Kinetics and extraction of heavy metals resources from automobile shredder residue

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ABSTRACT

Automobile shredder residue (ASR) has been considered as risky waste due to presence of high concentration of toxic metals, which can pose an environmental threat of being leached out under acidic conditions in the landfill. The present study investigated the extraction of Zn, Cu, Pb and Cd from ASR using water over a range of pH (2–8), temperature (25–55 °C), liquid/solid (L/S) ratio (10–100 mL g^{-1}) and particle size (0.0–4.75 mm). The extraction kinetics of Zn, Cu, Pb and Cd from ASR using water were also analyzed by the shrinking core model (SCM) and second-order reaction model. The extraction rates of metals from ASR were improved by increasing different temperatures and liquid to solid ratios. A maximum extraction of metals was achieved at pH—2, temperature—25 °C and liquid to solid ratio—100 mL g^{-1}. Metal extractions were not efficient at alkaline pH of water. The smallest size fraction of ASR was highly recommended for extraction of heavy metals rather than the larger fractions. The extraction data were best fitted ($R^2 \geq 0.95$) by the second order reaction model, but not by the SCM ($R^2 < 0.95$).

1. Introduction

Hazardous waste management has become an important issue, and serious apprehensions about reducing waste during the generation process. Waste generated from end-of-life vehicles (ELVs) must be utilized for resource recovery and recycling. Currently, reduction of waste discharge and to improve the situation of the automobile industry can be considered environmentally sound management. European Commission Directive 2000/53/CE reported at least of 95% (in average weight per vehicle and year) of ELVs necessity to be reuse and recover valuable materials. The recovery and recycling of ELVs are encouraging the expansion of innovative and well-organized recycling techniques as well as opening a new field of scientific investigation. Automobile shredder residue (ASR) is the final product of the ELVs recycling and recovery process (Joung et al., 2007). According to European Commission Directive 2000/53/CE commission, at least 85% of ASR must be reused or recycled by 2015.

ASR is contributing about 25% by weight of shredded materials in the US (Cheng et al., 2012). ASR is a waste produced through the grinding of ELVs. It can be classified in three fragments: low weight ASR, weighty ASR and fines (soil, sand etc.) (Simic and Dimitrijevic, 2012). ASR is contaminated with oil and metals about 5 and 8%, respectively. However other possible hazardous substances (mineral oils and hydrocarbons) having contribution around about 10% of total composition of ASR (Simic and Dimitrijevic, 2012). According to Gonazalez-Fernandez et al. (2008) and Santini et al. (2011), ASR with particle size <6.0 mm are predominantly polluted with heavy metals and others hazardous materials (mineral oils and hydrocarbons). The residual metal pieces, solder, plasticizers, and paint are key sources of heavy metals in ASR (Kurose et al., 2006; Lopes et al., 2009).
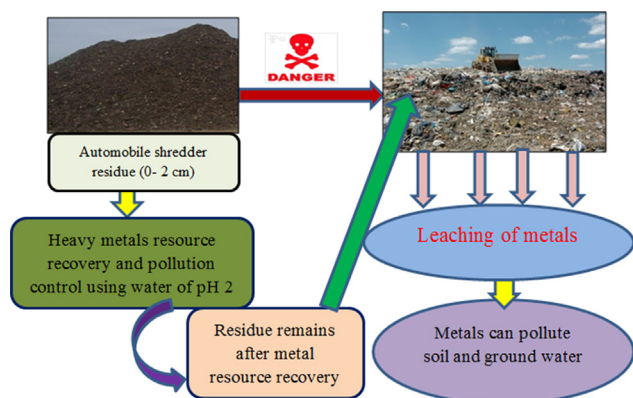
Fig. 1 – Schematic views of recovery and fate of heavy metals.

Fine ASR is directly disposed of into landfills due to its inapplicability for energy generation, and ASR contains hazardous materials such as heavy metals (Oshitani et al., 2003; Donaja et al., 2010). Presence of heavy metals in ASR, consequently their releasing into environments, is one of the major environmental issues worldwide. Fig. 1 demonstrates the occurrence of heavy metals in the ASR can pollute ground water and surface water through leaching. The toxicity of heavy metals in ASR can be minimized by extraction with water of pH 2, which is cost effective and much important for the decrease of environmental risk. According to the Wang et al. (2001), extraction of heavy metals from fly ash generated from municipal solid waste incineration, could reduce the toxicity and leaching characteristics of heavy metals greatly. Under acidic conditions such as pH 2, heavy metals in the landfill can be easily leached out from ASR.

For a fast reaction rate during extraction, the process can be controlled through the rate of distribution of the metal ions from the surface of the extracting substrate via the boundary layer. For slow reaction rate during extraction, the overall process can be controlled by chemical reaction (Aydogan et al., 2005). The diffusion-controlled reaction has been considered a heterogeneous process that is a little dependent on leaching temperature, whereas the chemically controlled process is mainly having dependency on leaching temperature due to the direct related to diffusion coefficients (Aydogan et al., 2005). Despite a few research on the extraction/leaching of heavy metals from ASR using acids (Kurose et al., 2006; Gonazalez-Fernandez et al., 2008; Granata et al., 2011), no information has been published on the kinetics and extraction of Zn, Cu, Pb and Cd from ASR using water.

Therefore, the aim of the present study are to extract Zn, Cu, Pb and Cd from ASR by extraction using water at pH 2, to determine the reaction kinetics during the extraction of heavy metals, and to reduce the environmental toxicity of heavy metals in ASR before disposal into landfill sites.

2.   Materials and methods

2.1.   Particle size distribution

A representative ASR sample (about 20 kg) was collected randomly from the shredder plants of Steel SCRAP Ulsan factory, Nam-gu, Ulsan, Korea. The different grain-size fractions of ASR were prepared according to the study of Singh and Lee (2015a) as shown in Table 1.

2.2.   Initial characterization of ASR

The moisture content, pH and volatile solid contents in different fractions of ASR were measured according to the Singh and Lee (2015a). The availability of moisture content of the five different ASR fractions was determined after drying in a hot air oven (C-DF forced convectional drying oven, Chang Shin Scientific Co.) at 105 °C for 24 h. The pH was measured using a digital pH meter (ORION 5 STAR, thermo scientific) (1:10, w/v waste: water extract) after extraction by shaking for 2 h at 150 rpm. A content of volatile solids and ash was measured by ignition loss of the sample at 550 °C using an electronic muffle furnace (C-FMA, Chang Shin Science Co.). An flame atomic absorption spectrometer (Varian Spectra 55) was used to analyze the Zn, Cu, Pb and Cd concentrations after digestion of 1.0 g of the ASR sample mixed with 20 mL of concentrated sulfuric acid and per chloric acid (5:1) mixture in a closed Teflon vessel for 8 h (Singh and Kalamdhad, 2012, 2013a; Singh and Lee, 2015a). All ASR samples were digested triplicates.

2.3.   Extraction study

Extraction study was accomplished in series of 250 mL covered conical flasks using a temperature-controlled water bath shaker (HST-205SW). The effects of pHs (2–8), L/S ratios (10–100 mL g^{-1}), temperatures (25–55 °C) and particle sizes (4.75–≤0.25 mm on extraction of heavy metals from ASR was carried out. The experimental extraction time was kept 120 min and the samples were collected at different time intervals. The samples were subjected for centrifugation followed by filtration using filter paper (0.45 μm) and the filtrates were used for heavy metal analysis. The pH of deionized water was maintained by adding 1.0 M HCl and 1.0 NaOH. The final pH of the extracted solution was measured. Extraction experiment was repeated three times. The all extraction results were presented as average values with their standard deviations. Heavy metal extraction

Table 1 – Size distribution of different ASR grain fractions.			
Grain fractions of ASR	Size range (mm)	Weight (kg)	Percentage of totals factions
A	4.75–2.0	8.3	41.56
B	2.0–1.19	0.83	4.16
C	1.19–0.425	0.6	3.00
D	0.425–0.250	0.22	1.10
E	<0.250	0.32	1.60
F	>4.75	9.7	48.57
Total weight (kg)	–	19.97	≈100%