Chemical Engineering Journal 276 (2015) 398–409

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Correlation of chemical composition and odor concentration for emissions from pig slaughterhouse sludge composting and storage

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HIGHLIGHTS

- PSS composting and storage gas samples were determined by chemical and olfactory analyses.
- For gas samples, correlations between the chemical composition and its OC was investigated.
- OAV_{MAX} assumed that OC was equal to the sample's highest OAV value.
- OAV_{SUM} assumed that OC was equal to the sum of all OAV for sample.
- The 3 most odorant compound offered a good prediction of the olfactory results.

ARTICLE INFO

Article history:
Received 28 October 2014
Received in revised form 30 March 2015
Accepted 2 April 2015
Available online 7 April 2015

Keywords:
Gaseous emission
Odor
Chemical composition
Composting
Storage
Pig slaughter house sludge

ABSTRACT

The objective of this study was to correlate the chemical composition and the odor concentration of emissions produced during storage and composting of pig slaughterhouse sludge (PSS). Seven experimental conditions were monitored using composting reactors with forced aeration and cells designed to simulate storage. Sixty-six gas samples were collected and characterized by both GC–MS and olfactometry. Two types of correlation were investigated between the chemical composition and the odor concentration (OC) of every gas sample. The odor activity value for a given emitted compound (OAV) was computed as the ratio of its chemical concentration to its odor detection threshold (ODT). The correlation OAV_{MAX} considered that the OC of a gas sample was equal to its highest OAV whereas the correlation OAV_{SUM} considered that the odor of the gas sample was equal to the sum of the OAV of every compound contained in the gas sample. As per Standard EN 13725, both OAV_{MAX} and OAV_{SUM} were compared using a confidence level for OC defined as [OC/1.65 to 1.65 × OC]. Whereas OAV_{MAX} values were within the confidence level of OC for 62% of the 66 gas samples, OAV_{SUM} values were within this confidence level for only 53%. Validating OAV_{MAX} as a satisfying correlation between chemical composition and OC, only three compounds among the 66 identified namely trimethylamine, hydrogen sulfide and methanethiol, accounted for the prediction of OC measured during composting and storage of PSS.

Abbreviations: BA, bulking agent; CH_3SH, methanethiol; GC–MS, gas chromatograph coupled with a mass spectrometer; H_2S, hydrogen sulfide; MDL, sampling and GC–MS method detection limit; NH_3, ammonia; OAV, odor activity value of a gaseous odorous compound defined as the ratio of its concentration to its odor detection threshold; OC, odor concentration of a gas volume measured by olfactometry and corresponding to the number of dilution required in order its odor is not detected anymore; OC_{INT}, bound of the confidence interval of the odor concentration measure; OAV_{MAX}, odor activity value of the compound exhibiting the highest concentration to ODT ratio in a gaseous mixture; OAV_{MAX2}, odor activity value of the compound exhibiting the second highest concentration to ODT ratio in a gaseous mixture; OAV_{SUM}, summation of the odor activity values of every odorous compound contained in a gaseous mixture; ODT, odor detection threshold; PSS, pig slaughterhouse sludge; RSH, mercaptan; TMA, trimethylamine; RD, Relative Deviation; VOC, volatile organic compound.

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http://dx.doi.org/10.1016/j.cej.2015.04.031
1385-8947/

1. Introduction

Odor emissions from composting plants are a common source of annoyance. Odorous nuisance can have significant impact on environmental health [1] and the quality of life. Negative neighborhood reactions to composting odors may lead to temporary or definite closure and a lack of acceptance of new facilities [2]. Good management of composting operations can help minimize odor impacts, although odor generation cannot be avoided [3]. Odor management should take into account operational conditions such as composting facility aeration process, levels of confinement, emission sources identification, collecting and treatment of gaseous emissions [4]. Such difficulties in controlling compost facility odor nuisance demonstrate the lack of efficiency of present and often expensive solution technologies.

Cost-effective strategies for solving odor problems require the identification of the major contributing odorants compounds as found in the gaseous mixture released [5]. This requires the correlation of the emission's chemical composition and its odor concentration. Targeting the most responsible compounds, such correlation can provide criteria for the development of: (i) odor prevention and abatement strategies; (ii) odor characterization using analysis of specific indicator compounds, and; (iii) specific sensors for online odor monitoring.

The first main step toward linking the chemical composition of a sample and its odor concentration is to define how to integrate the odorous potential of an individual compound in a complex odor mixture. Indeed, each compound contributes to a different extent to overall odor concentration [6]. Based on the odor detection threshold (ODT-the minimal concentration of a single compound which is perceived by 50% of the population), the odor activity value (OAV) has been widely used [6–11]. It was defined as the ratio of the chemical concentration to the odor detection threshold of a single targeted compound within a sample. The odor activity value is a dimensionless value also interpreted as the theoretical dilution factor required to reach the odor detection threshold of the compound. Thus, the first step in achieving this correlation consists in linking the odor activity value of individual compound (or their theoretical dilutions factors) to the dilution factor required by olfactometry to reach the threshold dilution for the complex emission. This dilution factor is equivalent to its odor concentration, or OC, as defined by EN 13725 [12]. A first mathematical function used to correlate the odor activity value (OAV) and the odor concentration (OC) consisted in numerically adding the OAV of all individual compound identified in the emission (OAV_{SUM}). The value OAV_{SUM} was used by Gallego et al. [11] to predict the concentration of composting odors in the absence of olfactometry. For odorous emissions produced by food and industrial wastes, Kim and Park [9] found a strong correlation between OC and OAV_{SUM}. In contrast, for odor emissions from cattle shelters, Parker et al. [6] found a poor correlation (R^2 = 0.16–0.52) between OC and OAV_{SUM}.

Taking into account potential synergic effects between a large numbers of compounds, multivariate analyses coupled with regression methods were widely investigated. These complex methods were directly used by: Noble et al. [13] for mushroom composting; Hanajima et al. [14] for swine manure; Mao et al. [15] and Tsai et al. [2] for food waste, and; Defoer et al. [16] for green waste. Multivariate analyses were also used to correlate odor to odorant compounds for swine facilities [17,18] or the headspace above stored slurry [19,20]. These investigations produced no clear correlation allowing for the prediction of composting or livestock odor. Indeed, each model led to a specific relationship [16] and moreover, showed no cause-and-effect relationship [5] between the odor concentration and the chemical composition of the gaseous samples. These drawbacks indicated the complexity of the human sensory perception and the limits of these methods.

The objective of this study was to find a simpler and generic model to correlate the chemical composition and the odor concentration of emissions produced during composting under forced aeration and during storage. Pig slaughterhouse sludge (PSS) was the wasted studied in this experiment. Seven laboratory experiments were monitored to simulate composting and storage of PSS. Sixty-six gas samples were collected and characterized by both GC–MS and olfactometry. Two types of correlation were investigated to link the chemical composition and the odor concentration (OC) of every gas sample: the first was the sum of the odor activity values (OAV_{SUM}), defined earlier, and; the second was OAV_{MAX} consisting of the highest OAV value associated with an individual compound within the sample.

2. Materials and methods

2.1. Experimental conditions

The composting experiments were performed in 300 L reactors consisting of insulated stainless cylinders, 800 mm in height and 700 mm in diameter. Immediately after loading the reactors, a low aeration rate of 1.3 L h^{-1} kg^{-1} of wet sludge was applied during 5 days. Thereafter, the aeration rate was increased to 9.3 L h^{-1} kg^{-1} wet sludge and maintained constant till the end of the experiment. A rotameter (FL-821-V, OMEGA Engineering Inc., Stamford, USA) regulated the in-coming airflow while a volumetric gas meter measured the flow (Gallus 2000, Actaris, Liberty Lake, USA). The reactor were equipped to continuously monitor the compost temperature and its total mass using respectively two Pt100 probes and weigh sensors. Concentrations in O_2 and CO_2 were continuously measured in both the in-coming and out-going airflows using respectively a paramagnetic analyzer (MAGNOS 206, ABB, Zurich, Switzerland) and an IR spectrometric analyzer (URAS 26, ABB, Zurich, Switzerland). Every 10 days, the compost was turned. The composting treatment was stopped after 36 days.

The composting experiments were carried out using PSS mixed with bulking agent. The sludge was collected from the primary wastewater treatment process of a pig slaughterhouse. The primary pig slaughterhouse sludge had collected at the plant, following its sieving using 6 mm and 1 mm sieves, its coagulation and flotation, and its centrifugation. At the laboratory, the sludge was stored in bags at −18 °C. The content of each bag was dumped into opened bins to be thawed at 4 °C, 1 week before being used.

The bulking agent (BA) consisted of oak and ekki wood chips with a particle size ranging from 0 to 40 mm. The characteristics of the feedstock (pig slaughterhouse sludge plus wood chips) are provided in the Supplementary Material 1. The wet mass BA/PSS ratios applied were respectively 0.55 and 0.73 kg kg^{-1}. For a BA/PSS of 0.73 kg kg^{-1}, the two moisture contents tested were 61.2–63.7%.

The storage cells were 28 L airtight stainless steel cylindrical vessels, with a height of 900 mm height and a diameter of 200 mm. The cover of the storage vessel was equipped with an air inlet and outlet to sample the volume over the stored material. Each vessel was filled with 720 mm of PSS with and without BA. A constant aeration rate of 40 L h^{-1} was applied to the cell, for a value of 1.72–3.95 L h^{-1} kg^{-1} of wet material. The gas samples were collected by connecting bags to the storage vessel ventilation exhaust port. The vessels were emptied after 14–30 days of storage.

The storage vessels were filled with fresh PSS, fresh PSS mixed with BA, and PSS composted for 15 and 30 days. The PSS composts were obtained from the composting experiments carried out with a