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Gaseous emissions in municipal wastes composting: Effect of the bulking agent

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HIGHLIGHTS

- Emission factors for MSW and organic fraction of MSW composting have been determined.
- Polyethylene tube has been compared to wood chips as bulking agent.
- Use of polyethylene tube as bulking agent reduces NH_3, CH_4 and VOC emissions.
- Alpha and beta pinene emissions are related with wood bulking agents.
- Terpenes are predominant VOC in all the processes, being limonene the most abundant.

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ABSTRACT

In this study, the emissions of volatile organic compounds (VOC), CH_4, N_2O and NH_3 during composting non-source selected MSW, source selected organic fraction of municipal solid wastes (OFMSW) with wood chips as bulking agent (OF_wood) and source selected OFMSW with polyethylene (PE) tube as bulking agent (OF_tube) and the effect of bulking agent on these emissions have been systematically studied. Emission factors are provided (in kg compound Mg^{-1} dry matter): OF_tube (CH_4: 0.0185 ± 0.004; N_2O: 0.0211 ± 0.005; NH_3: 0.612 ± 0.269; VOC: 0.688 ± 0.082) and MSW (CH_4: 0.0549 ± 0.0171; N_2O: 0.032 ± 0.015; NH_3: 1.00 ± 0.20; VOC: 1.05 ± 0.18) present lower values than OF_wood (CH_4: 1.27 ± 0.09; N_2O: 0.021 ± 0.006; NH_3: 4.34 ± 2.79; VOC: 0.989 ± 0.249). A detailed composition of VOC is also presented. Terpenes were the main emitted VOC family in all the wastes studied. Higher emissions of alpha and beta pinene were found during OF_wood composting processes.

1. Introduction

It is well known that recycling reduces the amount of waste going to disposal (landfilling), the consumption of natural resources and also improves energy efficiency. Therefore, recycling plays an essential role towards sustainable consumption and production (SCP). Accompanying SCP, the recycling sector has increased business with a current turnover of €24 billion employing about 500,000 people in Europe, distributed in more than 60,000 companies. The EU represents the densest area in waste and recycling industries, accounting for around 50% of world share (European Environment Agency, 2010). At the same time, sustainable management of resources and waste minimization and valorization has been the common objective of plans, directives and regulations in recent decades, including Municipal Solid Waste (MSW). According to this, in recent years, there has been a proliferation, either in Spain or Europe, of new solid waste treatment plants mainly as a result of Directive 1999/31/EC on the implementation of the limitation of landfill as final destination for organic wastes. Biological treatment plants, which allow waste valorization, are recommended as the main destination for this type of wastes (Commission of the European Community, 2008).

Generation of biodegradable organic residues is increasing worldwide and strategies for its environmentally sound use are being developed and optimized. Integrated waste management is considered the key point for a successful MSW treatment. Waste separation, that increases the quality of by-products (i.e., compost, digestate and biogas) and recyclables, is a critical component of this system. Integrated waste management also enables better financing of waste management activities and minimizes the energy and labor inputs to any downstream processes (Murray, 1999). European Directive 2008/98/EC points to the recovery of mixed municipal waste collected from private households. In order

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to comply with the objectives of this Directive, and to move towards an European recycling society with a high level of resource efficiency, Member States shall take the necessary measures to achieve by 2020 a minimum overall recycling percentage of a 50% by weight of paper, metal, plastic and glass from households and possibly from other origins (as far as these waste streams are similar to waste from households) (European Parliament, 2008). As a consequence of the implementation of all these Directives, by 2013, 19% of total household wastes are source selected in Spain, being the organic fraction a percentage of 20%.

As mentioned before, biological treatment plants based on anaerobic digestion and/or composting processes are being widely constructed. Focusing on the composting process, the presence of non-organic wastes (impurities) could decrease the compost quality, affect composting gaseous emissions or increase the investment costs and the energy demand due to the equipment dedicated to the separation of impurities. Bulking agents are used to provide air space in composting materials, regulate the water content or the C/N ratio (Iqbal et al., 2009). These studies show how important is the bulking agent in the composting process evolution. Gaseous emissions during the composting process are often related with the porosity of the material being composted, which depends on the type and amount of bulking agent used. Some authors have related the emissions of some volatile organic compounds (VOC) to wood wastes used as bulking agent (Komilis et al., 2004). Recent studies (Yang et al., 2013; Shao et al., 2014) have investigated the effect of several bulking agents on gaseous emissions in composting processes of organic wastes. Yang et al. (2013) have studied emissions of CH_4, N_2O and NH_3, while Shao et al. (2014) presented an in depth study on odor emissions, mainly VOC. Both studies pay attention to the composting process evolution and the quality of the final product. However, all the experiments have been done with a degradable bulking agent: cornstalks, rice straw, sawdust, etc. Therefore, the contribution of wood chips, the bulking agent mostly used nowadays in composting facilities, to VOC emissions is not described. The presence of plastics, glass and other non-organic wastes could replace the bulking agent (wood chips) function when mixed MSW are composted.

The objective of this work is to study the emissions of VOC, CH_4, N_2O and NH_3 during the composting process of MSW and the effect of the bulking agent in these emissions. With this purpose, three wastes have been composted: non source selected MSW (high level of impurities), source selected OFMSW (low level of impurities) with wood chips as bulking agent and source selected OFMSW with polyethylene (PE) tube as bulking agent since this non-biodegradable material will not contribute to the emissions of the studied compounds. This study can provide the baseline to distinguish between the emissions from the waste itself and the bulking agent, an aspect that it is not clear in composting scientific literature.

2. Methods

2.1. Waste composted

The wastes used in the experiments were different types of municipal solid wastes. Specifically, 100 kg of non-source selected MSW from a waste treatment plant located in Zaragoza (Spain) were composted as received at the plant (MSW). In the case of source selected OFMSW two cases were studied: (i) OF_wood, 100 kg of material that were already mixed with wood chips in the plant (ratio 1:1, v:v) and (ii) OF_tube, 100 kg of material that were used as received at the plant. In this case, the OFMSW was manually mixed with PE tube pieces of 25 mm diameter and 4–15 cm long (ratio 1:1, v:v). Both OFMSW were obtained from a composting plant in Manresa (Barcelona, Spain). All the composting experiments with the three wastes considered (MSW, OF_wood and OF_tube) were carried out with aliquots of 25 kg per reactor and performed in duplicate.

Air-filled porosity was determined using an air pycnometer according to previous studies (specific details about the methodology can be found in Ruggieri et al., 2009). The results of air-filled porosity for OF_wood and OF_tube, mixed in the laboratory, initial MSW (not mixed, the waste collected was composted as collected from the plant) and final samples for the six trials can be found in Table 1. A homogeneous sample from each waste and each mixture (waste plus bulking agent) was stored at −18 °C to be used for waste characterization.

The main characteristics of the initial wastes and the final products obtained from each experiment are presented in Table 1. Dry and organic matter, conductivity and pH have been determined in triplicate following the standard procedures for composting samples (US Department of Agriculture and US Composting Council, 2001).

2.2. Composting pilot plant

The results presented in this study were obtained in a pilot scale composting plant using two near-to-adiabatic non-commercial cylindrical reactors with an operating volume of 50 L each and forced aeration. A schematic diagram of the pilot reactors and a detailed description can be found elsewhere (Puyuelo et al., 2010).

Gas samples were collected in 1-L Tedlar® bags for VOC N_2O, CH_4 and NH_3 determination. Also a 250-mL glass gas collector was used for samples taken for VOC composition determination. In all cases, one sample per day and per reactor was withdrawn.

The data acquisition system is a PLC Data Acquisition. It consists of a microcontroller that interprets the potential changes of the sensors connected to its inputs in numerical values. It also realizes the reverse function: converting numerical values into voltage, thereby allowing performing an automatic control. Temperature (PT100 sensor, Desin Instruments, Barcelona, Spain), exhaust gas oxygen concentration (Alphasense, A2O2, UK) and inlet airflow (Bronkhorst Hitec, The Netherlands) were monitored during the experimental trials. According to the values of oxygen concentration, airflow and temperature, the PLC acts on the flow meter, allowing airflow from 0.2 to 10 L per minute. The controller performs roughly 25 readings per second, sending to the reader a temporal data every second and a real data each minute. The communication is done by a serial port interface. Data are visualized through the connection of the PLC data acquisition system to an internal Ethernet network.

The control strategy used in the experiments has been presented in Puyuelo et al. (2010). The main objective of this strategy is to obtain an automatic airflow regulation that maximizes the biological activity in the reactor measured as OUR (Oxygen Uptake Rate). OUR control permits the optimization of energy consumption during the process while achieving a high degree of stability in the final product. Briefly, the controller works in cycles of 1 h. The designed OUR control loop compares the variations in the OUR measurements reached among the successive cycles according to the airflow applied. After completing a cycle, the oxygen level is revised to avoid percentages below 5% of oxygen concentration in air (v/v). If the level is below this limit, airflow will be increased by 50%. If an adequate oxygen level has been measured, the next step will be the control loop based on the OUR measurement and the applied flow comparison between two consecutive cycles. For both parameters, three situations are possible, i.e., the system determines if the current value is lower than, higher than or equal to the previous value. Different absolute thresholds were