rate blown into the reactor is ca. 1000 m³ h⁻¹, equivalent to a volume of air over a 5-week biostabilization period of about 3650 m³ per ton of waste which fulfils the recommended “Best Available Technique” of between 2500 and 8000 m³ t⁻¹ (IPPC, 2006).

2.2. Description of the experiment and gas sampling methods

The study was conducted in one of the Municipal Waste Installations in Poland. Three experimental foil reactors, 10 m in length, were constructed and filled with approx. 30 t of undersize fraction of municipal waste. The average properties of the material used (Table S1), represented a typical undersize fraction separated in a MBT plant in Poland (Jędrzak and DenBoer, 2015). The three reactors were prepared to simulate the following scenarios:-

1. intact (airtight) foil reactor under normal conditions (Fig. S2a),
2. foil reactor perforated with small holes (total area 1 m²), as may occur from sharp objects such as glass contained in the waste (Fig. S2b),

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