



## Research article

## Heavy metals dispersion during thermal treatment of plastic bags and its recovery

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## ABSTRACT

One of the main worries for thermal treatment of plastic bag (PB) is the air pollution resulting from heavy metal (HM) evaporation and emission. The quest of the study was to investigate their fate during thermal treatment varying with temperature and atmosphere to explore the appropriate treatment technology. Four commonly consumed polymer bags such as PE, HDPE, LDPE and PVC were selected for the analysis. The elemental compositions, heating values and total metal contents of the samples were measured by an elemental analyzer, a sulphur/halogen analyzer, a bomb calorimeter and an ICP–OES, respectively. Thermal treatments of the samples were conducted in a tube furnace at 350, 550, 650, 750, and 850 °C with 1 L/min air or N<sub>2</sub> gas flow, respectively. 5% HNO<sub>3</sub>/10% H<sub>2</sub>O<sub>2</sub> solution was used for absorbing metals from gas phase, and then HM distributions both in flue gas and bottom ash were determined. Results revealed that the lower heating values of HDPE, LDPE, PVC and PE bags were 33.32, 34.28, 24.82 and 36.7 MJ/kg, respectively indicating energy recovery potential. Thermal treatment showed the maximum mass reduction (>90%) of PB at 850 °C. The higher percentage of metals was distributed in ash at initial temperature that promoted to gas with rise of temperature. The used absorption solution exhibited tremendous quantity of metals recovery. However, there was no significant difference between using air and N<sub>2</sub> gas flow during treatment of PB.

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## 1. Introduction

Plastic bag (PB) is widely used due to its high-quality, multi-utility and being more convenience. It has emerged as one of the most successful products in recent decades and gained surging popularity amongst consumers and retailers (Smith, 2004; UNEP, 2005). Recently, it has become as a common form of packaging materials as well as geotextile dewatering bag (Ayalon et al., 2009; Bahri, 2005; Kang and McLaughlin, 2016). Almost all plastic solid wastes (PSWs) are recycled but discarded PBs are not recycled; rather directly disposed of by dumping or landfilling (Williamson, 2003). Thereby, valuable resources like fuels and metals remain locked in landfills, leading demand of new materials and energy for PB production.

According to Miller (2012), about 500 billion to one trillion PBs are consumed worldwide annually, i.e., 1.4–2.7 billion per day. PB

consumption per capita is relatively high in top GDP growth countries compared to developing ones. However, developing countries suffer more from PB pollution due to the lack of environmental consciousness and illegal disposal (Bahri, 2005; Islam, 2011). The annual PB utilization per capita was found as 1370, 286, 263, 252, 235, and 223 in Hong Kong, the United States, Israel, Taiwan, Japan and China, respectively (Bahri, 2005). Likewise, the total amount of plastic packaging wastes increased from 0.2–1.5 million metric tons between 2015 and 2017 in China (Song et al., 2018). Shanghai(Reuters) (2017) estimated that merely the postal and courier businesses generated 0.16 million tonnes of waste in a single day.

Huge quantity of PBs is consumed worldwide and equivalent amount are discarded and most of which are illegally disposed of (Njeru, 2006; Ramaswamy and Sharma, 2011). Many studies have been performed on PBs to explore environmental and health hazards linked with discarded PBs, for instance – urban drainage block, carbon footprint, marine beach pollution, soil contamination, natural resources consumption, ecological footprint, policy and alternate of PB (Ellis et al., 2005; Jalil et al., 2013; Shamim et al., 2010).

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According to researchers, PB with a minimum thickness of 20–50  $\mu\text{m}$  have already been banned in many countries, particularly in developing countries while minimum charge or levy is imposed in states of developed countries. The alternative bags are also suggested but unfruitful (Dikgang et al., 2012; He, 2012; Ritch et al., 2009). The extreme consumption of disposable PBs is also a global environmental problem. The levy/charge is highly effective in encouraging people who already used reusable bags to use them more frequently, while having no effect on infrequent users (Rivers et al., 2017).

Though PB is so useful but also makes problematic when come to its end-of-life phase. PBs are often thrown away after single use (Miller, 2012; Mutha et al., 2006). The final destination of these discarded PBs is either landfill or incinerator or elsewhere, where they may slowly release toxicity and pollute surrounding environment (Njeru, 2006; Ramaswamy and Sharma, 2011). The adoption of recycling practices with a reduction in the consumption of single-use PB and a kerbside collection system in the EU countries showed around 1.46 million tonnes of CO<sub>2</sub> equivalent emissions reduction (Andreoni et al., 2015).

As additives, heavy metals (HMs) and organometallic compounds are encapsulated with polymer matrix to optimize its properties and to reduce production cost during production of PB. These additives are not chemically bound to polymer molecules (Dilli, 2007; Lajeunesse, 2004); therefore, they can gradually be leached out into environment throughout PB life cycle in-response-to light or heat. After and during disposal of PBs, their environmental impact needs to be concerned as they also have long term health effects indirectly (Al-Qutob et al., 2014; Huerta-Pujol et al., 2010).

Toxic metal contents in PBs should be monitored and regulated properly (Ramaswamy and Sharma, 2011). PB is not biodegradable naturally in aerobic or anaerobic or semi-aerobic environment (Williamson, 2003). Globally, around 96% of the daily discarded PBs directly goes to the landfills or dumpsites due to several unavoidable factors. They can last in landfill an anaerobic environment for hundreds of years. Even after hundreds of years, they will merely photo degrade but not completely. Consequently, collection and disposal of PB wastes has become a global challenge of late (Clapp and Swanston, 2009).

Pollutants are added to PB as stabilizers and pigments, and their contents in different PBs vary based on regions (Al-Qutob et al., 2014; Kumar and Pastore, 2007) and used colors (Huerta-Pujol et al., 2010). When these PBs are disposed of in dumpsites, they might contaminate water bodies, soil and plants in surrounding areas by spreading toxic metals and chemicals (Sakurai et al., 2006). In contrast, such discarded PBs have high heating value ranging from 18–48 MJ/kg that is equivalent to conventional fuels, which can be utilized for energy recovery. Through thermal treatment such locked energy can be recovered along with reducing CO<sub>2</sub> emission and HM leaching (Alam, 2015). Thereat, attention needs to be concerned that, during thermal treatment of PBs through different methods – incineration, pyrolysis and gasification (Ahmad et al., 2012; Olafisoye et al., 2013; Zhou et al., 2014), the metals might transfer to gas phase and cause potential air pollution.

The study was designed to investigate the metals distribution during thermal treatment of PBs at different temperatures and atmospheres to explore suitable treatment technology.

## 2. Methodology

### 2.1. Sampling and preparation

Four types of bags with higher HM contents and wider applications were selected in order to reflect HM dispersion during

thermal treatment. All the samples were repeated for each experiment/test and also triplicated when it was required (if the first obtained values were not close). The selected PBs are such as – a) PE blue garbage, b) HDPE blue garbage, c) LDPE pink garbage, and d) PVC mixed color ladies (Fig. SI-1). Firstly, all the bags were cut into small pieces (<2 mm) with scissor to make homogenous size and then dried at 50 °C for 24 h earlier on further analysis.

### 2.2. Reagents and materials

The guaranteed reagents used for acid digestion – nitric acid (HNO<sub>3</sub>), and hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), were purchased from SinoPharm Company Limited, China. The multi-element standard solution for inductively coupled plasma (ICP) analysis was supplied by SPEX CertiPrep, United States. The high purity (99.99%) air and nitrogen (N<sub>2</sub>) gas used for thermal treatment were supplied by Chun Yu Special Gas Company Limited, Shanghai.

All the glassware and experimental vessels were soaked in 10% HNO<sub>3</sub> solution overnight before use to remove trace metals and other impurities. Further, crucibles were heated in a muffle furnace at 900 °C for 3 h to destroy impurities. These wares were sequentially rinsed by tap water, distilled water and Milli-Q water. Afterwards, PTFE vessels, crucibles and impingers were dried at 55 °C for 2 h, while others at room temperature.

### 2.3. Characterization of plastic bag

#### 2.3.1. Moisture content measurement

The size-reduced PB samples were weighed and then heated in an oven (HH-B11-500-BS-II, Shanghai Yuejin Medical Instruments Co. Ltd., China) at 55 °C for 24 h and the weight losses were measured to calculate their moisture contents (Eq. (1)).

$$\text{Moisture content (\%)} = \frac{(\text{Initial weight} - \text{Final weight}) \times 100}{\text{Initial weight}} \quad (1)$$

#### 2.3.2. Heating value measurement

The heating values of the size-reduced PB samples were detected in a bomb calorimeter (MTUM-A4, Shanghai Mitong Tech. Ltd., China). A weighed (0.1 g) sample was put in a crucible. Then, a wire was set to make fire touching the sample. Subsequently, 10 mL of tap water was added into the bomb and the sample with connecting wire was placed into the bomb. After, the bomb was filled up with oxygen (O<sub>2</sub>) gas to facilitate making fire. Finally, the bomb was placed into the bomb calorimeter and then ignited. After 10–15 min, combustion was finished and the higher heating value (HHV) and lower heating value (LHV) were displayed which were recorded.

#### 2.3.3. Elemental composition analysis

About 5.0 mg of each size-reduced PB sample was weighed and placed in a crucible, then put into the auto-sampler of the Vario EL.III elemental analyzer (Elementar Company Ltd., Germany) for analyzing the concentrations of carbon (C), hydrogen (H) and nitrogen (N). Likewise, about 10.0 mg of each sample was put into a crucible in a sulphur/halogen analyzer (ICS 3000, DIONEX Company Ltd., United States) for analyzing sulphur (S) and chlorine (Cl). The analyzer includes a high temperature burning system which transforms the S and Cl in the sample to SO<sub>3</sub> and HCl, and an ion chromatograph which can detect the SO<sub>4</sub><sup>2-</sup> and Cl<sup>-</sup> in the gas absorption solution.

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