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Odorous gaseous emissions as influence by process condition for the forced aeration composting of pig slaughterhouse sludge

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ABSTRACT

Compost sustainability requires a better control of its gaseous emissions responsible for several impacts including odours. Indeed, composting odours have stopped the operation of many platforms and prevented the installation of others. Accordingly, present technologies collecting and treating gases emitted from composting are not satisfactory and alternative solutions must be found. Thus, the aim of this paper was to study the influence of composting process conditions on gaseous emissions. Pig slaughterhouse sludge mixed with wood chips was composted under forced aeration in 300 L laboratory reactors. The process conditions studied were: aeration rate of 1.68, 4.03, 6.22, 9.80 and 13.44 L/h/kg of wet sludge; incorporation ratio of 0.55, 0.83 and 1.1 (kg of wet wood chips/kg of wet sludge), and; bulking agent particles size of <10, 10 < 20 and 20 < 30 mm. Out-going gases were sampled every 2 days and their composition was analysed using gas chromatography coupled with mass spectrometry (GC–MS). Fifty-nine compounds were identified and quantified. Dividing the cumulated mass production over 30 days of composting, by odour threshold, 9 compounds were identified as main potential odour contributors: hydrogen sulphide, trimethylamine, ammonia, 2-pentanone, 1-propanol-2-methyl, dimethyl sulphide, dimethyl disulphide, dimethyl trisulphide and acetophenone. Five gaseous compounds were correlated with both aeration rate and bulking agent to waste ratio: hydrogen sulphide, trimethylamine, ammonia, 2-pentanone and 1-propanol-2-methyl. However, dropping the aeration rate and increasing the bulking agent to waste ratio reduced gaseous odour emissions by a factor of 5–10, when the required threshold dilution factor ranged from 10^5 to 10^6, to avoid nuisance at peak emission rates. Process influence on emissions of dimethyl sulphide, dimethyl disulphide, dimethyl trisulphide were poorly correlated with both aeration rate and bulking agent to waste ratio as a reaction with hydrogen sulphide was suspected. Acetophenone emissions originated from the wood chips. Olfactory measurements need to be correlated to gaseous emissions for a more accurate odour emission evaluation.

1. Introduction

The continuous production of large amounts of organic wastes becomes a worldwide environmental problem. Because of their biodegradability and moisture content, regulations within the European Union limit their disposal through landfilling and incineration. In contrast, biological treatments benefit from such properties, namely methanization and composting. Indeed, composting is promoted as an economical way to recycle organic wastes as soil amendments, although recently, its future has become uncertain. The European Union now requires the reduction of gaseous emissions from composting, as these impacts both the environment and human health. Methane and nitrous oxide are greenhouse gases contributing to the earth warming trends. Ammonia emissions are responsible for acid rain and eutrophication (Colon et al., 2010). Ammonia, hydrogen sulphide and some volatile organic compounds may also affect the health of the composting plant workers. Finally, composting emissions produce odours

Abbreviations: AR, aeration rate; BA, bulking agent; BAPS, bulking agent particle size; BAR, bulking agent ratio; Bio, biodegradable content; CV, coefficient of variation; DMDS, dimethyl disulphide; DMS, dimethyl sulphide; DMTS, dimethyl trisulphide; DT, detection threshold; GC–MS, gas chromatograph coupled with a mass spectrometer; GE, concentration of gaseous emission; H_2S, hydrogen sulphide; NH_3, ammonia; OM_0, initial content in organic matter; OT, odour threshold; OU, odour unit; PSS, Pig slaughterhouse sludge; TMA, trimethylamine; VOC, volatile organic compound; $V_{REACTOR}$, volume of reactor loaded; WC, wood chips.

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which are a nuisance for neighbourhoods. In some cases, composting facilities were closed because of their mal-odour production, while others were prevented from being built. Odour nuisance as produced by composting plants demonstrate the lack of efficiency of conventional yet expensive solutions used to confine, mask and/or treat gaseous emissions such as bio-filtration and chemical cleaning (Muller et al., 2004).

The exact link between odours and gaseous emissions remains unknown as a synergetic effect is created among odorous compounds (Smet et al., 1999). However, the exhaustive description of composting gases is the main step towards solving the problem since most scientific articles have limited their scope to a few pollutants. Moreover, gaseous emissions and their odour vary with substrate composition, process condition and composting progress, a subject dealt by only a few articles (Delgado-Rodriguez et al., 2011). So far, the main research focus was the characterization of volatile organic compounds (Delgado-Rodriguez et al., 2011; Smet et al., 1999; Maeda et al., 2009; Pagans et al., 2006a; Akdeniz et al., 2010; Eitzer, 1995; Komilis et al., 2004; Kumar et al., 2011; Staley et al., 2006; Turan et al., 2007) often limited to a single family (Wu et al., 2010). Only a few research projects deal with the influence of process condition on volatile organic compound emission (Delgado-Rodriguez et al., 2011), and even less deal with hydrogen sulphide emissions. Moreover, hydrogen sulphide was rarely monitored, except for Noble et al. (2001) who observed its significant odour impact during the composting of mushroom. Several articles account for the influence of process condition upon the emissions of ammonia (Pagans et al., 2006b; De guardia et al., 2008; Maeda et al., 2009) or ammonia plus greenhouse gases (Jiang et al., 2011; Beck-Friis et al., 2001; Shen et al., 2011).

According to Coker (2012) and Vandergheynst et al. (1998), gaseous emissions depend on 3 main types of parameters: (i) substrate or mixture composition such as the availability of microbial nutrients in the feedstock which in turn, relies on mixing level and other physical factors such as moisture and particle size; (ii) oxygen supply, and especially the uniformity of distribution within the composting material, and finally; (iii) the initial temperature rise, directly influenced by the microbial metabolic rate and the waste biodegradability, and indirectly influenced by water vapour pressure and moisture loss. According to Noble et al. (2001), high temperatures are coupled with an increased rate of pyrolysis, auto-oxidation and the Maillard reaction, which influence the release of gaseous compounds. Even though all of these mechanisms are more or less known, it appears that the gaseous emissions depend on the biodegradation process. During the composting of municipal solid wastes (MSW), D'imporzano et al. (2008) and Scaglia et al. (2011) correlated emissions of volatile organic compounds (VOCs) and odour emissions with the biodegradation progress measured by the Dynamic Respiration Index (DRI). However, Pagans et al. (2006a) did not observe such correlation during the composting of several wastes including MSW.

Although many projects dealt with the influence of aeration on compost quality (Gao et al., 2010), few investigated gaseous emission and often gaseous emissions were expressed in terms of concentration (Smet et al., 1999; Scaglia et al., 2011; Pagans et al., 2006a; Shen et al., 2011; Turan et al., 2007; Gao et al., 2010) without cumulating their mass. However, composting aeration rate seems to be a main parameter influencing gaseous emissions. Coker (2012) and Gao et al. (2010) observed that aeration serves several critical functions in the composting process such as: replenishing O_2; removing CO_2, water and volatile compounds, and; controlling temperature and moisture variations. Recently, Delgado-Rodriguez et al. (2011) found that rather than moisture and C/N ratio, aeration rate is the main parameter influencing emissions of volatile organic compounds. Wu et al. (2010) found that the emissions of volatile organic compounds and ammonia increase along with aeration rate (Pagans et al., 2006b; Bueno et al., 2008). According to Walker (1992), increasing the aeration rate decreases the concentrations of emissions but increases their cumulated mass over the duration of the process. Conversely, decreasing aeration led to higher concentrations but lower cumulated emissions. According to Schlegelmilch et al. (2005) aeration rate increases the dimension of the gas treatment system and as a result, the cost of the facility. However, for Smet et al. (1999), incomplete or insufficient aeration during composting is responsible for the development of anaerobic degradation and thus the production of mal-odours such as sulphides. As a result, an optimal aeration strategy is required to minimize the release of odour gases without favoring the production of odorous emissions.

The mixing ratio of waste to bulking agent also influences gaseous emissions. Indeed, adding bulking agent increases O_2 diffusion inside the compost (Jolanun et al., 2008), while reducing the amount of bulking agent allows for the formation of waste clumps favoring anaerobic degradation. Nevertheless, Pagans et al. (2006a) found a significant increase in emissions of volatile organic compounds when bulking agent incorporation increased, likely because of the release of terpens by the wood chips. Although Pagans et al. (2006a) showed that the bulking agent ratio is important in controlling emissions of volatile organic compounds, very few other experiments were pursued. Nakasaki et al. (2001) found that emissions of ammonia decreased when adding bulking agent.

The influence of the bulking agent particle size on gaseous emission was scarcely studied, although several authors (Gea et al., 2007; Raichura and McCartney, 2006; Blazy et al., 2013) showed its influence on temperature, moisture and compost quality. All of these parameters are closely linked to gaseous emissions.

Accordingly, there is a need for additional research to study the influence of process condition on gaseous emissions during composting. The purpose of the present study was therefore to investigate the influence of aeration rate, bulking agent incorporation ratio and bulking agent particles size on odorous gaseous emissions when composting pig slaughterhouse sludge. Composting treatment was achieved under forced aeration in 300 L laboratory reactors with forced aeration. Five aeration rates (1.68, 4.03, 6.22, 9.80 and 13.04 L/h/kg of wet sludge), 3 bulking agent ratios (0.55, 0.83, 1.11 on a wet basis) and 3 ranges of bulking agent particles size ([<10 mm], [10–20 mm], [20–30 mm]) were tested. The compost air outflow was monitored and its gaseous composition determined by gas chromatography to compute a cumulative mass generation for 30 days of experimentation. Main odour contributors were identified by dividing this concentration during peak emission events by their odour threshold concentration. The effect of compost process was correlated with the cumulative 30 day mass of the main odorous compounds to determine their significance.

2. Materials and methods

2.1. Experimental conditions

The experimental set-up consisted of 3 similar pilot reactors housed in a laboratory. Reactors consisted of insulated cylindrical containers of 300 L, with a bottom air inlet entering first into a plenum for a uniform compost aeration (Fig. 1). For every experiment, the in-coming airflow, the material temperature and its total mass were monitored using respectively a volumetric gas meter, 3 Pt100 temperature probes inserted in the bottom, middle and upper part of the compost and weigh sensors. Since exhaust gases could reach high temperatures and condense thereafter, a glass bottle condenser was used between the reactor exhaust and bag sampling point. Accordingly, ammonia and soluble VOCs were under-estimated. The outgoing gases were water-saturated. The