

Spatial distribution of odorous compounds in an enclosed waste mechanical biological treatment plant

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The concentrations and species profiles of gaseous pollutants emitted from a municipal solid waste (MSW) treatment plant were investigated to identify the major odorous substances. Three methods were used to measure different gaseous pollutants in this study, including gas-chromatography with mass spectrometry/flame ionization detection/pulsed flame photometric detection (GC-MS/FID/PFPD) preceded by cold trap concentration, GC-FID preceded by sorbent concentration, and high-performance liquid chromatography (HPLC) after derivation by 2,4-dinitrophenylhydrazine (DNPH). Seventy-five gaseous compounds belonging to nine groups (nitrogen compounds, sulfur compounds, alkanes, alkenes, aromatics, terpenes, alcohols, carbonyls, and volatile fatty acids (VFAs)) were identified. The major odour compounds in the plant were acetic acid, butyric acid, valeric acid, isovaleric acid and dimethyl sulfide.

1. Introduction

Mechanical biological treatment (MBT) technology could benefit resource and energy recovery from municipal solid waste (MSW), as well as the reduction on the landfilled amount of biodegradable waste. In recent years, MBT has been widely used in European countries (Calabro et al., 2007). For example, 6.35 million tons of MSW were treated by MBT technology in Germany (Weidemeier, 2007). MBT technology has also been used in some developing countries, including China (in Beijing and Shanghai City) (Tränkler et al., 2005). Due to dietary habits, the contents of organic matter and moisture in MSW in Asian countries are usually relatively higher than those in European and North American countries, which may induce more secondary pollution (i.e. leachates and gaseous pollutants) (Norbu et al., 2005; Pierucci et al., 2005). The gaseous pollutants mainly include inorganic compounds such as ammonia, hydrogen sulfide, as well as a large number of extremely complex volatile organic compounds (VOCs), most of which are toxic and hazardous and classified as priority pollutants in the United States, Europe, Japan and China (Bockreis and Steinberg, 2005; Karageorgos et al., 2005).

Studies of gaseous pollutants released during the MSW treatment process have primarily been focused on two aspects, i.e., the characteristics of gaseous pollutants and their impacts on the environment, and occupational exposure (Tolvanen et al., 2005; Domingo and Nadal, 2009). Among gaseous pollutants released in a waste composting plant, ammonia was found to be predominant, with an emission of around 18–1150 g/t waste (Clemens and Cuhls, 2003). The ammonia concentration in the exhaust gases of a sewage sludge composting plant was as high as 700 mg/m³ (Cadena et al., 2009). Other important compounds were VOCs, which had been detected with concentrations ranging from 10 mg/m³ to 15 mg/m³ in the air in MSW composting plants (Eitzer, 1995).

Rodriguez et al. (2010) investigated the impacts of operating parameters (moisture, oxygen and C:N ratio) on the release patterns of VOCs during a composting process and found that the C:N ratio was the most important factor, followed by the internal oxygen and moisture contents of the waste pile.

During the waste composting process, incomplete or inadequate ventilation could cause significant releases of odour substances such as hydrogen sulfide. Mao et al. (2006) found that dimethyl sulfide, dimethyl disulfide, limonene and α -pinene were the main odour substances in a MSW composting plant. A study conducted in a food waste composting plant by Tsai et al. (2008) showed that the relationships between concentrations and odour intensities of ammonia, dimethyl sulfide and acetic acid were logarithmic, while those of acetic acid, ethyl benzene and p-cymene were linear. It has also been reported that trimethylamine could be perceived and detected at greater distances than ammonia due to its higher persistence and lower odour threshold (Thriel et al., 2006).

This study investigated the spatial distribution of gaseous pollutants outside the treatment facilities of a MBT plant in Shanghai. Based on the concentrations, the main distributions of the pollutants of the plant were simulated and identified through the contour profiling.

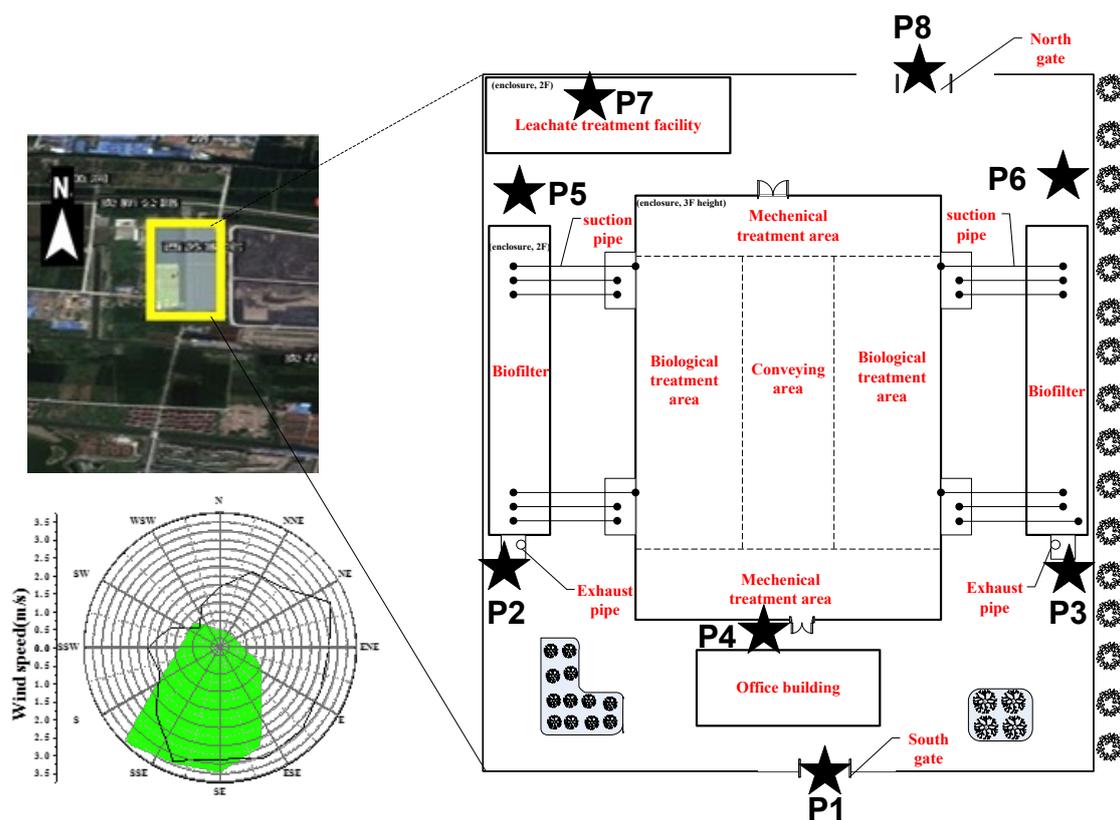


Figure 1: Arrangement of sampling points in the treatment plant and the wind-rose chart during the sampling campaign (left bottom). "P1-P8" with stars, represents the sampling points. The shadow area in the wind-rose chart represents the wind direction frequency and the curve represents the wind speed.

2. Materials and methods

2.1 Site Description and sampling location

The MSW treatment plant was 1200 t/d, with a working area of 20,000 m². A schematic diagram of the treatment processes is shown in Fig. 1. Briefly, MSW was delivered from the north gate to the mechanical treatment facility, where the waste was sorted manually, then size-separated using trommel screens. After the mechanical treatment, the waste was conveyed to the biotreatment facility for 20 days of aerobic fermentation. Next, the waste was sorted again in mechanical treatment facility, after which undersized material was delivered to a biotreatment again for another 30–60 days of aerobic fermentation. Two biofilters were located symmetrically on the left and right side of the treatment facilities. On the north of the plant, there was the leachate treatment facility. These facilities were all enclosed. The odour compounds inside the treatment facilities had already been discussed by Fang et al. (2013), while this present study focused on the surrounding circumstance outside the above-mentioned facilities in the plant. Two points were arranged on the south and north gate (P1, P8), two points were arranged in the exhaust pipe on the monitoring platform (P2, P3), one point was arranged between the facility and office building (P4), one point was arranged on roof of the leachate treatment facility (P7), the rest two points were arranged on the north of biofilter (P5, P6). Overall, 8 sampling points were arranged in the plant outside of the facilities (Fig. 1). The sampling campaign was conducted on May 10th 2013 and lasted from 8:00 to 19:00 (Noted: The operation time in the plant was from 7:00 to 13:00). Sampling in each point were respectively at 9:00, 12:00 and 17:00, totally 24 samples.

2.2 Gas sampling and analyses

Four methods were used to measure different gaseous pollutants in this study, 1) colorimetric tubes, 2) gas-chromatography (GC) with mass spectrometry (GC-MS) or flame ionization detection (GC-FID) or pulsed flame photometric detection (GC-PFPD) preceded by cold trap concentration, 3) GC-FID preceded by sorbent concentration, and 4) high-performance liquid chromatography (HPLC) after derivation by 2,4-dinitrophenylhydrazine (DNPH).

2.2.1 GC analysis after cold pre-concentration

Samples were grabbed using Tedlar bags from the air. Tedlar bag was placed in a vacuum-generating container. Using a vacuum pump connected to the container, the samples were drawn directly into the Tedlar bags via Teflon tube. These samples were then transported immediately to the lab for analysis (within 24 hours) to minimize the loss of reduced sulfur compounds (RSC) during storage.

Ambient air samples were pre-concentrated by cryogenic liquid nitrogen according to the EPA TO15 method. The pre-concentration instrument used was an Entech 7100A (Entech Instruments Inc., USA) and the injection volume was 50-500 mL.

Conditions for GC-PFPD and GC-FID had been reported by Fang et al. (2012, 2013)

2.2.2 GC-FID analysis after sorbent concentration

The sorbent concentration method was used to determine volatile fatty acids (VFAs) in the air samples. Commercial sorbent tubes (Silica Gel Tube, SKC, USA) were used to collect the air samples. The air flow rate was 1000 mL/min and the collection time was 120 min. After sampling, the tube were capped with the end plugs and transported back to lab for analysis. The silica gel was placed into 5 mL volumetric flask and was desorbed by 5 mL of deionized water. After standing 30 min in the ultrasonic

instrument, the supernate of the liquid were analyzed by GC-FID. The operation parameters for the FID detection system were the same as described above.

2.2.3 HPLC analysis after derivation by DNPH

EPA method TO11A was applied to determine aldehydes in the air samples.

Commercial cartridges (Cleanert DNPH-Silica, Agela Technology, China) were used to collect the air samples. The air flow rate was 1000 mL/min and the collection time was 30 min. After sampling, the cartridges were connected to a clean syringe (Visiprep DL, Supelco Analytical, USA) and placed on the solid phase extraction vacuum manifold (Visiprep, Supelco Analytical, USA), after which compounds absorbed onto the cartridges were eluted into a 5 mL volumetric flask with 5 mL of acetonitrile.

The analytical column used was a C18 (4.6 mm ID × 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. The detection limit of this method was 50 ppb.

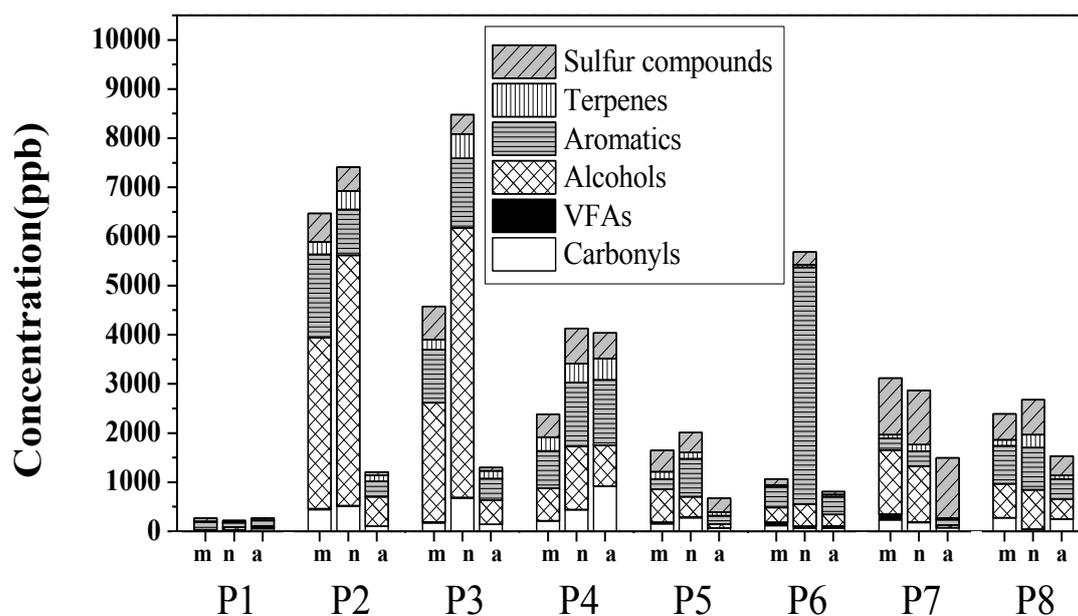


Figure 2: Total concentration and composition of the odour compounds in the 8 points. In X-axis, "m", represents 9:00, "n", represents 12:00, "a", represents 17:00.

3. Results and discussion

Six groups of pollutants including sulfur compounds, carbonyls, alcohols, aromatics, alkanes, alkenes, terpenes and VFAs were identified. The concentrations of the gaseous pollutants in the air at the 8 sampling points are shown in Fig. 2.

Carbonyls including ketones and aldehydes, and the dominant carbonyls in this plant were butyraldehyde and crotonaldehyde, as shown in Fig. 3(b). VFAs were almost below 50 ppb except P6 and P7, where the concentrations were higher than other

places and above this value, as shown in Fig. 3(c). Alcohols showed an extra high value in the biofilter exhaust pipe, and mainly was ethanol from the Fig. 3(d). Ethanol showed a great decrease in the afternoon, from 4745 ppb declining to 521 ppb in P2 and from 5342 ppb declining to 453 ppb in P3. The relatively higher concentrations of ethanol could be due to the anaerobic conditions of the materials.

Six representative aromatics were identified in this study, as shown in Fig. 3(e). Except for P6, the concentrations of the other places were below 2000 ppb. Some researchers have reported that aromatics originated from the decomposition of plastics and solvents (Pierucci et al., 2005), while others suggested that they were xenobiotic compounds disseminated from raw materials, rather than intermediate products of waste biodegradation (Komilis et al., 2004). Aromatics can also be found in the gaseous contaminants of sludge degradation (Huang et al., 2011). The dominant compounds of this family were not obvious.

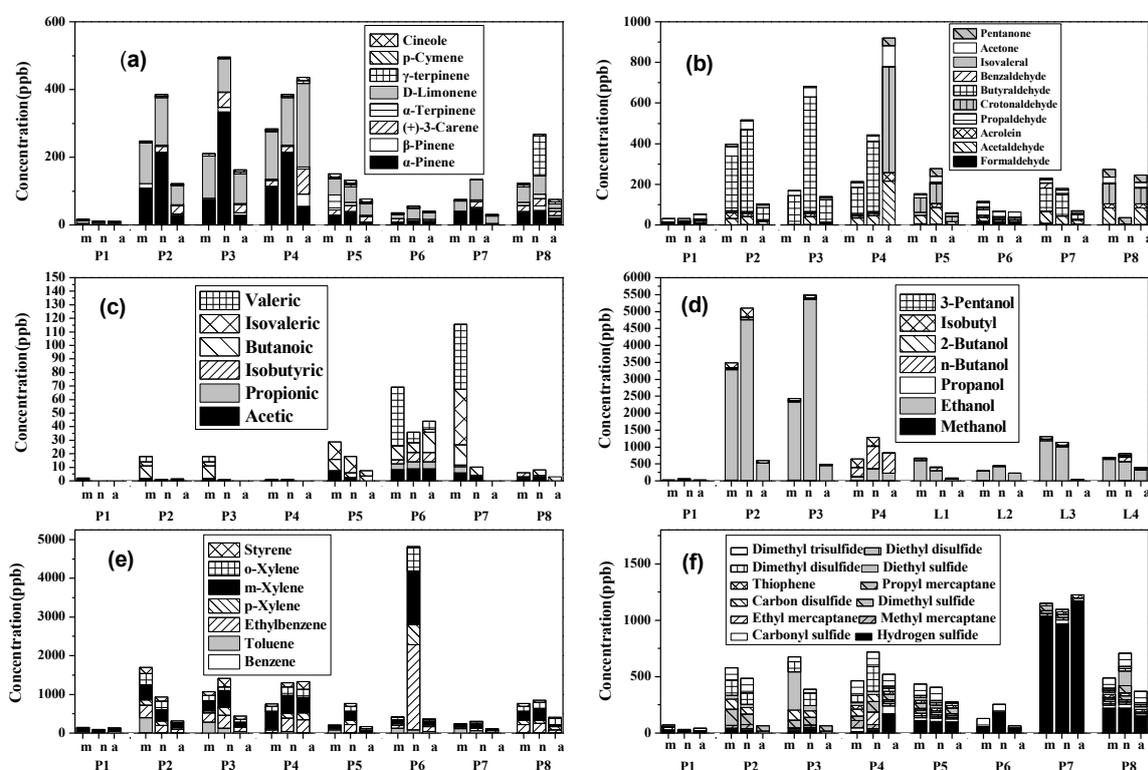


Figure 3: Composition of each odour family and concentration of each compound in the plant. (a) Terpenes, (b) Carbonyls, (c) VFAs, (d) Alcohols (e) Aromatics, (f) Sulfur compounds. In X-axis, "m" represented 9:00, "n" represented 12:00, "a" represented 17:00.

Sulfur compounds showed strong relationships with the physicochemical properties of the waste. In this plant, the characteristics of sulfur compounds composition could be discriminated into two groups. One was more similar in P2, P3 and P4, where the proportion of hydrogen sulfide was low, while the other group was more similar in P5, P6, P7 and P8, where the proportion of hydrogen sulfide was relatively high. Cysteine and methionine were two kinds of amino acids in proteins that contain sulfur. Decomposition of organic sulfur under oxic (presence of oxygen) conditions resulted in mercaptans (Organic group - SH) and anoxic conditions (absence of oxygen) resulted in

hydrogen sulfide. Both these products were generated when biodecomposition occurs. In addition, dimethyl sulfide was generated under conditions of anoxic circumstances predominate. Hydrogen sulfide occurred largely only when the pH and oxygen concentration of the waste reduced and in this case the high proportion of hydrogen sulfide were most probably caused by the anaerobic tank of leachate treatment facility. Due to the low odour threshold value of hydrogen sulfide, the odour impact of leachate treatment facility to the neighbourhood circumstance was much larger than the biofilters and the waste treatment facilities.

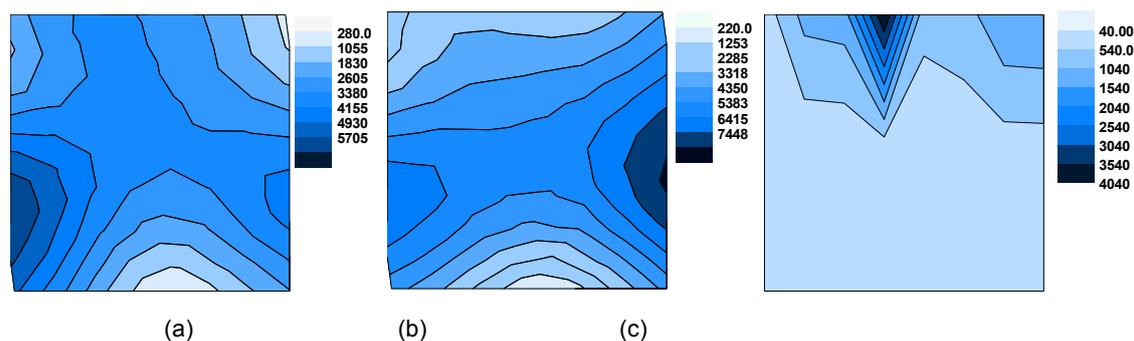


Figure 4: Contour figures of the total pollutants in different times in the plant. (a) At 9:00, (b) At 12:00, (c) At 17:00. The unit of the contour data is ppb.

The contour figures were got through the total concentration and the coordinate of each point, as shown in Fig. 4. From the figure, the distributions of odour pollutants in the plant were very similar in the morning and at noon, in which the biofilter exhaust pipe was the major source to the surrounding circumstance. Nevertheless, the leachate treatment facility became the major source in the afternoon, in which the waste treatment was ceased and the running of biofilter was stopped.

4. Conclusions

The odour concentration at noon in this plant was much higher than that in other times. The concentration fluctuation law in these places was more influenced by the operation time of the treatment plant. The main contributors to malodorous smell were carbonyls, alcohols and sulfur compounds, mainly butyraldehyde, crotonaldehyde, ethanol and hydrogen sulfide. The odour impact of leachate treatment facility to the neighbourhood circumstance was much larger than the biofilters and waste treatment facilities.

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