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Reducing H_2S production by O_2 feedback control during large-scale sewage sludge composting

Jun Chen, Tong-Bin Chen *, Ding Gao, Mei Lei, Guo-Di Zheng, Hong-Tao Liu, Song-Lin Guo, Lu Cai

Center for Environmental Remediation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 11A Datun Road, Beijing 100101, China

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ABSTRACT

Hydrogen sulfide (H_2S) production patterns and the influence of oxygen (O_2) concentration were studied based on a well operated composting plant. A real-time, online multi-gas detection system was applied to monitor the concentrations of H_2S and O_2 in the pile during composting. The results indicate that H_2S was mainly produced during the early stage of composting, especially during the first 40 h. Lack of available O_2 was the main reason for H_2S production. Maintaining the O_2 concentration higher than 14% in the pile could reduce H_2S production. This study suggests that shortening the interval between aeration or aerating continuously to maintain a high O_2 concentration in the pile was an effective strategy for restraining H_2S production in sewage sludge composting.

1. Introduction

Odorous emission is a serious concern for composting facilities (Pagans et al., 2005; Schlegelmilch et al., 2005a; Domingo and Nadal, 2009). Fatty acids, amines, aromatics, inorganic sulfide, organic sulfides, terpenes and ammonia were potentially significant odorants emitted during composting (Haug, 1993). The odor concentration of exhaust gas of composting was reported to exceed 180,000 OU m^{-3} (Schlegelmilch et al., 2005a).

Terminal treatment and process control are the two main approaches for composting odor elimination (Schlegelmilch et al., 2005a). Terminal treatment is a complex system involving off-gas collecting equipments, introducing pipes and treating reactors. Biological treatment (e.g. biofilters, bioscrubbers, biotrickling filters) were regarded as effective technologies to remove odors from off-gas of composting plant (Schlegelmilch et al., 2005a,b). However, capturing the waste gas for a large-scale composting plant is very difficult and requires a large quantity of power. Process control is a strategy for decreasing odor production and emission by means of optimizing the materials conveying process, adjusting physicochemical properties and optimizing composting parameters (Körner et al., 2003; Schlegelmilch et al., 2005a). It's an important aspect to reduce odor gas concentration of the exhausted gas during composting.

Most research works showed that odorous gases are mainly emitted at the early stage of composting. Schlegelmilch et al. (2005a) identified that the odor gases are released mainly during the first 2–3 weeks during a 7-week composting cycle. According to Eitzer (1995), most volatile organic compounds (VOC) in aerobic composting plants are emitted at early stages of full-scale composting process. Saludes et al. (2008) revealed that maximum concentrations of NH_3 reached its peak values of 8000 ppm on day 3 and began to decline rapidly thereafter during a 4-week composting process. These data suggested that odor control should focus more on the early stage of composting.

H_2S has been widely recognized as one of the major odorous gases produced during composting (Malhautier et al., 2003). H_2S produces a unique rotten egg smell and the odor threshold is only 0.5–2 ppb in air (Gabriel and Deshusses, 2003). H_2S is extremely toxic to living organisms and plants and harmful to human health (Eghbal et al., 2004; Lambert et al., 2006). At higher concentrations, it can be life-threatening (Meeyoo et al., 1998). As for terminal treatment of H_2S, biofiltration has proved to be an effective technology (Gabriel and Deshusses, 2003; Kim et al., 2008; Jiang et al., 2009; Rattanapan et al., 2009). However, little research has been published on H_2S control strategies during composting.

H_2S is produced as a result of bacterial reduction of sulfate and decomposition of sulfur-containing organic constituents of the substrates under anaerobic conditions (Arogo et al., 2000). Research into H_2S production mechanisms in sewage concluded that H_2S is produced in the absence of electron acceptors such as dissolved oxygen (DO), H_2O_2, Cl_2, NO_3^-, Fe^{3+}, ClO^- and $KMnO_4^-$ (Delgado et al., 1999; Gostelow et al., 2001; Zhang et al., 2008). The main reason for H_2S generation is the low redox potential (ORP). The optimal ORP for H_2S production was determined to be −100 to −250 mV (Boon, 1995). Sulfide production could be decreased by increasing the redox potential (Zhang et al., 2008). Methods for increasing the redox potential involve addition of thermodynamically favorable electron acceptor compounds. Oxidants (e.g. O_2, nitrate or nitrite) were proved effective in reducing H_2S production during wastewater transport and treatment (Hobson and

* Corresponding author. Tel./fax: +86 10 64889303.
E-mail address: chentb@igsnrr.ac.cn (T.-B. Chen).

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Yang, 2000; Chang et al., 2007). However, details of the ORP in the compost pile and the relationship between H_2S production and ORP during composting are not clear. Predicala et al. (2008) revealed that adding nitrite or molybdate into swine manure could effectively reduce H_2S emission during composting. However, adding oxidants (such as nitrate, nitrite or molybdate) is expensive and not worthwhile for controlling H_2S production from the viewpoint of operating cost. Moreover, mixing these oxidants homogeneously in the composting materials is not straightforward in composting engineering. Meanwhile, O_2 supply is an integral part of the static forced-aeration composting process. So optimizing the aeration parameter maybe a better choice for elevating ORP to control H_2S.

Aeration parameters for composting have been studied intensively but most of these studies were carried by bench-scale or pilot-scale level aimed at organic degradation and compost product maturation. The aeration parameters focus on odor gas elimination in full-scale are very few. Insufficient aeration and poor O_2 transfer are always considered as the main reason for odor gas production in the biological reaction (D'Imporzano et al., 2008; VanderGheynst et al., 1997). It is generally believed that H_2S is produced under anaerobic conditions (Li et al., 2008; Zhang et al., 2008) but the mathematical relationship between H_2S production and O_2 concentration haven't been established.

This study aimed to investigate H_2S production patterns and the relationship between H_2S production and the O_2 concentration in a large-scale composting plant. The results of this study can be used to optimize the aeration strategy to reduce H_2S production during sewage sludge composting. Furthermore, the spatial variations of H_2S in the composting pile will be reported in another paper.

2. Materials and methods

2.1. Composting materials

Sewage sludge (SS) was collected from the No. 4 Municipal Wastewater Treatment Plant of Qinhuangdao, China. Sawdust (SD) was acquired from wood-working factories in the same city. Mature compost (MC) was collected from a sewage sludge composting plant naming Lvgang Municipal Sewage Sludge Treatment Plant (Qinhuangdao, China) (Chen et al., 2010). These materials were filled in three feed bins and then fed to a mixing machine by screw conveyors. The mixing ratio could be adjusted by changing the rotating speed of screw conveyors. For fast temperature increasing, three materials were mechanically mixed at an approximate volume ratio of 3:2:1 (SS: MC: SD) in this plant. The physicochemical properties of the raw materials and the mixture are shown in Table 1.

2.2. Composting procedures

Composting experiments were carried out at the Lvgang Municipal Sewage Sludge Treatment Plant. The treatment scale for sewage sludge was 200 ton per day, and the process time for composting was 20 days. There were 20 fermentation compartments constructed from concrete. The composting mixture was loaded in the fermentation compartment. The size of composting pile was $30 \times 5 \times 1.6$ m (L × W × H). Air was supplied (from bottom to top of the pile) by air blowers. Each air blower was shared by three piles. The maximum air flow rate of the air blowers was $140\ m^3\ min^{-1}$ ($0.58\ m^3$ air m^{-3} pile min^{-1}) at a motor power supply frequency of 50 Hz and the flow rate could be adjusted by an inverter. The adjusting range was 30–50 Hz. The aeration strategy was controlled using an innovated static forced-aeration process named CTB auto-control technology (Control Technology of Bio-composting). It's a control technology based on a combination of temperature and O_2 concentration feedback from temperature sensors (Chen et al., 2001a) and oxygen sensors (Chen et al., 2001b). The composting process was controlled by Compsoft® 3.0 (GreenTech Environmental Engineering Ltd., Beijing, China) (Chen et al., 2001c). The aeration parameters were adjusted at different composting stages based on temperature (T) and the O_2 consumption rate (R_{O_2}). The aeration period was 20 min (aerated for 4 min and unaerated for 16 min) during the temperature increasing phase ($T < 60$ °C); 20 min (aerated for 5 min and unaerated for 15 min) during the early stage of the thermophilic phase ($T > 60$ °C, $R_{O_2} > 6 \times 10^3\ \mu L\ L^{-1}\ min^{-1}$); 35 min (aerated for 5 min and unaerated for 30 min) in the later stage of the thermophilic phase ($T > 60$ °C, $R_{O_2} < 6 \times 10^3\ \mu L\ L^{-1}\ min^{-1}$).

2.3. Sample analysis

Initial composting materials were sampled to analyze the following parameters: moisture content (105 °C for 10 h) (Bao, 1999); volatile solids (450 °C for 4 h) (Bao, 1999); Total *S* using an element analyzer (Vario EL) (Ma et al., 2007); Total *N* (Kjeldahl method) (Bremner, 1996); Total *P* (after acid digestion) using an ultra-violet visible spectrophotometer (SP-752PC, Shanghai, China) at a wavelength of 660 nm; Total *K* (after acid digestion) using an atomic absorption spectrophotometer (HG-5, Beijing, China).

H_2S and O_2 concentrations were detected by a custom-made H_2S–O_2 detection device. The sensors used for O_2 concentration (C_{O_2}) and H_2S concentration (C_{H_2S}) were O2-A3 (Alphasense, UK) and H_2S/C-200 (Alphasense, UK), respectively. Temperature was measured using a PT100 sensor, installed at the tip of the probe of the H_2S–O_2 detection device. The C_{O_2}, C_{H_2S} and temperature of the pile could be detected in situ using this device online. The measuring range for C_{O_2}, C_{H_2S} and temperature are 0–30%, 0–100 ppm and −20–100 °C, respectively. The response time of the device was 2 s. The probe was inserted into the pile at a depth of 0.8 m (from top to bottom). The working principle of this device and its installation position are shown in Fig. 1.

The O_2 consumption rate (R_{O_2}) was computed from the C_{O_2} decrease rate over the 3 min following stopping the air blower.

$$R_{O_2}(\mu L\ L^{-1}\ \min^{-1}) = \frac{C_{O_2(t0)}(\mu L\ \ L^{-1}) - C_{O_2(t3)}(\mu L\ \ L^{-1})}{3(\min)}$$

Table 1
Physicochemical properties of composting materials used in the study.

Material	Moisture (%)	Volatile solid (%, d.b.[a])	Density (g cm^{-3})	Total *S* (%, d.b.)	Total *N* (%, d.b.)	Total *P* (%, d.b.)	Total *K* (%, d.b.)
Sewage sludge	82.9 ± 0.28	61.9 ± 0.21	0.99 ± 0.03	0.78 ± 0.06	4.84 ± 0.04	3.64 ± 0.03	0.83 ± 0.04
Mature compost	46.5 ± 0.87	77.2 ± 1.21	0.71 ± 0.07	0.62 ± 0.05	1.84 ± 0.08	1.92 ± 0.07	0.63 ± 0.09
Sawdust	13.5 ± 0.12	83 ± 0.28	0.18 ± 0.03	0.38 ± 0.05	0.62 ± 0.04	0.46 ± 0.02	0.54 ± 0.07
Mixture	66 ± 1.05	69.2 ± 0.78	0.76 ± 0.08	0.70 ± 0.09	2.31 ± 0.06	1.91 ± 0.05	0.68 ± 0.07

Results are means ± SD, $n = 3$.
[a] d.b. refers to a dry basis.