Waste Management 79 (2018) 188–195

Contents lists available at ScienceDirect

Waste Management

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

Emission characteristics and health risk assessment of volatile organic compounds produced during municipal solid waste composting

Erqi Nie, Guodi Zheng *, Zhuze Shao, Jun Yang, Tongbin Chen

Center for Environmental Remediation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Science, Beijing 100101, China
College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 18 March 2018
Revised 2 July 2018
Accepted 11 July 2018

Keywords:
Municipal solid waste
Composting
Volatile organic compounds
Health risk assessment
GC–MS

ABSTRACT

Municipal solid waste degradation during composting generates volatile organic compounds (VOCs), which can pose health risks the staff at the composting site and people living nearby. This problem restricts the widespread application of composting techniques. The characteristics of VOCs emitted from different units at a composting plant and the health risks posed were investigated in this study. A total of 44 VOCs (including alkanes, alkenes, aromatic compounds, halogenated compounds, oxygenated compounds, and sulfur-containing compounds) were identified and quantified. The highest VOC concentration ($15484.1 \pm 785.3\ \mu g/m^3$) was found in primary fermentation, followed by the tipping unit ($10302.1 \pm 1334.8\ \mu g/m^3$), composting product ($4693.6 \pm 1024.3\ \mu g/m^3$), secondary fermentation ($929.9 \pm 105.2\ \mu g/m^3$), and plant boundary ($370.4 \pm 75.8\ \mu g/m^3$). The mean VOC concentration was $6356.0\ \mu g/m^3$. The main compounds emitted during primary fermentation were oxygenated and those emitted from the tipping unit were alkenes. Health risk assessments indicate that VOCs did not pose unacceptable non-carcinogenic risks i.e., the HR values were <1 and carcinogenic risks (CR) values were $<1.0 \times 10^{-4}$. These results indicate that VOC emissions do not pose health risks to the staff at the composting site or to people living nearby. However, the cumulative non-carcinogenic and carcinogenic risks posed by the VOC mixture were high, especially for the primary fermentation unit emissions. Therefore, protecting the staff working near the primary fermentation unit should be a priority. Measures should be taken to minimize cumulative non-carcinogenic and carcinogenic risks because people are exposed to a mixture of VOCs mixture rather than to a single type of VOC.

1. Introduction

Increasing quantities of municipal solid waste (MSW) are being produced because of rapid expansion of cities/towns owing to the massive migration from rural to urban centers (Awasthi et al., 2014). According to data reported by the National Bureau of Statistics of the People's Republic of China (2017), the amount of MSW collected and transported in China reached 2.03×10^8 t in 2016. Such a high amount of MSW presents numerous environmental, social, and economic challenges. Effective MSW management strategies are required to address these challenges (Sukholthaman and Sharp, 2016). There are three main MSW disposal methods, landfill, incineration, and composting (Tian et al., 2012). Due to its ease of operation and low costs landfilling is considered the simplest and most efficient MSW disposal method, and it has therefore been used as the main disposal method (Owusu et al., 2012). However, gases and leachates are released from landfill sites and cause numerous environmental problems (Domingo and Nadal, 2009). Further, constructing new landfills is challenging because of land scarcity. Other MSW disposal options near inhabited areas therefore need to be developed (Moh and Abd Manaf, 2017).

There has been great interest in incinerating MSW, especially in more developed areas where new landfill sites are not readily available. However, the viability of incineration has been questioned because of concerns about the effects of particulate matter, gaseous pollutants, and emissions of dangerous substances on environmental and human health (Tian et al., 2012). Composting is a biological process in which aerobic thermophilic and mesophilic microorganisms convert organic matter mainly into mineralized products (De Guardia et al., 2010). The composting product can replace soil conditioners to support humus formation (Hermann

* Corresponding author at: Center for Environmental Remediation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Science, Beijing 100101, China. College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China.

E-mail addresses: zhenggd@igsnrr.ac.cn (G. Zheng), yangj@igsnrr.ac.cn (J. Yang), chentb@igsnrr.ac.cn (T. Chen).

https://doi.org/10.1016/j.wasman.2018.07.024
0956-053X/

et al., 2011), improve plant growth, and exert biocontrol on different soil-borne phytopathogens such as fungi (Traversa et al., 2010). The number of composting facilities has, however, recently decreased because composting processes emit irritating odorants and volatile organic compounds (VOCs) that pose risks to human health (De Feo et al., 2013). VOC emissions are generated from waste with low calorific value, high water content, and high organic matter content (Pierucci et al., 2005; Yang et al., 2013). The types of VOCs emitted during composting are related to the composition of the MSW. Komilis et al. (2004) found that composting material containing food waste can generate large amounts of oxygen-containing compounds in the early stages of the composting process. Aromatic compounds are found in MSW containing chemical solvents, paint coatings, food additives, and aromatic detergents; green waste is a potential source of terpenes and hydrocarbons (Komilis et al., 2004; Pagans et al., 2006; Rodriguez-Navas et al., 2012). The types of VOCs emitted are not only related to the MSW composition but also to the conditions existing (temperature, humidity, oxygen concentration, conditioners added, and ventilation) during the composting process (Mustafa et al., 2017). For example, anaerobic fermentation, which occurs when the aeration rate is low, produces large amounts of sulfur-containing compounds. Saldarriaga et al. (2014) estimated VOC emissions during MSW composting and found that ventilation can accelerate the release of VOCs in a composting pile. Maintaining good operating conditions during MSW composting can therefore effectively decrease VOC production. Optimizing composting process parameters (e.g., ventilation, humidity, C/N ratio, and turnover time) can decrease VOC emissions, but some VOCs will inevitably be produced even under optimum conditions (Coker, 2016; Delgado-Rodriguez et al., 2011, 2012). Many studies have found that VOCs such as volatile organic sulfides, volatile fatty acids, alcohols, aldehydes, ketones, terpenes, and aromatic compounds are emitted during composting (Tsai et al., 2008; Zhang et al., 2013).

Emissions of VOCs contribute to environmental problems such as global warming and stratospheric ozone depletion, and can also cause severe human health problems such as cancer, respiratory irritation, and central nervous system damage (Domingo et al., 2015). Blount et al. (2006) found that short-term exposure to VOCs can cause local reactions such as acute irritation of the eyes, nose, throat, and skin. Long-term exposure to VOCs may increase the risk of neurasthenia, respiratory tract damage, and central nervous system damage. Determining the probability of exposure to a hazard that will cause an undesirable health effect is called "risk assessment" (Akdeniz et al., 2013; Durmusoglu et al., 2010). Risk assessment is one of the fastest evolving tools for evaluating the effects of exposure to hazards on human health and for determining the importance of solving specific environmental problems (Zhou et al., 2011). Risk assessments are also used to determine ways to develop appropriate hazardous chemical management strategies. Inhalation of VOCs present in air is a major route through which humans are exposed to VOCs in composting facilities (Domingo et al., 2015). Less severe health risks may be posed by composting facilities than by landfill sites and incineration facilities (Li et al., 2015). Niu et al. (2014) conducted a health risk assessment of odors emitted from urban wastewater pump stations. He et al. (2015) conducted health risk assessment of VOCs emitted from different plastic solid waste recycling workshops. However, the risks posed by VOC emissions, to the staff at composting sites and people living nearby, during composting should still be assessed (Mustafa et al., 2017). The aim of this study was to investigate the characteristics of and assess the health risks posed by VOCs emitted from different processing units at an MSW composting plant. Analyzing the VOCs emitted from the different units allowed major contributors to VOC emissions during composting to be identified. The units that need to be managed as a priority were identified through the VOC health risk assessment. The results of this study will provide an accurate reference point for VOC health risk assessments for composting facilities and will help determine effective actions be taken to prevent VOC emissions from different composting plant units.

2. Materials and methods

2.1. Sampling site

The study was conducted at an MSW composting plant in Beijing, China. This plant has been in operation since 1998 and is the most stable and longest running MSW composting plant in China. The plant had a treatment capacity of 400 t/d, but improvements in composting technologies have increased the capacity to 2000 t/d. The feedstock for the plant is mainly supplied by nearby transfer stations. The feedstock comprises particles in the size range of 15–80 mm and has an organic matter content of >50% (Li et al., 2009). The composting plant uses a high-temperature aerobic composting fermentation tunnel technique, with each tunnel equipped with a variable-frequency fan control and optical oxygen and temperature probes. The temperature, humidity, and oxygen concentrations can therefore be monitored and controlled in real time in each tunnel. A schematic of the composting facility is shown in Fig. 1.

The typical composition of the MSW is food waste, paper, plastic, and other ingredients. Among this, the quantity of food waste was found to be the highest followed by that of paper, plastic, and other ingredients (Fig. 2). The MSW treated at the plant was placed in a tipping unit, from which the organic components were collected using trommel screens while recyclable materials, such as plastic, glass, metal, ash, and stone, were removed. The organic components were then transferred by fermentation rollers to the primary fermentation unit. After 14 d of primary fermentation, the organic components were transferred to a secondary fermentation unit, in which they were fermented for 21 d. The material was then taken to a composting product workshop and sieved before final treatment and packing. About 6.3 t coarse composts are produced for landfill cover soil when the plant treats 100 t MSW, and 2.47 t compost are good in quality were used to fertilize the soil. Usually about 34.6 t residues are produced and they are transported for landfill. Air samples were collected from each unit and from the boundary of the composting plant.

2.2. Sampling method

Air samples were collected from the processing units from March 23 to 25, 2016. Each processing unit collected two gas samples a day. Each sample was collected at a height of approximately 1.5 m (i.e., in the breathing zone). Samples were collected between 10:00 and 12:00 and between 13:00 and 15:00, i.e., during working hours, to ensure that they represented the air that the plant workers would have inhaled. Each air sample was collected dynamically using an SOC-01 sampling system, connected to an 8 L polyester sample bag operated on the lung principle (Duan et al., 2014). A mass flow controller was used, and the collection rate was 15 L/min. Each ambient air sample was collected over 20 s, resulting in a sample volume of approximately 5 L. Each sample bag was cleaned three times, by collecting and discharging air at the sampling point, before a sample was collected to minimize the influence of VOCs already present in the bag. The input and connection lines each contained a polytetrafluoroethylene sampling tube. Each sample was analyzed in triplicate less than 24 h after being collected, and the mean concentrations were used.