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Gaseous pollutants from a small-scale aerobic biological treatment facility: odor and health risk assessment

Kexian Li¹, Xinhong Xu¹, Fan Lü², Pinjing He² and Jingjing Fang^{1*}

Abstract

Background: Biological treatment technology is good for the recovery of resources and energy from municipal solid waste (MSW) and cutting down biodegradable components in landfill waste. Recently, the aerobic biological treatment of MSW has increased in rural areas of China. These facilities are usually open setup and close to nearby residents, and complaints tend to be received regarding odorous gases. A semi-in-vessel setup facility was built in recent years, and its impact on the environment and personnel is not clear.

Results: Ammonia was the predominant compound released from the windrow and its concentration was one order of magnitude higher than those of other compounds. Terpenes and reduced sulfur compounds (RSCs) persisted throughout the entire active fermentation process, with only slight decreases. The biofilter pool had a greater odor impact on the surrounding neighborhood than the waste unloading and sorting operation. The concentrations of most compounds were reduced by the biofilter pool. Ten major substances that caused odors at the facility were analyzed, where most comprised RSCs. The odor impact of the facility was low, but it was associated with a carcinogenic risk to the operators, thereby indicating the need to improve personal protection.

Conclusions: Large amounts of ammonia and volatile organic compounds were released from the composting units, but they had a low odor impact on the environment because of the semi-in-vessel setup. The odor impact of the facility was low but it was associated with a carcinogenic risk to the operators. This technology can be popularized in rural areas.

Keyword: Small scale, Aerobic biological treatment, Gaseous pollutants, Odor assessment, Carcinogenic risk assessment

Background

Biological treatment technology is good for the recovery of resources and energy from municipal solid waste (MSW) and cutting down biodegradable components in landfill waste. Recently, the aerobic biological treatment of MSW has increased in rural areas of China. These facilities are usually close to nearby residents, and complaints tend to be received regarding odorous

gases. Ammonia is the predominant gaseous pollutant with emissions of around 18–1150 g/t waste [1]. Composting technology is one of the important methods for organic waste disposal. Windrow composting and trough composting are two main technology in China. Most of Windrow composting got lower H₂S emission, but higher NH₃ release comparing with trough composting [2]. The concentration of ammonia in the exhaust gas from sludge composting facilities can be as high as can be as high as 700 mg/m³ [3]. Volatile organic compounds (VOCs) are also one of typical air pollutants, with concentrations in the air around MSW composting facilities ranging from 8 to 16 mg/m³ [4]. Rodriguez et al. [5] researched the

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influence of the operating technology to VOC release, such as moisture, oxygen, and C:N ratios (ratio of carbon to nitrogen). They found that the most important factor was the C:N ratio, then was the internal oxygen and moisture contents of the windrow.

The emission patterns of gaseous pollutants during mechanical processes, such as waste sorting and shredding, differ significantly from those in aerobic biological treatment processes. Stirring and crushing processes can strip some compounds, especially xenobiotic organics, from the surface of the waste and make them readily volatilized [6]. Toluene and xylene are the dominant VOCs in the shredding, mixing, and sorting areas of composting facilities. Some studies reported that these aromatics originated from the decomposition of polymer and solvents [7], whereas others have shown that these aromatics compounds are released from raw materials rather than intermediate products of waste biodegradation. Volatile fatty acids (VFAs) can be produced by the hydrolysis and anaerobic digestion of carbohydrates [8, 9], fats, and proteins in waste, and they can accumulate when inadequate oxygen is supplied during aerobic biodegradation [10]. The olfactory threshold of VFAs is low, which has a great impact on the environment.

Sulfur compounds, nitrogen-containing compounds and terpenes have strong pungent odor also, so the emission of these gas pollutants will have odor impact on nearby communities. In the process of refuse composting, incomplete or inadequate ventilation will lead to the release of hydrogen sulfide and other malodorous substances [11, 12]. Fang et al. [13] found that limonene, dimethyl sulfide, dimethyl disulfide and α -pinene are the main odorants in municipal solid waste composting facilities. Tsai et al. [14] studied the kitchen waste composting

facilities and found that the concentrations of ammonia, dimethyl sulfide and hydrogen sulfide had a logarithmic relationship with odor intensity, while the concentrations of ethylbenzene, acetic acid and p-toluene had a linear relationship with odor intensity. This result tells us that reducing odor intensity of ammonia, dimethyl sulfide and hydrogen sulfide is much more difficult than other pollutants. It is reported that the odor of trimethylamine has high persistence and low odor threshold. Therefore, if the odor source contains trimethylamine, the influence range and distance of the source are larger than others [15].

The present study investigated the odor compounds emitted from a small-scale MSW aerobic biological treatment facility as well as assessing the odor impact and health risk for the operators. Based on the theoretical odor concentrations and exposure concentrations, the main odor compounds were identified in various treatment processes, as well as the hazard quotient and carcinogenic risk was evaluated.

Methods

Site description and sampling location

The study site was located in Shanghai Chong Ming Island, with a capacity of approximately 0.6–2 ton/day, and the service area comprising a community of 4000 resident was 100 m away from the facility. The facility comprised 20 composting units, a biofilter pool, and a sorting area, as shown in Fig. 1. The facility was opened except the composting unit and the board was not walls but railing. The composting unit was usually closed only when the waste feeding opened. Oxygen was supplied through the ventilation system in the bottom and the gas was collected for purification through the biofilter system. Chopped straw with a length of 2–5 cm was used

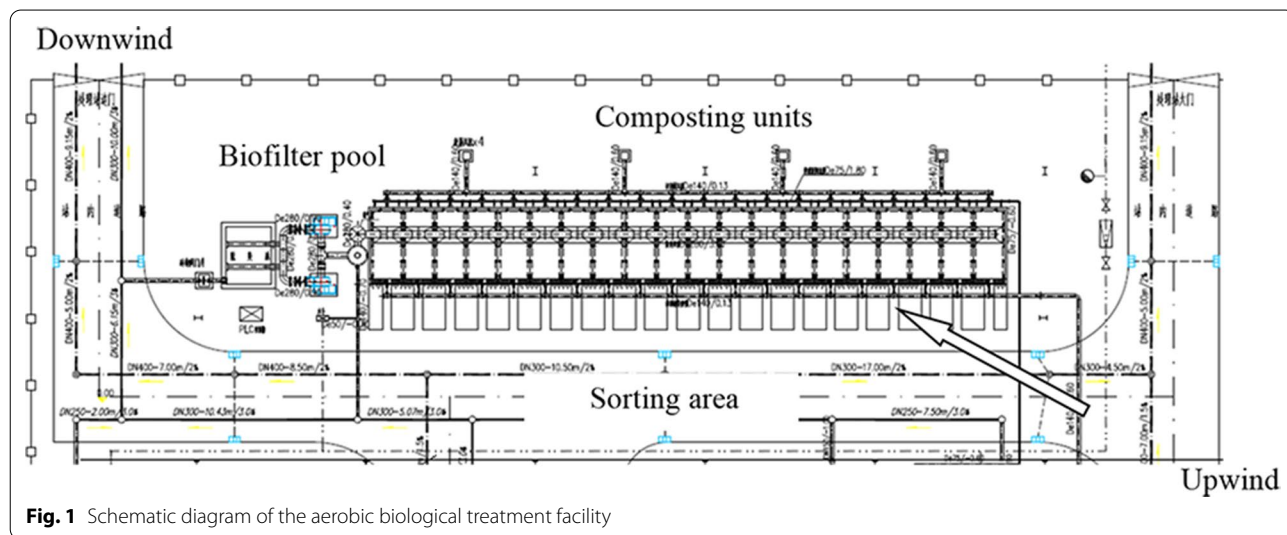


Fig. 1 Schematic diagram of the aerobic biological treatment facility

as a bulking agent. After removing glass and metal debris, the raw MSW was mixed with the bulking agent at a ratio of 10:1 (w/w) considering that the water content should not be excessively low, and an adequate specific surface area and free air spaces were necessary in the matrix [16]. The characteristics of the raw materials and mixture are presented in Table 1. The volatile solids content was analyzed by heating samples to a constant weight at 550 °C in a muffle furnace. The oxygen concentration and temperature at the core of the windrow were monitored using a probe (CYS-1; Xuelian Co., Shanghai, China). The elemental compositions of the freeze-dried samples were measured using an elemental analyzer (Vario EL III, Elementar Analysensysteme GmbH, Langensfeld, Germany). Active fermentation (static composting-like process) occurred for 20 days in the closed composting unit with controlled aeration and gas collection, as well as treatment with a biofilter.

Odorous gas sampling was conducted during waste loading, unloading, and sorting. Three sampling points were located in the sorting area, and upwind and downwind of the boundary of the facility. Sampling was also conducted at the same points when the facility was not in operation in order to conduct comparisons. One point was located in the biofilter pool when the ventilation process started. Inside the composting units, gas and solid sampling were conducted after 1, 3, 5, 7, 10, 15, and

20 days during the active fermentation phase. The wind speed during the sampling period was 3.1–3.6 m/s and the temperature was 20–24 °C. The relative humidity was approximately 55–65%. In total, seven chemical classes and 51 substances were determined in the gas samples, including ammonia, reduced sulfur compounds (RSCs), aromatics, terpenes, alcohols, carbonyl compounds, and VFAs.

Analysis of gas samples

Several methods were used to test different target gaseous pollutants, as showing in Table 2. These methods included sorbent concentration, cold trap concentration, derivatization concentration, gas chromatography method, liquid chromatography and colorimetric method.

Analysis of ammonia using colorimetric tubes

Ammonia in each sample was detected by colorimetric tubes (GV-100 s, GasTec., Kanagawa, Japan). Cut both ends of the colorimetric tube and insert the colorimetric tube into the hand pump in the direction of the arrow. A specific volume of 100 ml gas was extracted to the colorimetric tubes. Wait several minutes and confirm the completion of the sampling. The lengths of the color changes in the tubes indicated the concentrations of ammonia.

GC analysis after cold trap concentration

The air samples were collected by Tedlar bags (3L, SKC, PA, USA) which were placed in a sealed plastic box. There were two holes on the lid of the plastic box, one was connected with the Tedlar bag, and the other was connected with a vacuum pump. When the box was vacuumized by the pump, the air sample entered to the Tedlar bag through the hole connected with the bag. This will prevent the air pump from contaminating the air samples. The samples were placed for dark storage and transported to the laboratory within 12 h to minimize the loss of RSCs during storage.

According to the United States Environmental Protection Agency (USEPA) TO14A method [17], these air

Table 1 Characteristics of the raw materials and mixture feedstock in the tested composting unit

	MSW	Straw	Mixture ^a	Mixture ^b
Water content, % by wet mass	74.4 ± 2.7	87.2 ± 0.45	70.7 ± 1.3	68.4
VS, % by dry mass	79.7 ± 1.6	88.6 ± 0.3	84.3 ± 1.1	86.3
C:N ratio by dry mass	20.5 ± 1.8	41.5 ± 2.4	17.1 ± 2.9	17.8
Proportion (wet mass, w/w)	10/11	1/11	–	–
Weight (wet mass, kg)	550	55	605	605

^a The value was based on determination

^b The value was based on calculation

Table 2 Methods were used to measure different target gaseous pollutants

Pre-concentration method	Test method	Target gaseous pollutants
–	Colorimetric tube	Ammonia
Sorbent	Gas chromatography with flame ionization detection (GC-FID)	Volatile fatty acids (VFAs)
Cold trap	Gas chromatography with flame ionization detection (GC-FID)	Aromatics, terpenes, alcohols
Cold trap	Gas chromatography with pulsed flame photometric detection (GC-PFPD)	Reduced sulfur compounds (RSCs)
Derivatization	High-performance liquid chromatography (HPLC)	Carbonyl compounds

samples were concentrated by cold trap (Entech Instruments Inc., CA, USA) with liquid nitrogen, then detected by GC-FID and GC-PFPD (GC 450, Varian Inc., CA, USA). The injection volume was 100–1000 μl , according to the actual concentrations. The GC-PFPD and GC-FID parameters were described in detail in our previous study [17].

GC-FID analysis after sorbent concentration

Volatile fatty acids in air samples were determined by adsorbent concentration method. Air samples were collected using commercial adsorption tubes (silica gel tubes, SKC, PA, USA). The air flow rate was 2000 ml/min and the collection time was 120 min. After sampling, each tube was sealed and transported to the laboratory within 12 h. Take out the silica gel adsorbent, put it into a 5-ml volumetric flask and absorb it with 5 ml deionized water. After standing for 30 min in an ultrasonic apparatus, the supernatant was taken out and analyzed by GC-FID. The operation parameters of FID detection system were the same as our previous study [18].

HPLC analysis after derivation with DNPH

Commercial cartridges (Cleanert DNPH-Silica, Agela Technology, Tianjing, China) were used to collect carbonyl compounds in the air samples. Sampling flow rate was 1000 ml/min and the sampling time was 2 h according to EPA method TO11A [19]. After collection, the cartridges were sealed and transported to the laboratory within 12 h. The derived compounds in the cartridges were eluted into a 5-ml volumetric flask with 5 ml acetonitrile through a solid-phase extraction vacuum manifold (Visiprep, Supelco Analytical, Darmstadt, Germany).

A working standard calibration curve was prepared from serial dilutions of the aldehyde/ketone-DNPH standard stock solution (Cerilliant Inc., USA). The concentrations of the standard mix solutions varied from 0.075 to 15 ppm. The standard solutions and sample eluates were analyzed by HPLC (Agilent 1200, Agilent Inc., USA) attached to a diode-array detector (DAD) through an auto-sampler with a detector that was operated at 365 nm. The detection limit of this method was 50 ppb. The analytical column used was a C18 (4.6 mm ID \times 25 cm, 5 μm) stainless steel tube (Venusil XBP, Agela Technology, China) and the mobile phase was acetonitrile (Merck, Germany) and high purity water (Milli-Q Millipore, USA). The elution program was 45% acetonitrile for 1 min, followed by a linear gradient from 45 to 75% acetonitrile in 30 min, which was then held for 5 min. The flow rate was 2 ml/min and the sample injection volume was 25 μl .

Quality assurance and control

Five levels of mixed standard gases (50, 200, 400, 800, 1600 $\mu\text{g}/\text{m}^3$, Air Liquid, France) were determined to produce the standard calibration curves. Within the range of 0–1600 $\mu\text{g}/\text{m}^3$, the correlation was good ($R^2 > 0.93$). The detection limit of the instrument is determined by extrapolation of the linear ratio between the minimum peak area and the instrument noise. The concentration of the blank sample was less than 1 $\mu\text{g}/\text{m}^3$, indicating that there was no sample contamination during collection, transportation and storage. Ten kinds of repetitive standard gases were determined to evaluate their reproducibility. The relative standard deviation is less than 7%. The standard recoveries of these methods ranged from 81 to 114%.

Theoretical odor concentrations

Odor threshold concentration of each compound varies greatly and gases with high concentrations do not always contribute strong odors. Odor intensity can be measured by the ratio of its concentration and the odor threshold. When the composition of the odorous gas mixture is known, the theoretical odor concentration (C_{od}) of each sample can be estimated based on its analytical concentration and odor threshold according to Eqs. (1) and (2) [20]. The odor intensity of different sample points can be compared by this method:

$$C_{\text{od},i} = \frac{C_i}{\text{OT}_i}, \quad (1)$$

$$C_{\text{od}} = \sum_{i=1}^n \frac{C_i}{\text{OT}_i}, \quad (2)$$

where C_i is the analytical concentration of the i th compound (ppm); OT_i is the odor threshold value of the i th compound (ppm), where the OT_i value for each compound was obtained from a previous study [17]; $C_{\text{od},i}$ is defined as the theoretical odor concentration (dimensionless); n is the total number of odorous compounds; and C_{od} is the sum of the theoretical odor concentrations of n compounds of one sample.

Health risk assessment

Carcinogenic risk assessment

According to the Integrated Risk Information System of the United States EPA, the carcinogenic risks of gaseous pollutants were evaluated according to the inhalation unit risk (IUR) of carcinogens [21]. The cancer risk assessment was measured based on the lifetime carcinogenic risk (CRI) using Eqs. (3) and (4). The carcinogenic

risk value for a mixed source is the sum of that for each compound, according to Eq. (5). Synergistic and antagonistic effects among substances are not considered:

$$CRI = ECI \times IUR, \tag{3}$$

$$ECi = \frac{Ci \times ET \times EF \times ED}{AT \times 365 \times 24}, \tag{4}$$

$$CR = \sum_{i=1}^n CRI, \tag{5}$$

where IUR is the inhalation unit risk, $\mu\text{g}/\text{m}^3$; ECI is the exposure concentration of each gaseous pollutant in the air, $\mu\text{g}/\text{m}^3$; Ci is the concentration of each gaseous pollutant in the air, $\mu\text{g}/\text{m}^3$; ET is the daily exposure time of a worker, 8 h; EF is the exposure duration, 250 days/year; ED is the exposure duration, 30 years; and AT is the average age, 70 years. The parameters were selected based on a previous study [21]. There were six workers in total. All the workers were considered as similar exposure.

Non-carcinogenic risk assessment

For non-carcinogenic risk assessment, inhalation reference concentration (RfC) was used to calculate the hazard quotient of each pollutant (HQi) by Eq. (6). The non-carcinogenic risk value for a mixed source is the sum of that for each compound, according to Eq. (7).

Synergistic and antagonistic effects among substances are not considered:

$$HQi = \frac{ECi}{RfC \times 1000 \mu\text{g}/\text{mg}}, \tag{6}$$

$$HQ = \sum_{i=1}^n HQi, \tag{7}$$

where RfC is the inhalation reference concentration, mg/m^3 ; calculation method of ECI is the same as Eq. (4), which all values are the same except AT is the average age, 30 years. The parameters were selected based on a previous study [22].

Results and discussion

Gaseous pollutants inside the composting units

Inside the composting units, ammonia was the predominant compound and its concentration was one order of magnitude higher than that of other compounds (Fig. 2). The concentration of ammonia was $1300 \mu\text{g}/\text{m}^3$ after one day, but it increased to $35,000 \mu\text{g}/\text{m}^3$ after 5 days. After composting for 20 days, the concentration of ammonia was still $6000 \mu\text{g}/\text{m}^3$. Nitrogen in waste is readily converted into ammonia and this is more likely to occur when the C:N ratio is unbalanced. Except for ammonia, the total concentrations of the other chemical classes decreased rapidly from 8181 at the start to $224 \mu\text{g}/$

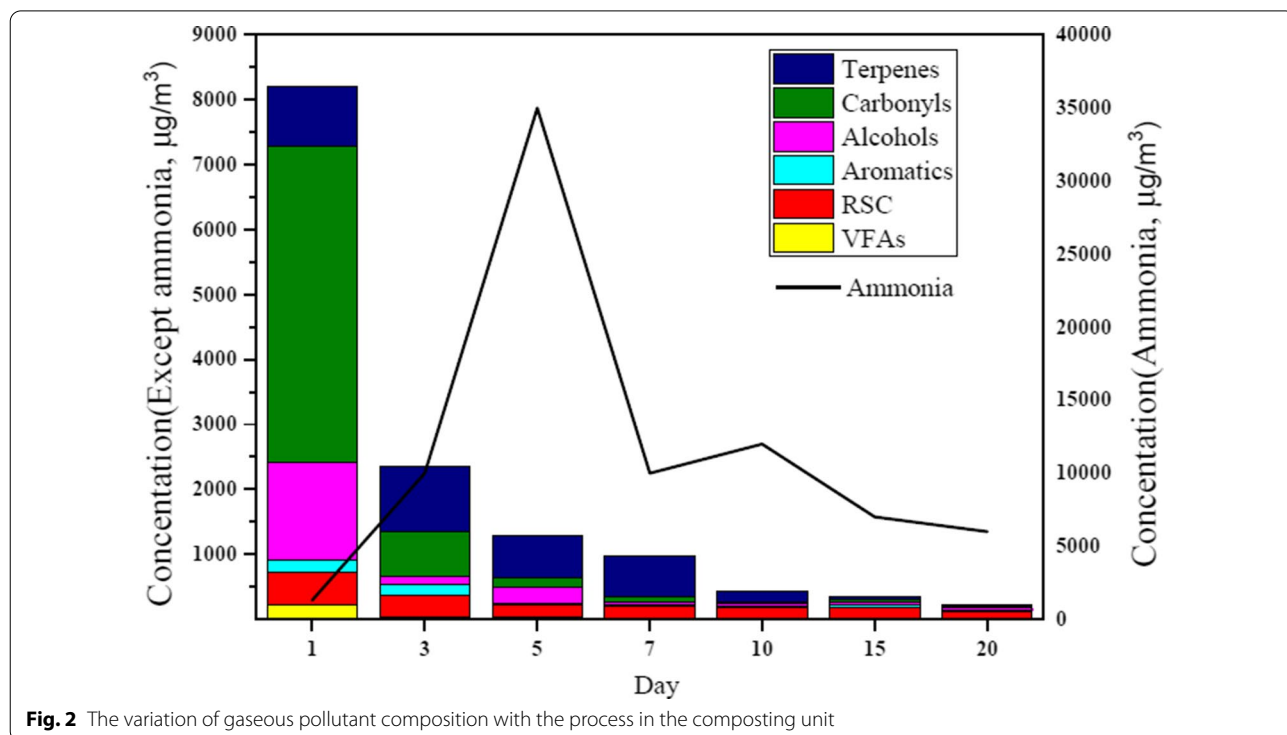


Fig. 2 The variation of gaseous pollutant composition with the process in the composting unit

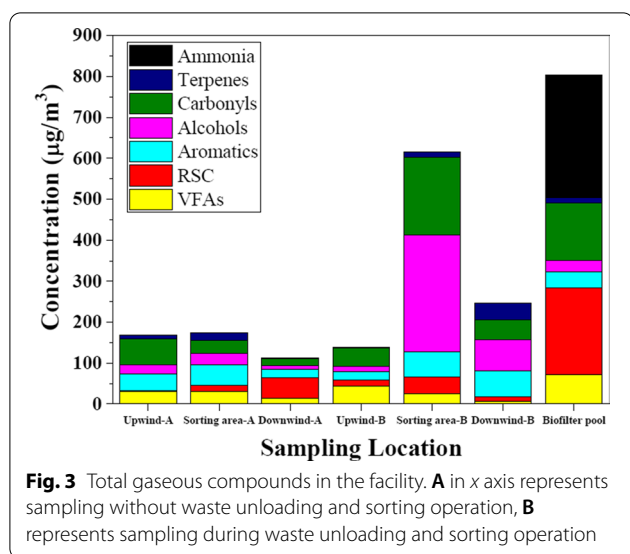


Fig. 3 Total gaseous compounds in the facility. **A** in x axis represents sampling without waste unloading and sorting operation, **B** represents sampling during waste unloading and sorting operation

m³ at the end, thereby indicating that they were mainly released at the start during the active fermentation process. In contrast to the other compounds, ammonia was mainly released in the middle stage. Terpenes and RSCs persisted throughout all stages, although their concentrations decreased slightly, whereas those of other compounds clearly decreased in the later stage.

Gaseous pollutants outside the composting units

The total contents and composition of the odor compounds outside the composting units are shown in Fig. 3 and Fig. 4, respectively. When the facility was not operating, the total concentrations upwind of the boundary, in the sorting area, and downwind of the boundary were 113 µg/m³, 173 µg/m³, and 168 µg/m³, respectively. The total concentration increased when the waste unloading and sorting processes operated, with 138 µg/m³ upwind of the boundary, 615 µg/m³ in the sorting area, and 246 µg/m³ downwind of the boundary. Ammonia was

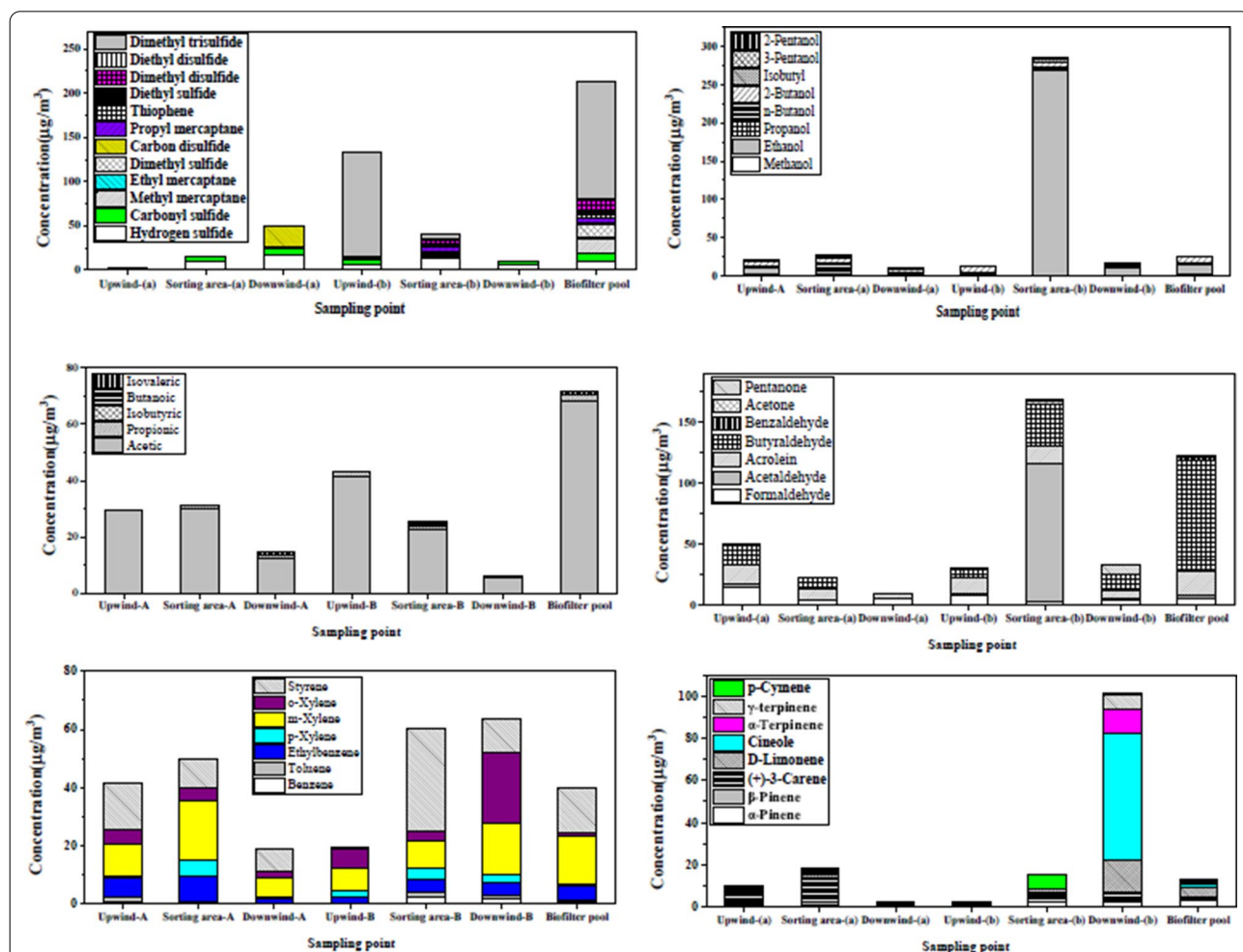


Fig. 4 Composition of the gaseous compounds in the facility. **A** in x axis represents sampling without waste unloading and sorting operation, **B** represents sampling during waste unloading and sorting operation

detected only in the biofilter pool at a concentration of 300 $\mu\text{g}/\text{m}^3$. Excluding ammonia, the total concentration was 503 $\mu\text{g}/\text{m}^3$ at this site. At the boundary of the facility, the concentrations of acetaldehyde, acrolein, acetic acid, and sulfur compounds (except for CS₂) were higher than their olfactory thresholds. This composting facility was community scale and the treatment capacity is relatively small, about 0.6–2 ton/day. In addition to the small treatment capacity, the aerobic fermentation of this facility was carried out in closed units so the pollutant concentration was much lower than that in large plants, which was several orders of magnitude higher than this case [13, 25].

The concentration of total pollutants was one or two orders of magnitude higher inside the composting units than outside the units. The concentrations of most compounds were reduced by the biofilter pool, thereby demonstrating that the breakdown of the contaminants in the off-gases was effective. The concentrations of seven odor compounds on the boundary were compared with the national secondary standard limit values (as shown in Table 3) and they did not exceed the limit values.

Major substances that caused odors of the facility

The “C_{od}” values at the facility were obtained using Eqs. (1) and (2), as shown in Fig. 5. Due to their low odor thresholds, RSCs and carbonyls were the main compounds that caused odors. The total “C_{od}” value at the biofilter pool was 27,475, which was mostly contributed by RSCs (99.4%). The total “C_{od}” value in the sorting area was 62 without operation and 2022 during operation. Downwind of the boundary, the “C_{od}” values were 61 without operation and 45 during operation. The odor impact on the neighborhood during the unloading and sorting operation was very slight compared with that at the biofilter pool. Without operation,

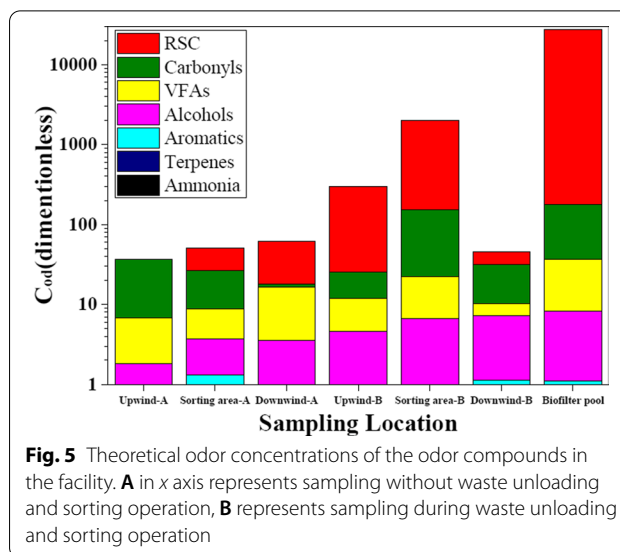


Fig. 5 Theoretical odor concentrations of the odor compounds in the facility. **A** in x axis represents sampling without waste unloading and sorting operation, **B** represents sampling during waste unloading and sorting operation

the major odor substances in the sorting area were acetic acid, acrolein, hydrogen sulfide, xylene, and styrene. During operation, the major odor substances were mostly sulfur compounds, isovaleric acid, and acetaldehyde. The 10 major odor substances detected at the biofilter pool followed the order of: dimethyl trisulfide (26,222) > propyl mercaptan (425) > ethyl mercaptan (239) > methyl mercaptan (228) > diethyl sulfide (144) > butanal (134) > hydrogen sulfide (22) > isovaleric acid (16) > acetic acid (11) > dimethyl disulfide (6). The concentrations of odor compounds such as ammonia, RSCs, alcohols, carbonyls, and VFAs were all lower at the boundary of the facility than the corresponding odor thresholds, and thus the odor risk due to the community-scale disposal facility was low for the nearby communities.

Table 3 The concentration ($\mu\text{g}/\text{m}^3$) of odor compounds in the boundary compared with TLV and the limit value of China

Compound	TLV ^a	Limit value ^b	Location			
			Upwind-A	Downwind-A	Upwind-B	Downwind-B
Ammonia	18,973	1970	< 300	< 300	< 300	< 300
Hydrogen sulfide	15,178	37	ND	17.9	6.2	5.8
Methyl mercaptan	1071	3	ND	ND	ND	ND
Carbon disulfide	3392	884	ND	23.8	ND	ND
Dimethyl sulfide	27,678	25	ND	1.3	0.9	ND
Dimethyl disulfide	2098	15	ND	ND	ND	ND
Styrene	92,857	1077	15.7	7.7	0.5	11.7

^a TLV, threshold limit value, the value was time weighted average concentration for a normal 8-h workday and reflected the level of exposure that the typical worker can experience without an unreasonable risk of disease or injury; the data come from “American Conference of Governmental Industrial Hygienists (ACGIH)”

^b Limit value, Emission Standards For Odor Pollutants (China, GB 14554–93); ND, not detected; “A” in x axis represents sampling without waste unloading and sorting operation; “B” represents sampling during waste unloading and sorting operation

Table 4 Characterization of carcinogenic risk compound from inhalation exposure

Compound	Classification	Tumor site	IUR ($\mu\text{g}/\text{m}^3$)
Acetaldehyde	B2	Respiratory	2.20×10^{-6}
Benzene	A	Hematologic	2.20×10^{-6}
Formaldehyde	B1	Respiratory	1.30×10^{-5}

Carcinogenic classification method from weight-of-evidence of IRIS; A, carcinogenic to human; B1, possible carcinogen; B2, probable carcinogen; C, carcinogenicity to human body has not been classified; D, may not be carcinogenic

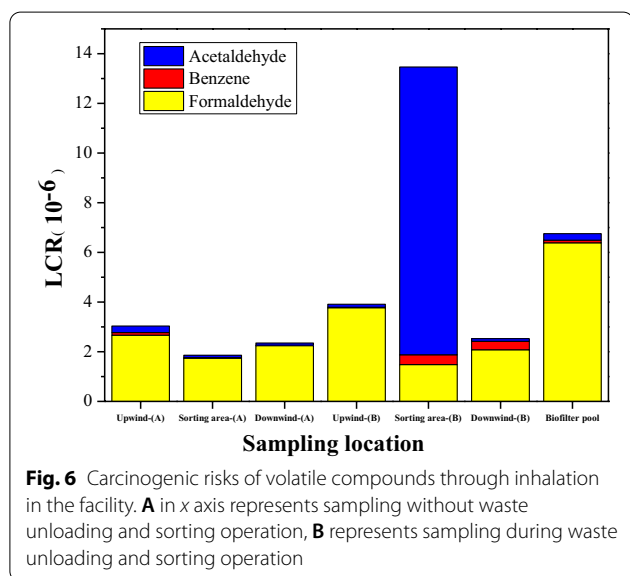


Fig. 6 Carcinogenic risks of volatile compounds through inhalation in the facility. **A** in x axis represents sampling without waste unloading and sorting operation, **B** represents sampling during waste unloading and sorting operation

Major substances associated with carcinogenic risk

Gaseous pollutants emitted from waste treatment facilities may comprise a carcinogenic risk for workers due to exposure by inhalation [23–25]. Thus, three compounds were selected to evaluate the risk value. Table 4 shows the carcinogenic classifications of the three compounds used in this study to evaluate the carcinogenic risk.

The USEPA acceptable LCR level for an individual compound is $1.0\text{E}-06$. According to previous studies [22, 26], compounds with LCR values larger than $1.0\text{E}-04$ and $1.0\text{E}-03$ are considered “definite risks” and “significant risks”, respectively. Compounds with LCR values between $1.0\text{E}-06$ and $1.0\text{E}-05$ are considered “probable risks”, and those with LCR values between $1.0\text{E}-05$ and $1.0\text{E}-04$ are considered “possible risks”. Fig. 6 shows the LCR values obtained for the waste treatment facility, where the LCR in the facility exceeded the acceptable range of $1.0\text{E}-06$. The LCR value determined in the sorting area (B) indicated that the sorting operation had a possible carcinogenic risk. The main compound associated with this carcinogenic risk was acetaldehyde during the unloading and sorting operation. When the operation

ended, the main compound associated with carcinogenic risk was formaldehyde. Thus, the sorting mode in this facility was a possible carcinogenic risk for the operators. Figure 6 also shows that the LCR determined for the off-gas from the biofilter pool was close to the acceptable value of $1.0\text{E}-05$. The risk may increase when the efficiency of the facility decreases.

Major substances associated with non-carcinogenic risk

Since there are workers in the facility for a long time, it is important to evaluate the non-carcinogenic risk of workers in these points. Table 5 shows the RfC value of odor compounds in this study, for evaluating non-carcinogenic risks. Altogether 13 substances were calculated in this scenario, for most of compounds in the list lack of the RfC value. For non-carcinogenic risk, when the total HQ was greater than 1, the non-carcinogenic health risk level to the operators caused by these pollutants was unacceptable. When the total HQ was less than 1, the non-carcinogenic health risk level to the operators was acceptable [22–26].

Figure 7 shows the non-carcinogenic risk value of the occupational exposure in the small-scale aerobic biological treatment facility. For the non-carcinogenic risk, the highest total HQ was at the biofilter pool, which was 0.043 and most of it was contributed by ammonia. The total HQ at all the sampling points was less than 1, which was within an acceptable range, indicating that pollutants released from the semi-in-vessel setup facility caused little non-carcinogenic health risk to the operators. From the proportion of non-carcinogenic risk of 13 pollutants, the mainly contributed compounds were ammonia and acetaldehyde and non-carcinogenic risk of the working place was negligible.

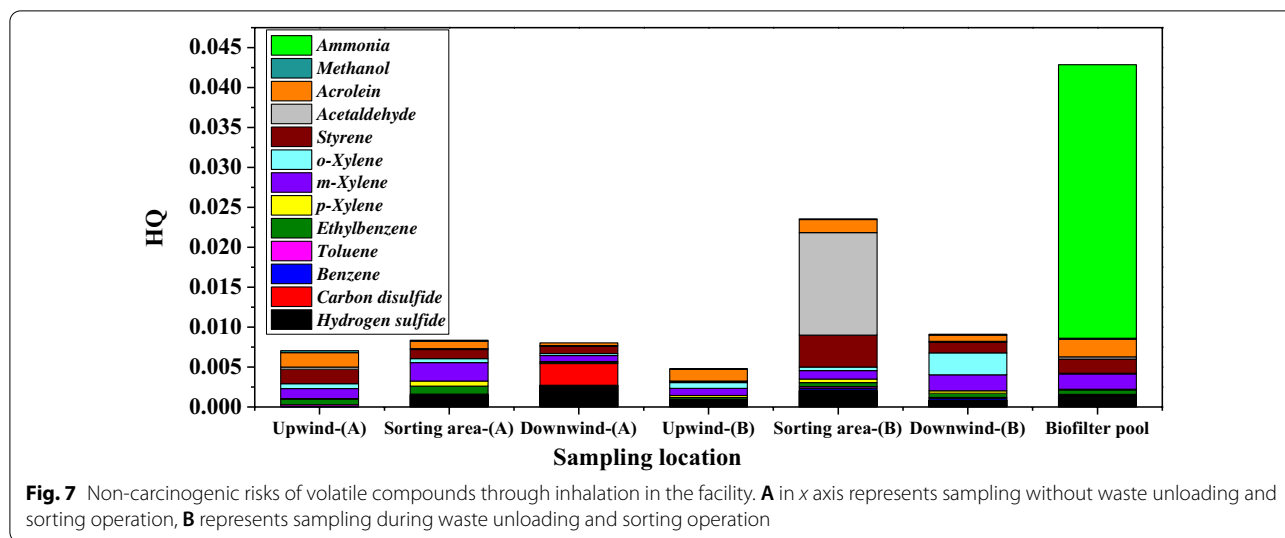
Conclusions

In this study, ammonia was the dominant compound released from the windrow and its release occurred mainly in the middle stage, unlike most other compounds. Terpenes and RSCs persisted throughout the whole process, with slight decreases in their concentrations. Sulfur compounds, butanal, and isovaleric acid were the main compounds that caused odors at the boundary of the facility. The biofilter pool had a greater impact on the odor in the surrounding neighborhood than the waste unloading and sorting operation. Large amounts of ammonia and VOCs were released from the composting units, but they only had a small impact on the odor in the environment because of the semi-in-vessel setup. The odor impact of the facility was low but it was associated with a carcinogenic risk to the operators, thereby indicating the need to improve protection to the operators.

Table 5 RfC values of odor compounds for calculating hazard quotients in this exposure scenario

Family	Compound	Classification	Critical effect system	RfC (mg/m ³)
VFAs	Ammonia	–	Respiratory	5 × 10 ⁻¹
	Acetic acid	–	–	–
	Propionic acid	–	–	–
	Isobutyric acid	–	–	–
	Butanoic acid	–	–	–
	Isovaleric acid	–	–	–
Alcohols	Methanol	–	Nervous	2 × 10 ¹
	Ethanol	–	–	–
	Propanol	–	–	–
	n-Butanol	–	–	–
	2-Butanol	–	–	–
	Isobutanol	–	–	–
	3-Pentanol	–	–	–
	2-Pentanol	–	–	–
Aromatics	Benzene	A	Immune(lymphocyte decreased)	3 × 10 ⁻²
	Toluene	D	Nervous	5.00
	Ethylbenzene	D	Hepatic, urinary	1.00
	p-Xylene	–	Nervous	1.00 × 10 ⁻¹
	m-Xylene	–	Nervous	1.00 × 10 ⁻¹
	o-Xylene	–	Nervous	1.00 × 10 ⁻¹
	Styrene	–	Nervous	1.00
Carbonyls	Formaldehyde	B1	Squamous cell carcinomas	–
	Acetaldehyde	B2	Respiratory	9 × 10 ⁻³
	Acrolein	–	Respiratory and peripheral	2 × 10 ⁻⁵
	Butyraldehyde	–	–	–
	Benzaldehyde	–	–	–
	Acetone	–	–	–
	Pentanone	–	–	–
	RSCs	Hydrogen sulfide	–	Nervous, respiratory
Carbonyl sulfide		–	–	–
Methyl mercaptan		–	–	–
Ethyl mercaptan		–	–	–
Dimethyl sulfide		–	–	–
Carbon disulfide		–	Nervous(peripheral nervous system dysfunction)	7.00 × 10 ⁻¹
Propyl mercaptan		–	–	–
Thiophene		–	–	–
Diethyl sulfide		–	–	–
Dimethyl disulfide		–	–	–
Diethyl disulfide		–	–	–
Dimethyl trisulfide		–	–	–
Terpenes		α-Pinene	–	–
	β-Pinene	–	–	–
	(+)-3-Carene	–	–	–
	D-Limonene	–	–	–
	Cineole	–	–	–
	α-Terpinene	–	–	–
	γ-Terpinene	–	–	–
	p-Cymene	–	–	–

Carcinogenic classification method from weight-of-evidence of IRIS; A, carcinogenic to human; B1, possible carcinogen; B2, probable carcinogen; C, carcinogenicity to human body has not been classified; D, may not be carcinogenic; –, not available.



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Authors' contributions

KL was responsible for interpreting results, updating reference lists and creating 'Summary of findings' tables. XX was responsible for writing the paper. JF was responsible for conducting the search. Pinjing He was responsible for screening potentially eligible studies, extracting and analyzing data. FL was responsible for extracting and analyzing data and interpreting results. All authors read and approved the final manuscript.

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Declarations

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Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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