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Assessment of the health risks and odor concentration of volatile compounds from a municipal solid waste landfill in China

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HIGHLIGHTS

- The odor and health risk of volatile compounds at a landfill were assessed.
- The odor concentration at landfill boundary exceeds the emission standard by 4 times.
- Sulfur compounds contributed the most to odor pollution and non-carcinogenic risk.
- Aromatics and halogenated compounds dominated the carcinogenic risk.
- Cumulative risks in waste areas largely exceed acceptable levels.

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ABSTRACT

Municipal solid waste (MSW) landfills are a source of odorous and toxic compounds. In this work, we present an integrated assessment of the odor concentration and human health risks of volatile compounds to evaluate the environmental quality at a MSW landfill. Air samples were collected seasonally from six areas of the landfill with different functions. The total concentrations of the compounds ranged from 204.0 to 7426.7 μg m^{-3}, and the concentrations in temporarily and permanently capped areas were 50.3 and 83.4% lower than those in the tipping area, respectively. The odor concentration was greatest at the leachate collection tank (1732–6254 ou_E m^{-3}) and tipping area (1573–4113 ou_E m^{-3}) and was mainly caused by hydrogen sulfide (57.9 and 49.1%, respectively). Moreover, the odor concentration was positively correlated with the temperature ($r = 0.500$, $p < 0.05$, $n = 24$). Although the non-carcinogenic (HI) and carcinogenic (R) risks of most compounds were largely below the acceptable levels (HI = 1, R = 1.0E-6), HI values of hydrogen sulfide (2.3), trichloropropane (2.0), and naphthalene (1.2) as well as R values of naphthalene (1.3E-4) and trimethylbenzene (1.2E-4) in the waste areas exceeded acceptable levels. Moreover, the cumulative HI (2.5–5.7) and R (1.0E-04 to 3.4E-04) in the waste areas should receive special attention since they were above acceptable levels during all of the seasons. Aromatic and halogenated compounds dominated the cumulative R, accounting for 79 and 21% of the total, on average, while for the cumulative HI, sulfur compounds contributed the most (67%).

1. Introduction

The social and environmental aspects of landfill gas emitted from municipal solid waste (MSW) landfills have received special attention in recent decades. People are concerned with potential health risks and odor nuisances due to gas emissions at landfills (Durmusoglu et al., 2010; Palmiotto et al., 2014; Liu et al., 2016; Wu et al., 2017). The gas emissions at landfills mainly consist of methane, carbon dioxide, water vapor and non-methane organic compounds (NMOCs). Although NMOCs constitute less than 1% (V/V) of the total landfill gas volume, their adverse impact on human

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health is not negligible (Liu et al., 2016). According to the EPA, volatile organic compounds constitute 39% of the NMOCs at MSW landfills in the US (Durmusoglu et al., 2010). The most reported components include sulfur compounds, nitrogenous compounds, oxygenated compounds, aromatics, halogenated compounds, and terpenes, which are major air pollutants due to their malodorous and hazardous properties (Gallego et al., 2014; Wenjing et al., 2015; Wu et al., 2017).

Landfill workers and nearby residents are directly exposed to volatile compounds found in the landfill air through inhalation. Long-term exposure to these volatile compounds has been associated with potential health risks, such as respiratory irritation, cancer and even central nervous system damage (Butt et al., 2016; Liu et al., 2016; Mustafa et al., 2017). Uncontrolled odor nuisances caused by the odorous compounds in landfill air are also concerning. Prolonged exposure to bad and harmful odors can generate unpleasant reactions ranging from emotional stress to physical symptoms, including anxiety, headaches, vomiting, eye irritation and respiratory problems (Capelli et al., 2011; Hayes et al., 2014; Palmiotto et al., 2014; Wu et al., 2015). Growing concerns and complaints (Palmiotto et al., 2014; Liu et al., 2015a; Kim, 2016) highlight the need for the evaluation of odor pollution and health risks induced by volatile compounds in landfills.

Only a limited number of systematic studies comprehensively assessing the health risk and odor concentration of volatile compounds from landfills can be found (Palmiotto et al., 2014). Several of them (Davoli et al., 2010; Durmusoglu et al., 2010; Martí et al., 2014; Palmiotto et al., 2014) have focused on the health risks of specific compounds such as aromatics (benzene, toluene, ethylbenzene, and xylenes (BTEX)) and halogenated compounds (trichloroethylene and vinyl chloride monomers), showing that the risks were within acceptable levels. However, many other compounds and their cumulative effects are still less known. Moreover, these studies were mainly conducted in developed countries, and the risks associated with volatile compounds in landfills of developing countries, such as China, have not been well studied (Liu et al., 2016).

In the current approach, we present an integrated risk assessment study on the olfactory perception and the effects on human health of volatile compound emissions from a MSW landfill in China. By monitoring the compounds from six different functional areas during a one-year period, we analyzed both the concentration distributions and influencing factors. Variations in and key contributors to the odor concentration were also evaluated. Risks for carcinogenic, non-carcinogenic and cumulative effects were assessed based on the concentration of the total components.

2. Materials and methods

2.1. Site description and air sampling

The study was conducted in one of the largest MSW landfills in Beijing, China. It is approximately 30 km from the center of Beijing near a busy highway (the Sixth Ring Road) to the north and surrounded by four villages within a 2.5 km radius (Fig. S1, Supplementary Material). The designed area and final potential volume of the landfill were 430 000 m^2 and 12 million m^3, respectively, and consisted of seven main cells. The use of the selected landfill began in 1994, and approximately 4000 tons of MSW has been processed per day. The disposed MSW originated from nearby districts and included organic matter, plastics, rubber, paper, and wood. The MSW was transported and dumped into the tipping area of the landfill by trucks. Afterwards, the waste components were pushed into an active cell by bulldozers and temporarily capped with a high-density polyethylene (HDPE) membrane. After a few years, the cells that were filled would be permanently capped by soil. Meanwhile, the leachate was collected in a leachate collection tank. Volatile compounds emitted from the landfill surface could easily diffuse to the office area and landfill boundary (brick wall approximately 2.5 m high), causing hazards and risks to workers and nearby residents.

Air was sampled during the working hours of selected days from 2013 to 2014 and represented the four different seasons of a one-year period. To characterize the volatile compounds in different areas, air samples were collected at six different functional locations of the landfill: the tipping area (TA), temporarily capped (TC) area, permanently capped (PC) area, leachate collection (LC) tank, office area (OA) and landfill boundary (LB), as marked in Fig. S2 in the Supplementary Material. Air samples were collected at a height of 1.5 m above the surface of these areas by the vacuum pump method, which was widely used in previous studies on landfills (Romain et al., 2008; Duan et al., 2014; Wenjing et al., 2015; Wu et al., 2017). Specifically, a 5 L Tedlar bag was inserted into a tightly closed vessel, and its sampling valve was connected to the ambient air through PTFE tubing. Afterwards, the air inside the vessel was removed by a pump at a rate of 0.5 L min^{-1}. Because of the vacuum depression created inside the vessel, the air to be sampled was withdrawn directly into the Tedlar bag, preventing the sampled gas from coming into contact with the pump (Capelli et al., 2013a; Wu et al., 2017). In addition, absorption solutions were used to collect ammonia (NH_3) and hydrogen sulfide (H_2S) according to the national standard method in China. Details of the sampling method have been described by the authors elsewhere (Wu et al., 2015, 2017). The meteorological conditions during sampling campaigns were measured with a thermo-anemometer (EXTECH, DK5158 45158, USA). The samples were then carefully transported to the lab in a dark box and analyzed within 24 h.

2.2. Chemical analysis

Chemical analysis was performed to identify and quantify the compounds in the air samples. The samples were analyzed by a gas chromatography-mass spectrometry/flame photometric detector (GC-MS/FPD, Trace DSQ, Thermo Fisher, USA) preceded by preconcentration with solid-phase micro extraction/cryogenic trapping. The absorption solutions of hydrogen sulfide and ammonia were analyzed by a UV/vis spectrophotometer (Shimadzu, Japan) according to the national standards of China (Wu et al., 2015). Detailed procedures regarding the analyses and relevant QA are similar to those reported in our previous work (Wu et al., 2015, 2017) and are provided in Section S1 in the Supplementary Material.

2.3. Olfactometric analysis

Olfactometric analysis was conducted to assess the odor concentration and odor intensity of the air samples. The odor concentration and odor intensity of the air samples were measured by an olfactometer (AC'SCENT, USA) and sniffing panelists using an identical method to that reported in our previous studies (Wu et al., 2015, 2016, 2017). The procedures followed the instructions of the *Forced-Choice Ascending Concentration Series Method*, which meets both ASTM E679-04 (ASTM-E679-04, 2011) and EN 13725:2003 (EN13725, 2003) standards. Briefly, air samples were diluted with odor-free air in specific dilution ratios by the olfactometer and then presented to the panelists. Each panelist is presented with a dilute air sample and two "blank presentations". The panelist sniffed the diluted air sample at increasing concentration levels until he or she discerned the diluted air sample from the two "blank presentations". The dilution factor of the air sample was then defined