Environmental Pollution 231 (2017) 845–853

Contents lists available at ScienceDirect

Environmental Pollution

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

Characterisation of volatile organic compounds (VOCs) released by the composting of different waste matrices☆

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ARTICLE INFO

Article history:
Received 15 March 2017
Received in revised form
20 July 2017
Accepted 28 August 2017

Keywords:
Mechanical-biological treatments
Composting
Odour
Sewage sludge
Food waste

ABSTRACT

The complaints arising from the problem of odorants released by composting plants may impede the construction of new composting facilities, preclude the proper activity of existing facilities or even lead to their closure, with negative implications for waste management and local economy. Improving the knowledge on VOC emissions from composting processes is of particular importance since different VOCs imply different odour impacts. To this purpose, three different organic matrices were studied in this work: dewatered sewage sludge (M1), digested organic fraction of municipal solid waste (M2) and untreated food waste (M3). The three matrices were aerobically biodegraded in a bench-scale bioreactor simulating composting conditions. A homemade device sampled the process air from each treatment at defined time intervals. The samples were analysed for VOC detection. The information on the concentrations of the detected VOCs was combined with the VOC-specific odour thresholds to estimate the relative weight of each biodegraded matrix in terms of odour impact. When the odour formation was at its maximum, the waste gas from the composting of M3 showed a total odour concentration about 60 and 15,000 times higher than those resulting from the composting of M1 and M2, respectively. Ethyl isovalerate showed the highest contribution to the total odour concentration (>99%). Terpenes (α-pinene, β-pinene, *p*-cymene and limonene) were abundantly present in M2 and M3, while sulphides (dimethyl sulphide and dimethyl disulphide) were the dominant components of M1.

1. Introduction

Mechanical-biological treatments (MBTs) of municipal solid waste (MSW) have been increasingly adopted in many industrialised countries as an efficient way for reducing the amount of waste sent to landfill, for improving the heating value of the waste sent to incineration, and for upgrading the organic fraction of MSW (OFMSW) by producing compost to be re-used in agriculture.

Aerobic MBTs (*i.e.*, composting, bio-stabilisation and bio-drying) use ambient air drawn from outside to biologically oxidise the organic component of waste. The process air, once it passes through the waste piles, is capable of stripping particles and volatile substances that are present in the waste, together with intermediate products formed during the biodegradation process. Thus, the air becomes enriched in substances like ammonia (NH_3), volatile organic compounds (VOCs), hydrogen sulphide (H_2S) and, to a minor extent, heavy metals, polychlorinated biphenyls and polychlorinated dibenzo-*p*-dioxins that may be present as traces in the waste (Austrian Federal Environment Agency, 1998; Schiavon et al., 2016a).

Besides carbon dioxide, which is the main product of biological oxidation, VOCs represent one of the dominant groups of chemicals generated in MBTs (Gutiérrez et al., 2015). VOCs are precursors of tropospheric ozone and, therefore, they indirectly contribute to global warming. Several VOCs have adverse effects on human health, and long-term exposure to some of them can increase the risk of developing cancer over a lifetime (Kume et al., 2008). Finally, due to their volatility and their low odour threshold, some VOCs can be easily perceived by the sense of smell and may cause odour

☆ This paper has been recommended for acceptance by Dr. Hageman Kimberly Jill.
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http://dx.doi.org/10.1016/j.envpol.2017.08.096
0269-7491/

nuisance (Sarkar et al., 2003). VOCs are generated by incomplete aerobic biodegradation and in local anaerobic regions in the waste piles promoting anaerobic biodegradation (Canovai et al., 2004; Domingo and Nadal, 2009; Diaz et al., 2011). Anaerobic conditions were reported as a favourable factor towards the formation of sulphides, while incomplete aerobic biodegradation is responsible for the formation of other VOCs, such as esters, ketones, alcohols and volatile fatty acids (Pagans et al., 2006). The creation of local anaerobic regions is favoured in waste piles characterised by low porosity (Shao et al., 2014). Following their formation, VOCs are released from MBT plants into the atmosphere, mainly through air leaks from the compartments of the plant. An additional contribution may derive from incomplete removal from the waste-gas treatment line. Indeed, although outlet concentrations generally do not exceed tens of ppm (Dorado et al., 2014), the effluent flow rate of a medium-size MBT plant is typically in the order of 10^4 Nm^3 h^{-1} (Schiavon et al., 2016b) and the resulting emission of VOCs may account for 10^2–10^3 g h^{-1}. Therefore, non-negligible contributions of VOCs to the environment are expected from MBTs (Ragazzi et al., 2014).

Odour nuisance is tightly linked with the waste sector (Canovai et al., 2004). The public concern and the complaints arising from the problem of odours may impede the construction of new MBT facilities, may preclude the proper activity of an existing MBT plant and may even lead to its closure (Beloff et al., 2000).

The literature on the health effects of odour emissions from waste treatments is scarce (Giusti, 2009) and results are controversial (Aatamila et al., 2011). However, increased reporting of symptoms such as headache, respiratory problems, excessive tiredness, and nausea, are associated with exposure to odorants (Aatamila et al., 2011). Though odours may be classified as "harmless" (*i.e.*, not toxic or hazardous) according to public health authorities, they may still have adverse effects on individuals and communities (Beloff et al., 2000). These effects include discomfort (such as reduced enjoyment of property), psychological impacts, property devaluation (Isakson and Ecker, 2008), tourism and employment decline.

In this sense, the reduction of odour emissions from composting plants would imply many advantages. Firstly, the location of plants depends on two main issues at least: the odour acceptability in the neighbourhood (Cariou et al., 2016a) and the operating costs, which have to be minimised (Diaz et al., 2011). Odour abatement would allow the plant location to be chosen mainly (if not entirely) on cost reduction, and plants could be located nearby densely populated areas in order to minimise transport and collection costs. Secondly, a major reduction of odour emissions would also reduce public concern and complaints from people living nearby composting plants, since adverse effects on individuals and communities (*e.g.*, discomfort, property devaluation and tourism decline) would be limited to a smaller area. Thirdly, symptoms associated with exposure to odour emissions would be reduced, with a corresponding reduction in public and private health spending. Finally, properly designed removal technologies would allow existing plants to reduce their social cost impact (Beloff et al., 2000). In particular, despite an investment in abatement equipment may be required, the risk of lawsuits from neighbours or citizen groups and the risk of fines and penalties from regulatory agencies would be reduced.

Although it is not easy to assess societal costs associated with odour emission (Beloff et al., 2000), overall, the cost for enhanced odour abatement systems would be probably lower than the cost incurred for shutting down and relocating a plant (with transportation cost increasing with the distance from the original location).

A first step towards the understanding of the implications of odorant VOCs released by composting processes and towards the development of improved abatement technologies requires a deeper analysis of VOC emissions. Indeed, little is known about which VOCs are released by composting plants as a function of the kind of input waste. Improving the knowledge on VOC emissions associated with composting processes is of particular importance since different VOCs imply different odour impacts. VOC speciation depends on the substrate that is composted and on the conditions under which the composting process is carried out (Turan et al., 2007; Phan et al., 2012). Thus, the problem of odorant VOC emissions from composting plants lacks a systematic characterisation of the released VOCs. Studies carried out during the last decade report the results of odorant characterisations of OFMSW (Sironi et al., 2006; Tsai et al., 2008; Zhang et al., 2013; Maulini-Duran et al., 2014) or zootechnical waste (Webb et al., 2014; Jo et al., 2015; Dunlop et al., 2016; Szulejko et al., 2016). The different conditions under which the various studies were carried out complicate the inter-comparison of the obtained results.

In the light of this scarcity and inhomogeneity of information, this paper aims at filling this gap in the scientific literature in a unified and repeatable approach. For the first time, this study analyses in detail the possible formation of odorant VOCs from the aerobic biodegradation of different waste matrices under the same process conditions, through a specific bench-scale experimentation set up for this purpose. Three matrices of organic origin are characterised and aerobically biodegraded in a bench-scale bioreactor. Samples of the process air, collected at the outlet of the bioreactor using a homemade automatic sampler, were analysed for VOC detection, speciation and quantification. The information on the concentrations of the detected VOCs was combined with the VOC-specific odour thresholds available from the literature, with the aim of estimating the odour concentrations associated with the VOCs released by the aerobic biodegradation of each waste matrix. Finally, the relative contribution of each matrix was estimated in terms of VOC-related odour emissions during the aerobic biodegradation process. Indeed, this study does not claim to provide the VOC and odour concentrations expected in the emission of real-scale composting plants but intends to estimate the expected relative weight of each matrix in terms of odour contribution. The choice to carry out each test under the same operating conditions allows for the inter-comparison of the relative VOC-related odour contributions.

2. Materials and methods

2.1. Waste matrices

Three waste matrices were chosen to characterise the emissions deriving from the aerobic degradation of waste biomass. The first matrix (M1) is composed of dewatered sewage sludge from a wastewater treatment plant (WWTP) mixed with green waste (80% and 20% m/m, respectively); the second matrix (M2) contains digested OFMSW and green waste (80% and 20% m/m, respectively); the third matrix (M3) contains untreated food waste and green waste (70% and 30% m/m, respectively). All mixing ratios are on a wet basis, in order to reproduce the mixing procedure that normally occurs in waste treatment plants. Dewatered sewage sludge was taken at the end of the sludge treatment line of a local municipal WWTP, after sludge conditioning and mechanical dewatering. Digested OFMSW was taken immediately downstream of the digester of an MBT plant performing anaerobic digestion and post-composting. Untreated food waste was taken from the accumulation chamber of the sorted food waste arriving at a local composting plant. Here, an efficient selective collection system is implemented, and a 67% selective collection rate is achieved (Rada