



Full length article

## Pollution characteristics and health risk assessment of volatile organic compounds emitted from different plastic solid waste recycling workshops



Zhigui He <sup>a,b</sup>, Guiying Li <sup>a</sup>, Jiangyao Chen <sup>a</sup>, Yong Huang <sup>a,b</sup>, Taicheng An <sup>a,\*</sup>, Chaosheng Zhang <sup>c</sup>

<sup>a</sup> The State Key Laboratory of Organic Geochemistry and Guangdong Key Laboratory of Environmental Protection and Resources Utilization, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China

<sup>b</sup> University of Chinese Academy of Sciences, Beijing 100049, China

<sup>c</sup> GIS Centre, Ryan Institute and School of Geography and Archaeology, National University of Ireland, Galway, Ireland

### ARTICLE INFO

#### Article history:

Received 16 October 2014

Received in revised form 1 January 2015

Accepted 5 January 2015

Available online 6 February 2015

#### Keywords:

Plastic recycling

VOCs

Pollution characteristics

Health risk assessment

Occupational exposure limits

### ABSTRACT

The pollution profiles of volatile organic compounds (VOCs) emitted from different recycling workshops processing different types of plastic solid waste (PSW) and their health risks were investigated. A total of 64 VOCs including alkanes, alkenes, monoaromatics, oxygenated VOCs (OVOCs), chlorinated VOCs (ClVOCs) and acrylonitrile during the melting extrusion procedure were identified and quantified. The highest concentration of total VOCs (TVOC) occurred in the poly(acrylonitrile-butadiene styrene) (ABS) recycling workshop, followed by the polystyrene (PS), polypropylene (PP), polyamide (PA), polyvinyl chloride (PVC), polyethylene (PE) and polycarbonate (PC) workshops. Monoaromatics were found as the major component emitted from the ABS and PS recycling workshops, while alkanes were mainly emitted from the PE and PP recycling processes, and OVOCs from the PVC and PA recycling workshops. According to the occupational exposure limits' (OEL) assessment, the workers suffered acute and chronic health risks in the ABS and PS recycling workshops. Meanwhile, it was found that most VOCs in the indoor microenvironments were originated from the melting extrusion process, while the highest TVOC concentration was observed in the PS rather than in the ABS recycling workshop. Non-cancer hazard indices (HIs) of all individual VOCs were <1.0, whereas the total HI in the PS recycling workshop was 1.9, posing an adverse chronic health threat. Lifetime cancer risk assessment suggested that the residents also suffered from definite cancer risk in the PS, PA, ABS and PVC recycling workshops.

© 2015 Elsevier Ltd. All rights reserved.

### 1. Introduction

The global production of plastic and the associated plastic solid waste (PSW) generated by households and industries have grown exponentially in recent decades due to their low costs, easiness to mold, lightweight, and many other advantages (Nkwachukwu et al., 2013; Rochman et al., 2013). The growing amount of PSW can lead to various environmental problems, including “white pollution”. It is reported that marine litters consist of up to 60 to 80% of plastics (Moore, 2008), which also serve as a carrier of persistent organic pollutants (POPs) transferable to aquatic organisms (Koelmans et al., 2013). Dealing with these enormous PSW remains a challenging task in many countries. The widely-used traditional landfill is becoming an undesirable way of disposal due to legislation pressures, rising costs and the poor biodegradability of commonly used petroleum-based plastics (Achilias et al., 2007). The alternative, incineration, has been criticized for generating large amounts of bottom ash and various toxic air pollutants, like

polycyclic aromatic hydrocarbons, as well as dioxins in case of halogen-containing plastics (Shen et al., 2010; Vejerano et al., 2013). Therefore, the recycling of PSW is a highly desirable way for resource, energy conservation and reduction in waste gas emissions (Ignatyev et al., 2014). This is particularly important in the electronic waste (e-waste) dismantling industry, since plastics are one of the main components of e-waste (Wang and Xu, 2014).

The commonly adopted PSW recycling approaches include primary recycling, mechanical recycling, chemical recycling and energy recovery (Achilias and Karayannidis, 2004). The mechanical recycling is the main recycling approach in the e-waste dismantling process in Southern China, which is used to recover PSW for the reuse in manufacturing plastic products via the mechanical means. Mechanical recycling can be generally divided into several steps: collection, separation, milling, washing, agglutination, extrusion, quenching and granulation (Al-Salem et al., 2009). Among these steps, only during the extrusion process (Patel and Xanthos, 1995), PSW begin to melt and thermally degrade at a certain temperature, while other steps might not change the property of PSW. Previously, high temperature treatment processes like pyrolysis of thermoplastics

\* Corresponding author.

E-mail address: [antc99@gig.ac.cn](mailto:antc99@gig.ac.cn) (T. An).

were well studied (Aboulkas and El Bouadili, 2010; Elordi et al., 2011; Wang et al., 2013). At the high temperature (more than 400 °C), PSW could be converted into valuable substances, which can be used as either fuels or feedstock in the petrochemical industry (Williams, 2005). However, various toxic gases including alkanes, alkenes, as well as chlorinated and aromatic hydrocarbons could also be produced during this process. Although the melting temperature in the mechanical recycling is around 150–300 °C which is much lower than the pyrolysis, various volatile organic compounds (VOCs) might still be produced and released into the atmospheric environment at this temperature due to the aging, long thermal exposure, intrinsic sensitivity, and the interactions between the additives and polymers (Pospíšil et al., 2003). Furthermore, owing to the rather primitive and crude facilities used during the extrusion process, the VOCs are discharged directly into atmospheric environment without any ventilation or treatment in most PSW workshops in many developing countries. The VOC emission characteristics remain unclear during these recycling processes. Only a few studies were reported on the pollution characteristics of VOCs in the plastic waste recycling granulation step (Huang et al., 2013) without involving the extrusion process.

In addition, these VOCs may contain massive hazardous compounds posing health risks to workers and neighboring residents (An et al., 2014; Colman Lerner et al., 2012; Sax et al., 2006; Sofuoglu et al., 2011). The human health effects of VOCs can be classified as either non-cancer or cancer risks. The main non-cancer chronic effects of VOCs are sensory effects, damages to the liver, kidneys and central nervous system, asthma and other respiratory effects (Rumchev et al., 2007). The main cancer effects are lung, blood (leukemia and non-Hodgkin lymphoma), brain, liver, kidney and biliary tract cancers (WHO, 2000). For instance, benzene can induce not only non-cancer risks of hematotoxicity and aplastic anemia, but also cancer risks of acute myelogenous leukemia and lymphoma (Sarma et al., 2011). Thus, it is necessary to assess the health effects on the residents in the industrial areas. However, the risk assessment for human health has not yet become a routine task in the PSW recycling area, and most studies have only focused on VOC emission levels.

In this study, the VOC emission characteristics, health risks, and indoor microenvironment exposure during the melting extrusion of the recycling processes at seven different types of plastics were investigated in detail. The health risks of the emitted VOCs on the human beings were carried out in two ways: the occupational exposure limit assessment for workers in the extrusion assembly lines and the health risk assessment including non-cancer risks and cancer risks for the residents living near the PSW recycling workshops.

## 2. Materials and methods

### 2.1. Descriptions of the sampling sites

The recycling PSW can generally be divided into seven types: poly(acrylonitrile-butadiene styrene) (ABS), polystyrene (PS), polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyamide (PA), and polycarbonate (PC). Particularly, PA is a kind of thermoplastic polymers containing amide (–NHCO–) unit, where hydrocarbon segments between the amide groups could be aliphatic, partially aromatic, or wholly aromatic. In this study, PA 6 (monomer: caprolactam) and PA 66 (hexamethylenediamine and adipic acid) were the main recycling PSW in the PA workshop. The description for the structure, monomer and polymerization methods of the studied plastics is listed in Table 1.

All the exhausted gases were only fanned out and emitted through the outlet on the side-door or the roof (approximately 8 m above ground) of the workshops without any proper treatment. Sampling was conducted using 2.7 L vacuum Summa canisters at about 1 m away from the extruding machine during the extrusion process, as the workers stand at a similar distance in the workshops. The indoor

**Table 1**

Structure, monomer and polymerization methods of studied plastics.

Material	Monomer	Polymerization methods	Temperature (°C)	
			Decomposition	Extrusion
ABS	Styrene, 1,3-butadiene, acrylonitrile	AP <sup>a</sup>	290	200–300
PS	Styrene	AP	290	200–260
PE	Ethylene	AP	350	150–250
PP	Propylene	AP	350	150–250
PVC	Vinyl chloride	AP	210	150–200
PA	Diamine, dicarboxylic acid	AP/CP <sup>b</sup>	300–355	200–230
PC	Bisphenol A, carbonyl chloride	CP	>350	100–150

<sup>a</sup> Addition polymerization.

<sup>b</sup> Condensation polymerization.

microenvironment samples were simultaneously collected from three different sites in each of the workshops.

### 2.2. Analytical methods

The VOCs' samples were qualitatively and quantitatively detected by a Entech 7100 pre-concentrator (Entech Instruments Inc., CA, USA) and GC-MS (7890A GC-5975C MS, Agilent Technologies, USA) combined techniques with the USEPA TO-15 method (He et al., 2012; U.S. EPA, 1999). First, a volume of 150 mL of the VOCs from sampling Summa canisters was concentrated in the glass bead trap (module 1), which was maintained at 150 °C with liquid nitrogen. The trapped analytes were then desorbed at 20 °C and transferred to a Tenax-TA trap (module 2) maintained at –40 °C. The concentrated components were again desorbed at 190 °C and then focused at the cold top of the capillary column, which was cooled to –180 °C. After 2.5 min, the highly focused VOCs were quickly desorbed at 120 °C min<sup>–1</sup> and swept into the column for the separation.

A DB-1 column (60 m × 0.32 mm × 0.25 μm, Agilent Technologies, USA) was used with the GC oven temperature program: initially 35 °C for 5 min, programmed to 150 °C at a rate of 5 °C min<sup>–1</sup>, and then to 250 °C at a rate of 15 °C min<sup>–1</sup> which was held for 2 min. The carrier gas was ultrahigh purity helium at a constant flow rate of 1.2 mL min<sup>–1</sup>. Mass spectrometer conditions were as follows: temperature of the transfer line: 290 °C; ionizing energy: 70 eV; scan range: 45–260 m<sup>e</sup>. The concentrations of most VOCs were quantified by external standard calibration which was determined by standard samples Photochemical Assessment Monitoring Stations (PAMS) and TO-15 (Linde Spectra Environment Gases, USA). The calibration standards were prepared by dynamically diluting 100 ppbv PAMS standard mixture (33 compounds were detected) and 1 ppmv TO-15 standard mixture (30 compounds were detected) to 1, 5, 10, 15, 30 and 50 ppbv with high purity nitrogen. For some ketones (3-hexanone, cyclopentanone, 2-methylcyclopentanone, cyclohexanone and 2-ethylcyclopentanone), their concentrations were calculated using 2-hexanone as the reference compound due to their similar properties. For acrylonitrile and n-butanol, the concentrations were manually quantified to 342 and 245 ppbv, then they were dynamically diluted to five levels ranging from 1 to 30 ppbv. Each target VOC was identified by both retention time and mass spectra using the NIST 05 database (National Institute of Standards and Technology).

### 2.3. Quality control and assurance

Before sampling, all canisters were flushed at least five times by repeatedly filling and evacuating with high purity nitrogen. All canisters were evacuated after the cleansing procedures, re-filled with high purity nitrogen, stored in the laboratory for at least 24 h, and then analyzed in the same way as field samples to make sure that all the target VOC compounds were not present. All the samples were analyzed within 24 h after the collection. The target VOCs were identified based on

Download English Version:

<https://daneshyari.com/en/article/6313670>

Download Persian Version:

<https://daneshyari.com/article/6313670>

[Daneshyari.com](https://daneshyari.com)