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Characterization of odorous charge and photochemical reactivity of VOC emissions from a full-scale food waste treatment plant in China

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ABSTRACT

Food waste treatment plants (FWTPs) are usually associated with odorous nuisance and health risks, which are partially caused by volatile organic compound (VOC) emissions. This study investigated the VOC emissions from a selected full-scale FWTP in China. The feedstock used in this plant was mainly collected from local restaurants. For a year, the FWTP was closely monitored on specific days in each season. Four major indoor treatment units of the plant, including the storage room, sorting/crushing room, hydrothermal hydrolysis unit, and aerobic fermentation unit, were chosen as the monitoring locations. The highest mean concentration of total VOC emissions was observed in the aerobic fermentation unit at 21,748.2–31,283.3 $\mu g/m^3$, followed by the hydrothermal hydrolysis unit at 10,798.1–23,144.4 $\mu g/m^3$. The detected VOC families included biogenic compounds (oxygenated compounds, hydrocarbons, terpenes, and organosulfur compounds) and abiogenic compounds (aromatic hydrocarbons and halocarbons). Oxygenated compounds, particularly alcohols, were the most abundant compounds in all samples. With the use of odor index analysis and principal components analysis, the hydrothermal hydrolysis and aerobic fermentation units were clearly distinguished from the pre-treatment units, as characterized by their higher contributions to odorous nuisance. Methanthiol was the dominant odorant in the hydrothermal hydrolysis unit, whereas aldehyde was the dominant odorant in the aerobic fermentation unit. Terpenes, specifically limonene, had the highest level of propylene equivalent concentration during the monitoring periods. This concentration can contribute to the increase in the atmospheric reactivity and ozone formation potential in the surrounding air.

Introduction

With the accelerating socioeconomic growth and urbanization in China, people's living standards have been improving rapidly. However, such improvement has had the negative effect of the generation of a large amount of food waste (FW). The current FW generation in China is estimated to have reached 60 million tons per year (Wang et al., 2013). Compared with other bio-wastes, FW is rich in easily biodegradable organic matters and high water content, thus becoming a potential source of environmental pollution.

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Under this scenario, industrial FW treatment has been paid considerable attention in China, where a series of regulations and technical specifications have been issued recently.

However, during FW processing, a mass of volatile organic compounds (VOCs) are inevitably released into the indoor and outdoor environment. These VOC emissions mainly contain hydrocarbons, ketones, esters, alcohols, aldehydes, terpenes, and organic sulfur compounds (Mao et al., 2006; Tsai et al., 2008; Wu and Wang, 2012). It was reported that total non-methane organic compounds and total volatile sulfur compounds derived from FW anaerobic decomposition and aerobic composting accounted for 0.221 and 0.379 mg-C/dry g, respectively, and these values were comparatively higher than those emitted from paper, yard waste, and municipal solid waste decomposition (Staley et al., 2006; Zhang et al., 2013). Most VOC emissions are generally responsible for odor nuisance and health risks due to their relatively low olfactory thresholds and potential toxicity. On the other hand, such compounds also can contribute to the atmospheric OH radical budget and tropospheric ozone production, while VOC oxidation can facilitate the formation of secondary organic aerosols (SOAs), which are the main components of particulate matter 2.5 ($PM_{2.5}$) (Chen et al., 2013; Ran et al., 2011).

The "Technical code on food waste treatment" has been issued in China recently, and this specification is anticipated to accelerate the development of the domestic FW treatment industry. However, the corresponding technical specifications on risk assessment and pollution control during FW treatment remain unavailable in China. One possible reason for this unavailability is the scarcity of information on the *in-situ* monitoring of pollutant emission, specifically for VOC emissions from a full-scale food waste treatment plant (FWTP). Although VOC emissions from both aerobic and anaerobic processes have already been reported in the literature, most of the references were only related to bench or pilot experiments (Pierucci et al., 2005; Staley et al., 2006; Zhang et al., 2012), and others were only focused on an isolated operating unit, *i.e.*, the composting process (Kumar et al., 2011; Mao et al., 2006; Tsai et al., 2008), rather than the whole treatment process from initial receiving to final treating (Gallego et al., 2012; Nadal et al., 2009). Moreover, despite the growing interest in the atmospheric reactivity of VOC emissions, most papers have primarily referred to such scenarios as atmospheric environment, industrial environment, vehicle sources, and even VOC emissions from waste water treatment and incineration plants (Jia et al., 2009; Ran et al., 2011; Tang et al., 2011; Wei et al., 2014), while few reports have focused on the atmospheric reactivity contributions of VOC emissions derived from FWTPs. Hence, a better understanding of VOC emissions released from industrial FWTPs and their potential contributions to atmospheric pollution is required.

With these findings, this study aims to develop a surveillance program focused on VOC emission in a full-scale FWTP with the core processes of hydrothermal hydrolysis followed by aerobic fermentation. This FWTP was selected for its relatively advanced technology, good management practices, large scale, long period of normal operation, and potential for widespread application in China. In addition, the main odorous charge and atmospheric reactivity of target VOC emissions were estimated based on the *in-situ* monitoring results to provide new insights into air pollutants released from FWTP. Such findings can also contribute to preventive recommendations for VOC abatement during industrial FW treatment to help regulatory bodies.

1. Materials and methods

1.1. Site description

The study was conducted in a full-scale FWTP in China. The FWTP was put into operation in 2004 and has a treatment capacity of 300 ton/day. The feedstock used in this plant was mainly obtained from local restaurants. The basic compositions of FW were as follows (represented as mean ± SD): moisture = 74.4 ± 1.7 (%, W/W); VS = 80.2 ± 6.4 (%, DM (dry matter)); carbohydrate = 23.8 ± 5.2 (%, DM); protein = 24.8 ± 2.0 (%, DM); lipid = 25.9 ± 5.1 (%, DM); and salt content = 4.6 ± 0.6 (%, DM). After being received and stored for a short period, FW was sorted mechanically and manually to remove the inorganic materials, followed by the crushing treatment. The crushed FW was then pumped to the hydrothermal hydrolysis reactors (treated at 120°C for 80 min), where the macromolecular organic matters were converted into simple organic matters through physical and chemical reactions. After hydrothermal processing, solid–liquid separation was conducted by a simple gravity effect. The solid residue was pumped up to aerobic fermentation reactors for the final protein feed, whereas the liquid fraction was used for biodiesel production (oil phase) and anaerobic digestion (aqueous phase) after oil–water separation. The aerobic fermentation unit adopted forced ventilation mode with an average discharge rate of approximately 100 m^3/min. The retention time and fermentation temperature were set as 12–18 hr and 70–80°C, respectively. Meanwhile, exogenous microbes were added to accelerate the aerobic decomposition of thermally hydrolyzed food waste. The process flow chart and plan view are shown in Fig. 1.

1.2. Sampling and analysis

The four three-month basis samples were collected from April 2012 to January 2013 and fairly represented the possible conditions during the seasons of spring, summer, autumn, and winter. According to the treatment process and the potential discharge capacity of VOC emissions, four major treatment units inside the plant were chosen as sampling points. The locations were as follows: (1) storage room; (2) sorting and crushing room; (3) hydrothermal hydrolysis unit; and (4) aerobic fermentation unit (Fig. 1). Monitoring was conducted once or twice a day within the continuous five-day working period. The mean of the monitored data was recorded.

Different sampling strategies were used for fugitive and fixed emission sources. The fugitive emission samples, mainly from treatment units 1 and 2, were collected beside the raw waste storage poll and discharge port of the crushing device with a distance and a height of 0.5 and 1.2 m respectively. For the fixed emission samples in treatment units 3 and 4, sampling was carried out at the open face of the respiration valve of the hydrothermal hydrolysis reactor and the exhaust outlet of the aerobic fermentation reactor, respectively. To assure their representative nature, samples were collected during working hours, and simultaneously to avoid air disturbance caused by anthropic factors. The concentrations of total VOC emissions (TVOC) were first measured on site using a hand-held TVOC analyzer with PID detector (ppbRAE 3000 PGM-7340, ICON Safety Co., Inc., Cerritos, USA) equipped with a gas-discharge lamp (10.6 eV). Subsequently, the air samples were dynamically collected by using self-extracting equipment connected to an 8 L Teflon sampling bag for component analysis of VOC emissions. The speed of the mass flow controller (Buck Libra Pump L-4, A. P. BUCK, Inc., Orlando, USA) was 0.1 L/min and continually sampled for 1 hr. Therefore, approximately 6 L ambient air