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VOCs released from municipal solid waste at the initial decomposition stage: Emission characteristics and an odor impact assessment

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ABSTRACT

The nuisance from odor caused by municipal solid waste (MSW) is resulting in a growing number of public complaints and concerns. Odor pollution occurs in the initial decomposition stage of MSW, including waste collection, transportation and early pre-treatment. Furthermore, decomposition takes place in waste facilities that are often close to living areas, which can result in odor impacts on local inhabitants. However, this aspect of odor impact from MSW has not been well studied. In the current study, lab-scale waste cells were designed to simulate MSW storage conditions in the early stage. The characteristics of VOCs emissions with different waste compositions were analyzed. The odor concentration (C_O, non-dimensional) method and odor intensity were used for the assessment of odor. Ethanol was the substance with highest emission rate. The release rate of VOCs increased with the growth easily biodegradable waste (EBW). VOCs emissions was reduced by 25% when the proportion of EBW decreased from 60% to 45%. Methyl sulfide, ethanol, dimethyl disulfide and ethyl acetate were identified as typical odorants. The EBW proportion in waste is the main factor significantly influencing odor pollution. The C_O was 244.51 for the 60% EBW condition, which was only 61.46 for 15% EBW condition. These study results provide important information for the implementation of a garbage sorting policy and the monitoring of odor pollution from waste management.

Introduction

Odor is ranked No. 2 among the 7 biggest environmental threats. Nuisance complaints during the municipal solid waste (MSW) management process have long been a public issue of concern (Nie et al., 2018). Organic compositions are mainly related to the emissions of odorants from MSW (Liu et al., 2018). Due to economic conditions and living habits, easily biodegradable organic compounds are the major composition in most developing Asian countries, particularly in China (He, 2010a; Yue et al., 2014). For example, 215 million tons of MSW were cleaned in China in 2018 (National Bureau of Statistics, 2019) and over 60% of the wet base was food wastes (Dong et al., 2010). As a result, large amounts of odorants are released from MSW. Although waste-sorting is becoming compulsory in several big cities in China (China GOSC, 2017), odor pollution is the current and future constraint on the development of solid waste disposal facilities.

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Recently, volatile organic compounds (VOCs) from MSW management facilities have been widely studied (Chang et al., 2019b; Cheng et al., 2019). Over 140 species of VOCs have been detected from landfills (Allen et al., 1997). The landfill working face is considered the greatest source of VOCs emissions (Duan et al., 2014; Liu et al., 2016; Liu et al., 2015). In addition, VOCs, especially volatile sulfur compounds, are the main causes of odor pollution at landfill sites (Kim et al., 2009; Liu et al., 2018; Wu et al., 2018). In a recent study, oxygenated compounds were identified as the dominant component from an MSW transport station (Zhao et al., 2015). Above all, most studies mainly focused on MSW management facilities. However, before arriving at landfill sites or other facilities where they are properly treated, MSW are generated and stored in households and communities. The easily biodegradable organic fractions in MSW are degraded and result in by-products, such as VOCs, which are released from the time the waste is generated. This stage of the process is most closely related to where people live, but few studies have investigated the release of VOCs during the initial decomposition process of MSW (Statheropoulos et al., 2005).

In the initial decomposition stage (including waste collection, transportation and early pretreatment), MSW are naturally piled in open or partially sealed waste containers. VOCs are mainly released through direct volatilization from waste, aerobic bio-degradation and anaerobic bio-degradation (Wu et al., 2010). Hence, the waste composition and optional conditions are major impact factors on fugitive emissions of VOCs. Tan et al. (2017) investigated the emission characteristics of VOCs in the first 24 h after waste generation, and ethanol was detected as the dominant compound. Wu et al., 2020 identified ethanol, methyl mercaptan and hydrogen sulfide were as the key pollutants in waste storage stage. In large cities, MSW can be transported to waste management plants within 24 h of generation. Nevertheless, in less developed cities and rural areas, it is not possible to implement daily waste cleaning, and wastes are usually held in containers for a few days before being transported. Mowever, odor impacts in the initial decomposition stage have not been well studied.

For odor impact assessments, the olfactory test and theoretical threshold test are two principle methods that are used (Liu et al., 2018). The olfactory test is a subjective sensory assay method used to measure olfactory ability. In this test, the panelists' sensitivity determines the results and the odor pollution of each chemical compound cannot be analyzed (Blank, 2002; Oleszkiewicz et al., 2018). The theoretical threshold test is calculated based on an odor threshold value and provides results as an odor concentration (C_O) (Feilberg et al., 2010). The C_O is a measure of importance of a specific compound to the odor of a sample. Compared with the olfactory test, the theoretical threshold test provides an option to combine the chemical concentration of a substance with its odor concentration (Feilberg et al., 2010; Wu et al., 2017). In addition, the theoretical threshold test could also help to identify the odor contribution of each substance.

The objective of this study was to reveal odor pollution in the initial decomposition stage of MSW in China. Lab-scale waste cells were designed to simulate MSW storage conditions in the early stage. Then, the characteristics of the emissions of VOCs during the process were analyzed, and the impacts of waste composition on VOCs emissions were investigated. An odor impact assessment was also conducted based on the theoretical threshold test. The typical odorant and odor intensity were identified during the initial decomposition stage of MSW. The results of the current study could provide further understanding of the emission characteristics of VOCs in the initial decomposition stage of MSW. In addition, with the implementation of a garbage sorting policy in China, the results could provide more information for monitoring odor pollution from waste management.

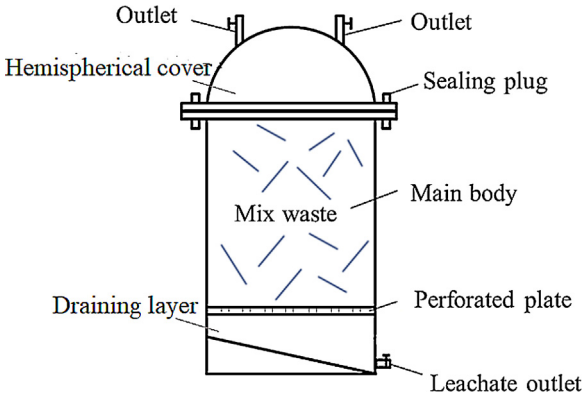

Fig. 1 – The schematic of the MSW initial decomposition simulation cell.

1. Materials and methods

1.1. *Experimental laboratory apparatus*

Lab-scale waste cells were designed for the simulation of the MSW initial decomposition condition. These were chosen instead of full-scale dustbins or a landfill site as they permitted a more controlled system and improved the possibility of drawing findings more easily regarding the relationship between VOCs emissions and waste fractions. As shown in Fig. 1, the cells were cylindrical and made from polymethyl methacrylate, 3 reactors were operated for each condition at the same time.

Each reactor consists of two main parts: the main body and the hemispherical cover. The effective volume of the main body is 3.2 L with an inner diameter of 30 cm and 45 cm in height. The height of the hemispherical cover is 15 cm. At the lower part of the main body, there is a perforated plate to let the leachate gravity flow to the draining layer. The leachate can be collected from the outlet valve at the bottom of the draining layer. The main body is connected to the hemispherical cover by flanged joints, and there are two outlets on the top of the hemispherical cover for gas collection. The airtightness of the reactors was checked before the experiments were conducted.

1.2. *MSW characterization*

The strength of environmental impacts on MSW fundamentally depends on both the quantity and characteristics of the easily biodegradable organics in MSW (Scaglia et al., 2011). In the current study, the simulated MSW was divided into three proportions according to the biodegradability in terms of easily biodegradable waste (EBW), biodegradable waste (BW) and non-biodegradable waste (NBW). The three proportions were mixed in different fractions to study their impacts on the emissions of VOCs at the initial decomposition stage of MSW.

Three levels of EBW were designed to simulate different MSW generation conditions, namely, 60%, 45% and 15%. The 60% EBW proportion was set for the simulation of the current characteristics of MSW generated in China. And the other two levels were set to simulate different stage of MSW sorting. Chen et al. (2020) reported that the proportion of EBW in MSW in Shanghai, where garbage classification has been implemented, has been reduced from 88.3% to 36.2%. And the "Shanghai Municipal Action Plan for Building a Whole process Waste Classification System (2018-2020)" sets a goal to achieve MSW sorting rate of 90% in 2020 (Shanghai Municipal Greening and Appearance Administration Bureau, 2018). In England

Table 1 – Composition and source of the simulated MSW (W/W).

Waste composition		Proportion of each composition in the waste (%)			Source	Referenced waste fraction (%)*
		60% EBW	45% EBW	15% EBW		
EBW	Food waste	48.0	36.0	12.0	Obtained from a canteen	52.0 ± 12.4
	Fruit waste	12.0	9.0	3.0	Obtained from fruit shops	12.8 ± 9.0
BW	Wastepaper	22.5	36.0	63.0	Waste newspaper	13.4 ± 14.1
	Wood and yard waste	2.5	4.0	7.0	Woodchips and leaves	2.3 ± 1.8
NBW	Waste plastic	7.5	7.5	7.5	Plastic bags	11.9 ± 6.0
	Metal	0.2	0.2	0.2	Beverage cans	0.3 ± 0.1
	Glass	1.1	1.1	1.1	Glass beads	0.8 ± 1.0
	Textile	1.8	1.8	1.8	Waste clothes	3.4 ± 2.4
	Ash	4.5	4.5	4.5	Commercial quartz sand	4.6 ±2.9

* Refer to Yang et al. (2015) and Zhang et al. (2013).

and Wales, only 16.9% EBW was found in MSW after garbage classification (Bees and Williams, 2017). Hence, it is possible to achieve 15% EBW condition for China. Detailed information regarding the simulated MSW is presented in Table 1.

During the material preparation of the simulated MSW, wastepaper, fruit waste wood and yard waste, waste plastics and textiles were cut into small pieces. Then, all the waste compositions were homogeneously mixed before the experiment. Due to the fast degradation rate of food and fruit waste, these items were collected an hour before the experiment to avoid any possible decomposition.

1.3. *Experimental design*

Generally, the actual MSW collection, transportation and pretreatment processes would last a few days. In some less developed regions, MSW waste would be exposed to the environment for up to a week before treatment. Thus, the duration of the initial decomposition simulation experiment was conducted for 7 days. In the experiments, exactly 2 kg of mixed fresh waste was loaded into the reactor and the reactor was sealed. Gas samples were withdrawn from the reactor And then the reactor was opened for air exchange. The impact of waste composition on the emissions of VOCs was investigated with the temperature controlled at 25°C. Moreover, the experiments of the three EBW levels were operated simultaneously.

1.4. *Sampling and analyses*

Sampling campaigns were conducted every other day during the experiment. During the initial degradation stage of MSW, the garbage might not be well exposed to oxygen all the time, such as MSW in the sealed waste bins, or in the transfer stations where MSW was compacted. And for the simulation of insufficient contact of MSW with oxygen, the reactors were opened every other day, i.e., the 1st, 3rd, 5th, and 7th day. For each EBW level, 12 samples were collected in each round (i.e. 15% EBW, 45% EBW, and 60% EBW).

Gas samples were withdrawn from the outlet of the reactor with a passivated (Summa) canister (3.2 L). Summa canisters, which are widely used for VOCs gas sample collection, provide a high-quality and long-term sample storage solution. After gas collection, the reactor would be opened for 5 min for air exchange.

The qualitative and quantitative analyses of the VOCs were conducted according to a Chinese National Standard named "Ambient air-determination of volatile organic compounds collected by specially-prepared canisters and analyzed by gas chromatography/mass spectrometry" (China MEP, 2015) and TO-15 (US EPA, 1999b). The gas samples were pre-concentrated with a three-stage cold trap concentrator (Entench 7200, USA) and then analyzed by gas chromatography-mass spectrometry (GC-MS, Agilent 5975C, USA) equipped with a DB-5MS column (I.D. 60 m × 0.32 mm; df 1.0 μm). Helium was used as the carrier gas with a flow rate of 30 mL/min. The heating program has three ranges and initially increased from 35°C to 150°C with a step rate of 5°C/min, increased to 220°C with a step rate of 15°C/min, and was then maintained at 220°C for 7 min. VOCs were identified in terms of the retention time, target, and qualifier ions and quantified using the internal standard calibration procedure that included the US National Institute of Standards and Technology 98 Library (US EPA, 1999a) and a US Environmental Protection Agency standard solution (US EPA, 1999b).

1.5. *Odor impact assessment*

The odor impact was assessed from two dimensions: C_O and odor intensity. The C_O is based on the detection threshold of odor, whereas odor intensity represents the perceived strength of an odor above its threshold.

C_O, which is a simple and technically valid approach, was used to determine odor pollution. The C_O can be calculated as shown in Eq. (1),

$$C_{Oi} = \frac{C_i}{OTV_i} \quad (1)$$

where C_{Oi} (non-dimentional) is the odor concentration of an individual compound i; C_i (ppm) is the concentration of compound i detected and determined by GC–MS; and OTV is the odor threshold value, which is the lowest concentration of a chemical that can cause olfaction. OTV_i (ppm) is the odor threshold value of compound i. In this study, the OTVs of the VOCs were based on Nagata. (2003) as shown in **Table S1 (see Supplementary material)**.

If $C_O < 1$, then the olfaction impact was negligible; otherwise, the compound was considered based on the total $C_O$calculation as shown in Eq. (2),

$$C_O = \sum_{i=1}^{n} C_{Oi} (C_{Oi} > 1) \quad (2)$$

where C_O is the odor concentration of all compounds; n is the number of compounds with $C_{Oi} > 1$.

Odor intensity is determined by an odor panel and is described in categories, which progress from "No odor" to

Table 2 – Average concentration and typical compounds in different VOC categories*.

Category of VOCs	No. of detected compounds	Subtotal concentration in category (ppm)	Typical compound in each category	Concentration of the typical compound (ppm)
Sulfur compounds	3	0.36 ± 0.57	Methyl sulfide	0.18
Aromatics	6	0.18 ± 0.05	1,2,4-Trimethylbenzene	0.09
Halogenated compounds	12	11.44 ± 6.32	Chloroethylene	3.29
Hydrocarbons	10	0.79 ± 0.31	n-Pentane	0.31
Oxygenated compounds	9	22.14 ± 9.35	Ethanol	17.23

* The average concentration was calculated from all the tested data (12 samples).

"Very weak," "Weak," "Distinct," "Strong," and "Intolerable" (Zaman et al., 2012). Moreover, the intensity of an odor can be determined according to its concentration using dynamic olfactometry. The Weber-Fechner Law is widely used to define the relationship between the intensity and concentration for a particular odorant (Zhang et al., 2011) as shown in Eq. (3),

$$I = k \lg C \quad (3)$$

where, I (non-dimentional) is the odor intensity; C is the sensory concentration of an odorant; k is a constant for the case of the odor intensity assessment.

Zhang et al. (2011) investigated the relationship between odor intensity and odor concentration according to the "Emission standards for odor pollutants" (GB 14554-1993) in China (China MEP, 1993). An C_O below 10 is perceived as "No odor" and over 265 is perceived as "Intolerable." Detailed information between odor intensity scales and C_O are shown in **Table S2 (see Supplementary material)**.

2. Results and discussion

2.1. *Characteristics of VOCs emissions during the initial decomposition stage of MSW*

A total of 43 VOC species were identified in the experimental batches, which can be classified into 5 categories, namely, sulfur compounds, aromatics, halogenated compounds, hydrocarbons, and oxygenated compounds. The qualitative and quantitative results across all tested batches are summarized in Table 2. Overall, the category and number of VOCs detected were similar for all the tested batches, but the concentrations of VOCs varied significantly during the process. These variations might be attributed to both internal and external factors such as waste composition, environmental conditions, and the biodegradation process (He et al., 2010b; Nie et al., 2018).

In nearly all cases, the oxygenated compounds had the highest concentration, and ethanol was the substance with the highest concentration. For example, the average concentration of ethanol was 17.23 ppm, which accounts for over 49.36% of the total emissions of VOCs. Similar phenomena were confirmed from a waste transfer station (Zhao et al., 2015) and several landfills in China (Li et al., 2015). The large generation of oxygenated compounds from the initial decomposition stage was mainly attributed to the relatively high proportion of EBW in MSW (Zhao et al., 2015). In addition to ethanol, aldehydes and ketones were also detected in the initial decomposition process and are recognized as the final product in the phase of aerobic processes (Staley et al., 2006; Young and Parker, 1983).

Halogenated compounds also expressed a relatively high level of emissions, which accounted for approximately 32.77% of the total emissions. A total of 12 species of halogenated compounds were detected, and chloroethylene was the dominant substance (Table 2). Similarly, relatively high emissions of halogenated compounds had been previously detected from a waste transfer station and a landfill working face (Chang et al., 2019a; Liu et al., 2017). These compounds could mainly come from the direct vitiation of non-biodegradable components, including plastics, textiles, and cleaning agents in food waste, as well as the degradation of easily degradable components (Statheropoulos et al., 2005). Due to the low level of garbage sorting in China, wastes containing halogenated compounds are carelessly thrown in and mixed with other substances in a dustbin.

In contrast, the concentration levels of sulfur compounds, hydrocarbons, and aromatics were rather small compared with oxygenated and halogenated compounds. Methyl sulfide is the dominant substance of sulfur compounds and it is released from the biodegradation of peptides in organic materials (i.e. animal manure and plants) as a significant odorous pollutant (Di et al., 2012; Galvin et al., 2003). In addition, methyl sulfide has been identified as an odorous indicator for landfill sites (Liu et al., 2018; Lu et al., 2015). Aromatics from MSW are mainly released from the direct volatilization of plastics. At the same time, the degradation of lignin in wood and yard waste could also emit aromatics, but the reaction rate is slow (Zhang et al., 2012). Hydrocarbons commonly come from the degradation of wood waste, yard waste, and food waste (Duan et al., 2014).

The proportion of each typical compound in the total concentration of VOCs is shown in Fig. 2. During the initial decomposition process, the proportion of the 5 compounds decreased from 81.63% to 55.74%. Ethanol was the most abundant compound and accounted for over 40% of the total emissions of VOCs. Oxygenated compounds, with ethanol as the main representative, are intermediates or by-products in the early stage of incomplete aerobic processes (Paola et al., 2005). Ethanol can be transformed into aldehydes, ketones and carboxylic acids (Statheropoulos et al., 2005). Consequently, during the 7-day experiment, the proportion of ethanol failed to accumulate and decreased from 76.65% to 46.96%. Additionally, due to the low concentration levels, the variations of methyl sulfide, 1,2,4-trimethylbenzene, and n-pentane were unremarkable (< 1.50%).

The variation of VOCs concentrations during the initial decomposition process is illustrated in **Fig. S1 (see Supplementary material)**. The concentration of VOCs increased during the process and a remarkable increase was found after the 5 days of the experiment. The concentration of total VOCs increased from 15.13 ppm (day 1) to 51.26 ppm (day 7), which was

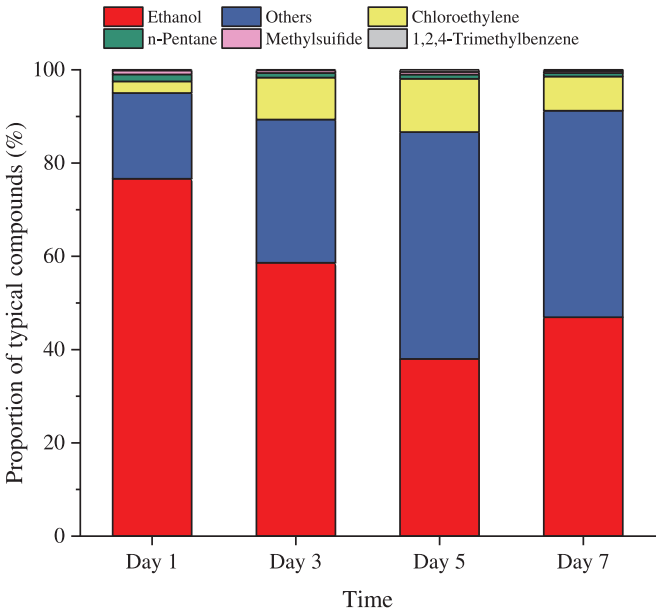

Fig. 2 – The proportion of typical compounds in the MSW initial decomposition stage.

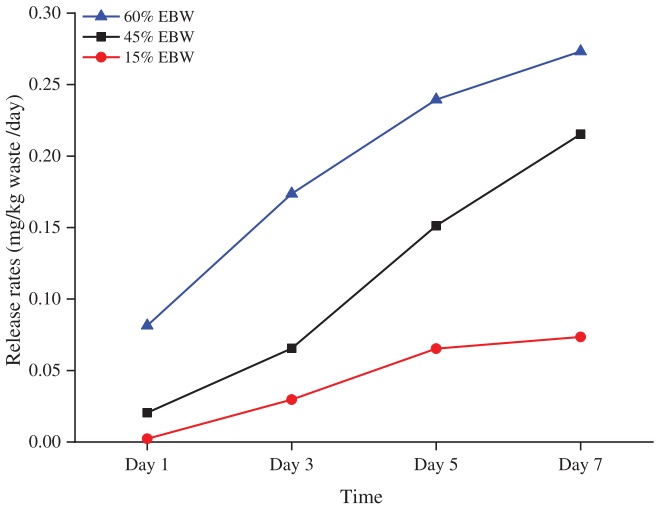

Fig. 3 – Release rate of VOCs at different waste composition conditions.

mainly attributed to the enhancement of oxygenated compounds and halogenated compound emissions.

2.2. *Impacts of waste composition on VOCs emissions*

To investigate the effects of waste composition, 3 mass ratio levels of EBW were set (i.e. 15%, 45% and 60%) and the temperature was controlled at 25°C. The concentration of VOCs emitted during the initial decomposition process decreased with the reduce of the proportion of EBW (**see Table S3, Supplementary material**). When the proportion of EBW decreased from 60% to 45%, the concentration of VOCs decreased from 50.72 ppm to 37.76 ppm, the amount of VOCs emissions was reduced by at least 25%. Indicating that the more EBW the higher the generation of VOCs. This result is consistent with a previous study where more odorous gas was generated from EBW (food waste and fruit waste) than yard waste and paper (Lou et al., 2015). Indeed, oxygenated compounds are the key elements for this phenomenon. Few oxygenated compounds could be generated from the less EBW condition. For example, only 0.17 ppm of oxygenated compounds was detected from the 15% EBW condition. However, the concentration of oxygenated compounds was 36.92 ppm in the 60% EBW condition, which was approximately 217 times greater than the 15% EBW condition. Similar results have been reported by Tan et al. (2017), where oxygenated compounds mainly came from the fast-aerobic decomposition of organic components such as food waste in MSW. Except for oxygenated compounds, the mass ratio of EBW expressed a slight impact on the release of other VOCs categories.

The release rate of VOCs at different waste composition conditions was estimated. As shown in Fig. 3, the release rate of VOCs increased with the experimental duration for all conditions. Taking the 60% EBW condition as an example, the release rate of VOCs was estimated at 8.14×10^{-2} mg/kg waste/day on the 1st day, which increased to 0.27 mg/kg waste/day by day 7. The proportion of EBW expressed a great effect on the release rate. The highest release rate of the 15% EBW condition was even lower than that of the 60% EBW on the 1st day. The average release rate at the initial decomposition stage was 0.19 mg/kg waste/day (60% EBW), 0.13 mg/kg waste/day (45% EBW), and 4.27×10^{-2} mg/kg waste/day (15% EBW), respectively. Hence, the more EBW in the waste the higher the release rate was observed.

With progression of the MSW sorting policy in China, food waste would be separated from the mixed MSW. It could be inferred that less EBW would be found in MSW and the VOCs emissions at the initial decomposition stage would be alleviated. For example, about 9248 tons of MSW were collected and transferred per day in (Beijing Bureau of Statistics, 2019). It was assessed that approximately 647.88 kg/year VOCs could be released from the initial decomposition stage at the current status, however, which would be reduced to 381.89 kg/year (for the 45% EBW condition) and 144.08 kg/year (for the 15% EBW condition), respectively.

2.3. *Odor impact assessment during the MSW initial decomposition stage*

The data from all the experimental batches was summarized for the odor impact assessment. Typical odorants were selected from common VOCs with a detection rate more than 70%. The odor concentrations of common VOCs were calculated and ranked. The top 10 compounds with the highest C_O values are listed in Table 3, and only those with C_{Oi} >1 were recognized as odorants. Hence, 4 substances were identified as odorants in the current study, which were methyl sulfide, ethanol, dimethyl disulfide and ethyl acetate. Comparing odor pollution from different stages of the MSW treatment processes, most of the nuisances were caused by oxygenated compounds and sulfur compounds in the initial decomposition stage (Duan et al., 2014; Liu et al., 2018; Zhao et al., 2015). In addition, as the process continues, complex sulfur compounds become the dominant contributors of odor pollution and the nuisance of oxygenated compounds transitions to a slight contributor. For example, odor pollution at the transfer station was mainly caused by ethyl sulfide, dimethyl disulfide, ethanol and limonene (Zhao et al., 2014). However, at the MSW landfill, odor nuisance was mainly caused by ethyl sulfide, dimethyl disulfide, methyl mercaptan, and hydrogen sulfide (Lu et al., 2015; Yao et al., 2019).

Methyl sulfide was the dominant contributor of odor pollution ($C_O = 61.29$). Although the concentration of methyl sulfide comprised less than 1% of the total VOCs emissions, its C_O

Table 3 – Typical odorants and odor concentrations from different studies.

This study	C_{Oi}	Waste transfer station *	C_{Oi}	Landfill working face **	C_{Oi}
Methyl sulfide	61.29	Ethyl sulfide	97.29	Ethyl sulfide	228.71
Ethanol	41.15	Dimethyl disulfide	11.52	Methyl mercaptan	151.53
Dimethyl disulfide	24.56	Ethanol	8.54	Acetaldehyde	73.56
Ethyl acetate	5.12	Methyl sulfide	2.79	Hydrogen sulfide	63.52
1,2-Dichloropropane	0.83	Limonene	1.80	Dimethyl disulfide	6.08
Carbon disulfide	0.60	α-Pinene	1.02	Methyl sulfide	1.94
1,3-Butadiene	0.50	m-Xylene	0.66	1,4-Diethylbenzene	1.25
Styrene	0.42	p-Xylene	0.47	Ethanol	0.64
2-butanone	0.33	Toluene	0.38	Limonene	0.40
1,2-Dichloroethane	0.27	p-Ethyl toluene	0.38	α-Pinene	0.16

* Refer to Zhao et al., (2014)
** Refer to Duan., (2015).

Table 4 – Typical odorants and their odor concentration.

Order	15% EBW		45% EBW		60% EBW	
	Typical odorant	C_{Oi}	Typical odorant	C_{Oi}	Typical odorant	C_{Oi}
1	Dimethyl disulfide	56.03	Ethanol	56.95	Methyl sulfide	162.72
2	Methyl sulfide	3.15	Methyl sulfide	18.00	Ethanol	66.19
3	1,2-Dichloropropane	2.28	Ethyl acetate	1.05	Ethyl acetate	9.19
4	Styrene	0.83	Carbon disulfide	0.92	Dimethyl disulfide	6.41
5	1,2,4-Trimethylbenzene	0.76	Dimethyl disulfide	0.75	1,3-Butadiene	0.88
6	Ethanol	0.33	1,2-Dichloroethane	0.48	2-Butanone	0.56
7	1,3-Butadiene	0.12	n-Pentane	0.12	n-Pentane	0.34
8	3-Methylpentane	4.7×10^{-2}	2-Butanone	0.10	1,2-Dichloroethane	0.33
9	1,2-Dichloroethane	4.0×10^{-2}	Toluene	0.03	Carbon disulfide	0.27
10	Octane	3.1×10^{-2}	Dichloromethane	0.03	Toluene	0.12
	Other compounds	3.0×10^{-2}	Other compounds	0.07	Other compounds	0.21
ΣC_O		61.46		76.00		244.51

value accounts for over 46% of the total C_O due to its low OTV (3.0×10^{-6} ppm). Ethanol is not commonly regarded as a nuisance substance. However, it could become an odorant when mixed with other odorous compounds. Moreover, during the initial decomposition process of MSW, ethanol was found with the highest emission concentration. Despite its relatively high OTV (0.52 ppm), ethanol still expressed a great odor effect. Ethyl sulfide and dimethyl disulfide were remarkable odorants in the initial decomposition stage of MSW. In addition, they were also suggested as significant odor indicators for landfills (Duan, 2015).

The impact of waste composition on odor pollution was conducted. As shown in Table 4, with the increasing of EBW's proportion, both the number of typical odorants and the average C_O value were enhanced. The sum of C_O value reached 244.51 at the 60% EBW condition, which was nearly 4 times more than the 15% EBW condition (61.46). Methyl sulfide was a typical odorant for all mass ratio levels. Also, more oxygenated and sulfide odorants were released in higher EBW conditions. The results of the correlation analysis are listed in **Table S4 (see Supplementary material)**. The C_O value was positively correlated with the waste composition at a confidence level of 0.05, which confirmed that the proportion of EBW is the major factor that impacts the C_O value.

To quantify the perceived strength of odor sensation, the odor intensity was introduced and the relationship between C_O and odor intensity was revealed according to the Weber-Fechner Law as shown in Eq. (3). The variations of the C_O value and odor intensity during the initial decomposition process at different EBW conditions are illustrated in Fig. 4a. Both the odor intensity and the C_O value increased with the experimental duration and the proportion of EBW. The C_O of the 60% EBW was increased from 193.09 to 289.5 over the whole duration. For the conditions of 15% and 45% EBW, the variations of C_O were similar, but the C_O value was only 27.67 and 40.94, respectively, on the 1st day. The odor intensity was scale 4 (Strong) on the 1st day for the 60% EBW condition and was raised to scale 5 (Intolerable) on the 5th day. The trend of odor intensity was the same for the condition of 45% EBW and 15% EBW. But the odor intensity was not as strong as the 60% EBW condition. The odor intensity was only at scale 2 (Very weak) for both the 45% and 15% EBW conditions at the beginning and increased to scale 4 on the last day of the experiment.

Odor pollution from different waste treatment processes were analyzed in Fig. 4 b. The C_O values at the landfills was 526.59 (Duan, 2015), which was much greater than the waste transfer station (122.96) (Zhao et al., 2014) and all the initial decomposition stage conditions in this study. The odor intensity at the waste transfer station was "Strong" (scale 4) and "Intolerable" (scale 5) at the landfill working face. For the initial decomposition stage, the odor intensity was "Strong" (scale 4) for the 60% EBW condition and "Distinct" (scale 3) for the 15% and 45% EBW conditions. This indicated that the odor intensity would aggravate with prolonging of the MSW treatment process.

As the initial decomposition of MSW mainly happens in neighborhoods and communities, shortening the duration of waste transfer and increasing the frequency of waste collec-

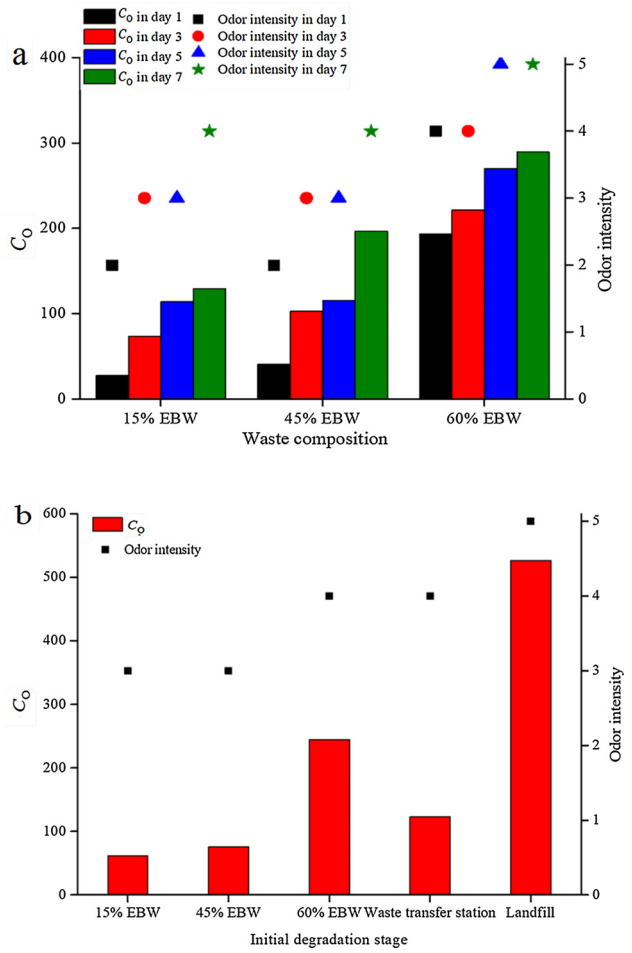

Fig. 4 – (a) CO and odor intensity at different waste composition conditions and (b) The average CO and odor intensity from different studies. Data of the waste transfer station is from Zhao et al. (2014), and data of the landfill is from Duan (2015).

tion would relieve the odor nuisance at the initial decomposition stage. Moreover, waste sorting could reduce the proportion of EBW in MSW, which could also alleviate odor pollution. The current study revealed the impacts of waste composition and duration on odor pollution; however, due to the limitation of the simulation experiments, additional studies could focus on the odor effect in actual facilities.

3. Conclusions

The characteristics of VOCs emissions and their odor impacts at the initial decomposition stage of MSW were studied. Oxygenated compounds had the highest concentration, and ethanol was the dominant compound. Methyl sulfide, ethanol, dimethyl disulfide and ethyl acetate were identified as typical odorants ($C_O > 1$). The release rate of VOCs was mainly influenced by the proportion of EBW in the waste. The average release rate at the initial decomposition stage was 0.19 mg/kg waste/day (60% EBW), 0.13 mg/kg waste/day (45% EBW), and 4.27×10^{-2} mg/kg waste /day (15% EBW), respectively. The amount of VOCs emissions was reduced by 25.56% from 60% EBW (50.72 ppm) to 45% EBW (37.76 ppm) in the initial decomposition stage. The EBW proportion in waste is the main factor significantly influencing odor pollution. The proportion of EBW was reduced from 60% to 15%, and the C_O decreased from 244.51 to 61.46, which reduces 1 scale of the odor intensity.

With the implementation of the waste sorting policy and the improvement of the waste management system in China, food waste would be separated from mixed waste, as well as, can effectively reduce VOCs emission. The results of the current study could provide significant evidence to comprehensively understand odorant generation in the initial decomposition stage of MSW. Furthermore, it could help to formulate strategies for odor control and abatement in MSW management systems.

Declaration Competing of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A Supplementary data

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jes.2020.05.009.

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