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Recycling of a fine, heavy fluff automobile shredder residue by density and differential fragmentation

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ABSTRACT

A compilation of the physical properties of materials which might typically occur in automobile shredder residue and an analysis of their suitability for the separation of materials in fine (<15 mm) heavy fluff ASR (fhf-ASR) is presented. Differences in density and resistance to crushing of fhf-ASR materials were identified as potentially the most suitable low cost, technologically simple means for the separating this waste into its three principal components – metals, minerals (glass/stones) and organics (plastics).

Results presented of laboratory scale tests demonstrate that fhf-ASR can in large part be separated into three principal components. Tests were conducted with 0.63–2.0 mm and 2–10 mm fractions. Recovery of plastics by density separations were conducted with water only jigs for the 2–10 mm fraction and shaker tables for the 0.63–2 mm fraction. Comparisons are presented of the separations of glass and stones from metals obtained by linear screening and vibratory screening of roller mill and impact mill crushing products of the high density 2–10 mm fraction. Equipment used for these tests are of a laboratory or demonstrative scale. It is reasonable to anticipate that industrial scale processing would produce significantly better results.

The 2–15 mm fraction was found to constitute 91.6% of the fhf-ASR sampled. The metals content of the 2–10 mm portion of this fraction was upgraded from 2.5% to 31% and 76.9% with recoveries varying inversely with grade from 91.9% to 40.1%. From 63.6% to 17.1% with a recovery of 93.5% of the organic materials. A residual product of fine sand of crushed glass/stones of 99.4% purity recovered 71.3% of these.

1. Introduction

Complying with the EC Directive (2000/53/EC) that end-of-life vehicle (ELV) recycling operations achieve 85% recycling and 95% recovery rate with a maximum of 10% being energy recovery represents a serious challenge to this industry. There is significant variation in reported or forecasted amounts of automobile shredder residue (ASR) production in the EC as they are based on calculated estimations, and can differ significantly. According to a study by Nourreddine (2007), 2 Mt/y of ASR was produced in the EU. However, Johnson and Wang (2002) estimated that 3 Mt of ASR were produced in Europe. Other sources, such as the European Environmental Agency Baseline (1999) projection of selected waste streams showed that the amount of vehicles sent to shredder plants in the 12 state members increased a 34% from 1995 until 2010, being about 14 Mt in 2010. Eurostat (2014a) estimated for its 27 state members that 85% of 8.37 Mt were recycled or reused in 2009. It also estimates that recycling or reuse increased to 89% in 2012 but that total ELV waste had dropped to 5.57 Mt. Since most shredder plants also process other wastes such as white goods, the total amounts of shredder residues (SR) ending up in landfills as ASR may be significantly greater. With the recovery of approximately 75 wt.% of ELVs presently recovered as metals, for the EC Directive to be met an additional minimum of about 10% to be recycled and another 10% recovered. This requirement implies that significant quantities of ASR are to be processed.

The heterogeneous composition, high chorine and heavy metals content as well as the presence of persistent organic pollutants (POPs) such as polychlorinated biphenyls, dioxins, bromated flame retardants, etcetera significantly complicates the reuse and recovery of ASR. Comprehensive descriptions of typical ELV processing and reviews of options for treatment of ASR are presented by Buekens and Zhou (2014) and Vermeulen et al. (2011). They indicate a number of processing options for upgrading ASR products but that the very heterogeneous content of ASR limits options for mechanical recovery while the presence of POPs, chlorine and bromine compounds as well as high ash and heavy metals contents complicate reuse and recovery processes and in some instances requires substantial dilution of ASR with other residues

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so as to comply with environmental emissions specifications. Investigations into the use of ASR in low value products such as aggregates (Rossetti et al., 2006) and building material (Perá et al., 2004 and Siddique et al., 2008) met with significant limitations in quality of products and treatments required.

Reutera et al. (2006) erroneously claimed that due to technological limitations in separation and production efficiencies, the EC Directive could be totally unattainable. The authors failed to realize that although a given economically viable recycling process may not attain total recovery or purity, the impurities in the product obtained are included in the amount classified as recycled or reused. With EC recycling and reuse rates for some EC countries surpassing the EC Directive requirements (Eurostat, 2014b), there is reason to anticipate that all EC countries will attain this objective. As argued by Miller et al. (2014), economic viability and sound markets for recycled materials is and must remain a corner stone to ELV recycling.

Options for the recycling of those materials are varied, but all have disadvantages which may make them less than optimal. Recycling processes recommended in the literature are generally limited to energy sources (thermal-electric, blast furnace, cement kilns…), as a hydrocarbon sources (pyrolysis, hydrogenation, gasification and thermal cracking), or as raw material for the same or other applications based on recycling by specific dissolution, optical/infrared/thermal infrared sorting, thermo-mechanical sorting, blending, density separation, conductivity and triboelectric separation, skin-flotation, differential fragmentation, hydrometallurgical extraction, etcetera. All the energy or hydrocarbon recovery methods have pros and cons but the metals and ash or minerals content are usually indicated as major contaminants (Vermeulen et al., 2011; Jody and Daniels, 2006 and Miller et al., 2014). The recovery of distinct types of plastics from ASR requires a complex treatment due to the large variety of plastics present in vehicles, and each one of them may have a number of variations in filler contents, additives, and colorants. Furthermore, many plastics cannot be mixed due to chemical incompatibilities and a large proportion of the recoverable components are contaminated with metal chips, screws, labels and foams, all of which should be removed before reusing.

Investigations for recycling ASR tend to document the elemental and material composition by particle size of ASR. Analysis of elemental compositions may be of value for documenting potential contaminants when reusing ASR as a source of energy or hydrocarbons but for investigations for the separation of specific types of plastics, provide little information. The very heterogeneous material composition of ASR and variety of fillers used in plastics, all of which are in continuous change and the evolution of vehicle manufacturing technology complicates defining any definitive conclusion as to a specific ASR recycling process.

If the EC Directive is to be met at realistic and admissible costs, it is suggested that: optimization be made of the actual process of production of ASR. Since light fluff ASR (lf-ASR) and heavy fluff ASR (hf-ASR) product fractions have sufficient chemical and physical differences they should be processed separately for recycling or recovery of materials. Although some finer particle size ranges may be difficult to characterize, their abundance and tendency to consist of particles composed of liberated materials should facilitate their separation.

ASR is composed primarily of plastics, rubber, foamed plastics, paper, textiles, glass, soil/sand, wires, wood and residual metals Morselli et al. (2010). Ambrose et al. (2000) reported that the material composition by mass of shredder waste in the UK consisted of- plastics (9.4–16.8%), metals (1.7–13.2%), polyurethane foam (2.6–5.8%), wood/paper/cardboard (2.8–5.5%), rubber (0.8–5.3%) and wire (0.6–6.3%). Smaller quantities of other materials such as glass, stones, textiles and fibers make up 50% by mass of the samples. Buekens and Zhou (2014) have shown that of ASR produced, 10–24% of ELV is light fluff, 2–8% heavy fluff, <2.5% fine soil and sand, They indicate that ASR is composed of 2–23% metals, 20–49% plastics, 3–38% rubber, 4–45% textile and fiber materials, 2–5% wood and 2–18% glass. They also observe that only 2% of ASR is >10 cm and is composed of foam, rubber and plastics.

Investigations documenting the distinct compositions of lf-ASR and hf-ASR are limited to those of Buekens and Zhou (2014), de Marco et al. (2002), Hjelmar et al. (2009), Kim et al. (2004), Lin et al. (2010), OVAM (2008) and Vermeulen et al. (2011). Their studies show variations between ELV plant operations and the materials being treated in these plants can result in substantial differences in the characteristics of the ASR fractions produced. The metals recovery process from ELVs requires that the vehicles be shredded into particle sizes where mechanical processes effectively separate metals present from other materials present. Shredder mills vary in capacity, grating which limits maximum particle size produced, hammer wear and air evacuation of the shredder chamber. Four product streams are produced by this shredding process:

1. Air evacuated from the shredder chamber passes through a cyclone which separates out fine sands and dusts that constitute <2.5% of the ASR. This fraction is frequently combined with material forming the fourth ASR product stream which is recovered in an air scrubber.
2. After shredding the particles pass through a zone of aspiration that extracts lf-ASR particles. These have large surface areas and/or low densities. They are classified in a cyclone where their resistance to air flow is less than the force of gravity. This lf-ASR fraction tends to constitute about 75 wt.% of ASR. The amount and composition of this fraction can vary significantly with the diameter and pressure drop in the classifier cyclone.
3. Material not extracted by the aspiration of lf-SR contains the vast proportion of metals recovered from ELVs. The fhf-ASR residue remaining after recovery of metals present constitutes about 25 wt.% of ASR generated.
4. Limitation of dust and gas emissions of the shredder and air classification processes usually requires that the air from the shredder chamber evacuation cyclone and cyclone classifier pass through an emissions control device which usually consists of a scrubber. This generates an oily slurry with dust, fine sand and fine fibers which constitutes $\ll$0.1% of ASR.

Morselli et al. (2010) has reported that of the ASR investigated the particle size distribution was 2% < 100 mm, 14% 50–100 mm and 39% 20–50 mm and the <20 mm fraction constituted 45% but suggests that this finest fraction was not considered for recycling due to complexity of its composition. No mineral/glass was reported in any of the fractions >20 mm and metal content increased from 1% in the 20–50 mm fraction to 4% in the 50–100 mm fraction. Cossu et al. (2014) has compiled data from publications on the metals content of ASR and the material composition of the >20 mm ASR from various Italian shredder plants. They report that the <20 mm ASR fraction constitutes up to 70 wt.% with a mean of about 35% and it is composed of glass, plastics and metals. Ahmed et al. (2014) have documented the variations in particle sizes, material calorific values and elemental composition of Danish ASR from 2000 to 2010. Their study sorted >10 mm particles by type of material but the results do indicate a substantial chronological variation in composition of SR of ELVs and white goods. Of particular note are the variations in shredder residue compositions for metals (7–35%) and plastics (plastics/rubber/foam) (36–69%). Bareel et al. (2006) have investigated a <2 mm shredder waste from ELVs and waste electrical and electronic