



Pollution control and metal resource recovery for low grade automobile shredder residue: A mechanism, bioavailability and risk assessment



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ABSTRACT

Automobile shredder residue (ASR) is considered as hazardous waste in Japan and European countries due to presence of heavy metals. This study was carried on the extraction characteristics of heavy metals (Mn, Fe, Ni, and Cr) from automobile shredder residue (ASR). The effects of pH, temperature, particle size, and liquid/solid ratio (L/S) on the extraction of heavy metals were investigated. The recovery rate of Mn, Fe, Ni, and Cr increased with increasing extraction temperature and L/S ratio. The lowest pH 2, the highest L/S ratio, and the smallest particle size showed the highest recovery of heavy metals from ASR. The highest recovery rates were in the following order: Mn > Ni > Cr > Fe. Reduction of mobility factor for the heavy metals was observed in all the size fractions after the recovery. The results of the kinetic analysis for various experimental conditions supported that the reaction rate of the recovery process followed a second order reaction model ($R^2 \geq 0.95$). The high availability of water-soluble fractions of Mn, Fe, Ni, and Cr from the low grade ASR could be potential hazards to the environment. Bioavailability and toxicity risk of heavy metals reduced significantly with pH 2 of distilled water. However, water is a cost-effective extracting agent for the recovery of heavy metals and it could be useful for reducing the toxicity of ASR.

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1. Introduction

The management and treatment of end-of-life vehicles (ELVs) and the environmental influence of persistent residue disposal have become important issues worldwide. Finding proper treatments for automobile shredder residue (ASR) along with valuable resource recovery is a major problem for the vehicle recycling industries. ASR is the by-product of the vehicle recycling process (Joung et al., 2007) and it contributes up to 20–21% of average ELV weight. According to the report of the European Commission Directive 2000/53/CE, a minimum of 95% (in average weight per vehicle and year) of ELVs must be reused or recovered (including energy recovery) and at least 85% must be reused or recycled by 2015. Therefore, reducing the disposal of ASR in landfills will be less than 10%. Around 87.4% and 82.9% of ASR in Spain were reuse and recovery and reuse and recycling, respectively, and 85.3% and 84.8% in Italy, respectively, in 2011 (Eurostat (2013) “End of life vehicle statistics”) (available at http://ec.europa.eu/eurostat/statistics-explained/index.php/End-of-life_vehicle_statistics). In Japan, recycling and material recovery from ASR will be increased up to 70% by 2015 (Sakai et al., 2014). Currently, in Korea, material

recycling and energy recovery from ASR are about 85% (of which energy recovery rate is within 5%). They are planning to increase up to 95% of ASR for recycling and energy recovery, out of which energy recovery rate is within 10% by 2015 (Sakai et al., 2014). In China, recycling possibility of ASR was about 90% in 2012, and they are try to increase recycling around 95% by 2017 (Sakai et al., 2014). In the United States, around 95% of ELVs enter for recycling route, out of which 80% recovered for the material recycling (Kumar and Sutherland, 2009). Approximately, 0.55 million and 5 million of ELVs are generated per year in Korea and Japan, respectively (Joung et al., 2007). The major parts of ELVs are recycled for reuse with a high rate of 75–80% of the total ELVs generated in Korea (Joung et al., 2007), however, the residual materials (size < 5 mm), termed low grade automobile shredder residues (ASR), are neither reused nor recycled.

The ASR is heterogeneous waste material; it is difficult to develop proper technologies for its recycling (Santini et al., 2011). ASR generally categorized into coarse and fine fractions. The composition of coarse fraction is mainly foam, plastics, rubbers and textiles; however, the fine fraction consists of pieces of glass, plastic sand metals along with dust and dirt (Morselli et al., 2010). The composition, density and moisture content of ASR vary depending on the location (Boughton, 2007). The coarse fraction has the lowest ash content and the highest calorific value (15–30 kJ/kg) and highly

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applicable for energy generation. However, the fine fraction (low grade ASR) has higher ash content and a lower calorific value (11–21 MJ/kg) than the coarse fraction. The fine fraction can also generate problems in incineration process, so it is not much considered for energy production (Mancini et al., 2010; Morselli et al., 2010; Vermeulen et al., 2011; Mancini et al., 2014a,b; Cossu et al., 2014). According to the Morselli et al. (2010), about 20–100 mm fractions of ASR are the richest in polymers that would have the highest calorific values among the other fractions of ASR. Fines occupy about 50% of the total ASR, and they are predominantly polluted with hazardous materials, such as heavy metals, mineral oils, and hydrocarbons (Santini et al., 2011). The major sources of heavy metals in ASR are residual metal pieces, solder, plasticizers, and paint (Kurose et al., 2006; Lopes et al., 2009). In the thermal process of ASR, concentration of the heavy metals increased by a factor of up to 20, in the generated ash residues (Mancini et al., 2014a,b). As shown in Fig. 1, the presence of heavy metals in the low grade ASR can pollute ground water and surface water through leaching, so ASR has been classified as a hazardous waste. It cannot be disposed of in uncontrolled landfills without proper treatment. A small fraction of heavy metals present in the water-soluble fraction may readily leach out, and can be bioavailable in the environment (Iwegbue et al., 2007; Liu et al., 2008; Singh and Kalamdhad, 2013a). Thus, study is needed on cost-effective extraction agent(s) for recovery and reduction of toxicity of heavy metals from ASR for its safe disposal in landfill sites. At lower pH, leaching of heavy metals may occur during the landfilling of ASR. The fast recovery rate can be controlled by the rate of diffusion of the ions from the surface of the solid through the boundary layer, while a slow recovery rate can be controlled by chemical reaction (Aydogan et al., 2005).

According to Tessier et al. (1979), the chemical speciation of heavy metals in a solid environmental matrix is distributed into five fractions (exchangeable, carbonate, reducible, bound to organic matter, and residual fractions). The exchangeable fraction (F1) is likely to be affected by changes in water ionic composition

as well as sorption/desorption processes. This form can be released by ion-exchange processes. The carbonate or acid-extractable fraction (F2) is susceptible to changes in pH and this can become soluble and be mobilized at lower pH. The F1 and F2 fractions of the total metals are considered to be the most mobile forms. Thus, the mobility, bioavailability, and eco-toxicity of heavy metals depend on their speciation rather than their total content (Singh and Kalamdhad, 2012, 2013a, 2013b; Zhu et al., 2014). The term “bio-availability” of any element may be considered as that part of the total concentration of the element that is readily soluble in water. The bioavailable fractions of the metals may be potential contaminants of the food chain, surface water, and groundwater (Singh and Kalamdhad, 2013b). Few studies are available on the recovery of heavy metals from ASR (Kurose et al., 2006; Gonazalez-Fernandez et al., 2008; Granata et al., 2011), but the recovery and kinetic study of heavy metals (Mn, Fe, Ni, Cr) from the ASR has not been reported before. Thus, the objectives of the present study were to assess the recovery of heavy metals from ASR using water, to examine the governing reaction kinetics during the recovery, and to reduce the bioavailability and toxicity of ASR.

2. Materials and methods

2.1. Physicochemical characterization of ASR

The ASR sample (20 kg) was collected from an automobile shredder plant, Nam-gu, Ulsan, Korea. The collected sample was air dried at room temperature with 25 ± 1 °C for two weeks after collection. The ASR sample was sieved using different sizes of sieves and five different grain-size fractions were found, classified as A: 4.75–2.0 mm, B: 2.0–1.19 mm, C: 1.19–0.425 mm, D: 0.425–0.250 mm, and E: 0.250–0.0 mm. The moisture content of different size 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 (Kalamdhad et al., 2009). A digital pH meter (ORION

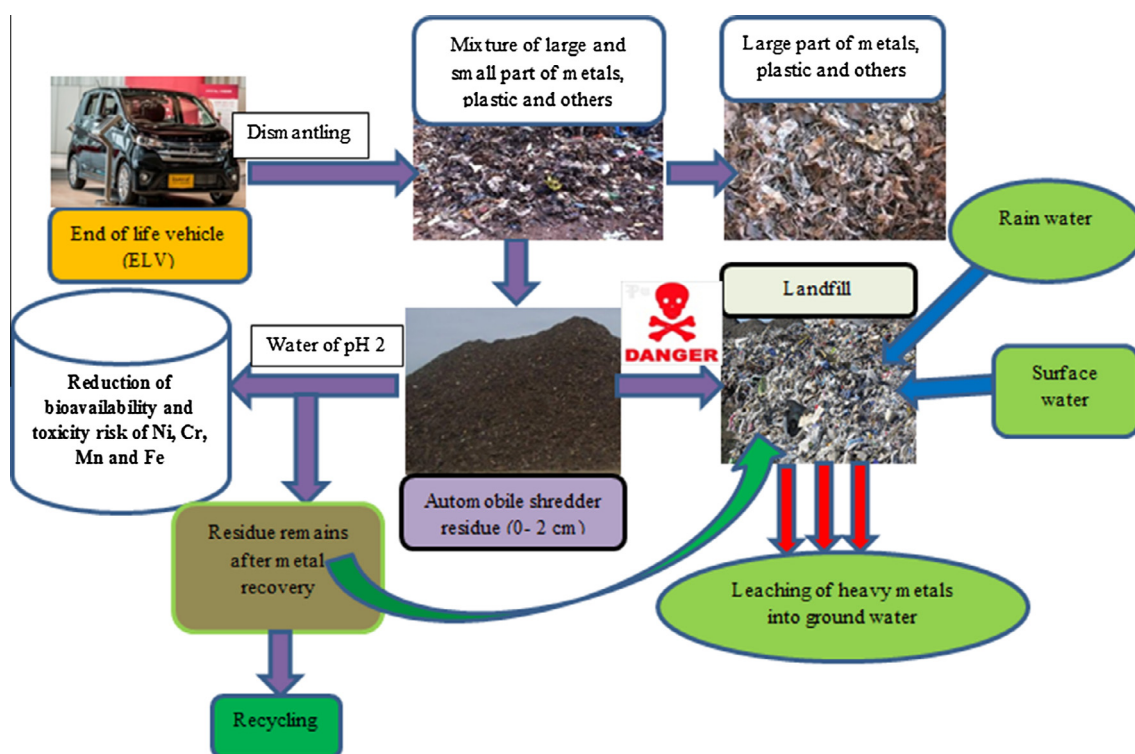


Fig. 1. Schematic views of ASR processing and heavy metals recovery.

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