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Characterization of Shredder Residues generated and deposited in Denmark

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ABSTRACT

This study presents a detailed characterization of Shredder residues (SR) generated and deposited in Denmark from 1990 to 2010. It represents approximately 85% of total Danish SR. A comprehensive sampling, size fractionation and chemical analysis was carried out on entire samples as well as on each individual size fraction. All significant elemental contents except oxygen were analyzed. The unexplained "balance" was subsequently explained by oxygen content in metal oxides, carbonates, sulphates and in organics, mainly cellulose. Using mass and calorific balance approaches, it was possible to balance the composition and, thereby, estimate the degree of oxidation of elements including metals. This revealed that larger fractions (>10 mm, 10–4 mm, 4–1 mm) contain significant amount of valuable free metals for recovery. The fractionation revealed that the >10 mm coarse fraction was the largest amount of SR being 35–40% (w/w) with a metal content constituting about 4–9% of the total SR by weight and the <1 mm fine fraction constituted 27–37% (w/w) of the total weight. The lower heat value (LHV) of SR samples over different time periods (1990–2010) was between 7 and 17 MJ/kg, declining with decreasing particle size. The SR composition is greatly dependent on the applied shredding and post shredding processes at the shredding plants causing some variations. There are uncertainties related to sampling and preparation of samples for analyses due to its heterogeneous nature and uncertainties in the chemical analyses results (≈15–25%). This exhaustive characterization is believed to constitute hitherto the best data platform for assessing potential value and feasibility of further resource recovery from SR.

1. Introduction

The European Union (EU) Directive 2000/53/EC on End-of-life vehicles (ELVs) lays down specific requirements for the management of waste arising from ELVs and addresses the problems created by it. 10 million ton of ELV waste was disposed in 2005 within the EU with a projected increase to 14 million ton by 2015. The ELV Directive aims to reduce the amount of hazardous waste, increase re-use, recycling and other forms of materials' recovery from ELVs and improve the environmental performance of ELV waste management. By 1st January 2015, EU member states have to meet the set targets of 95% for re-use and recovery of ELVs and at least 85% recycling and re-use (EU Directive, 2000, GHK-BioIS, 2006; Vermeulen et al., 2011). Authorized shredding companies recover ferrous and non-ferrous metals after collecting, dismantling and shredding ELVs and also other discarded metal containing products – including white goods which make a small fraction of the shredder feed material (Isager, 2009 and Skibdal, 2009). Shredder residues (SR) are the leftover waste material after recovery of dismantled parts and main metals (Boughton and Horvath, 2006; Forton et al., 2006). SR from automobiles alone are also known as "auto shredder residues" (ASR), auto shredder fluff, shredder light fraction, residues from shredding, auto fluff or fluff. ASR comprises approximately 50% by weight of the total SR stream (assumingly at European level) (GHK-BioIS, 2006). SR from white goods contains more copper than ELVs, lesser or no fractions such as textiles, foam/fluff and may contain PCBs which ASR does not (Hjellnes Consult, 2008 and Nielsen et al., 2006). One of the largest Danish shredding companies, H.J. Hansen Genvindingsindusri A/S, states that ELVs constitutes 10–20% of the input to the shredding process (Isager, 2009).

Yearly, 2 million ton of SR are generated in the EU countries (Kanari et al., 2003 and Nourredine, 2007). In 2008, approximately 0.25 million ton of SR were generated in Denmark. SR is classified as hazardous waste in Denmark and more than 1.5 million ton have been landfilled in Denmark at three large landfill sites since 1990 as hazardous waste until now was exempted from landfill

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tax. However, this legislation is under revision and landfill tax on hazardous materials to be landfilled will be implemented over the next five years. SR hence constitutes a major European and national waste stream that should be managed in a safe and environmentally sound manner (NMR Report, 2011 and Danish EPA Report, 2012).

SR still contains metals that can be recycled, organic materials that can be exploited for energy recovery and recovery of plastic fractions, and a residual fraction which may be used in the form of soil and gravel. The Danish waste strategy for the period of 2009–2012 has focused on understanding the resource potential and subsequent recovery of resources from SR in an efficient manner taking into account the environment and economics (Danish EPA Report, 2004). The amount of metals and increasing market prices, the presence of scarce elements, high calorific value materials, limited landfill space and changes in legislations are some of the driving forces for recovering the resources from SR generated and deposited. Due to these reasons, a feasibility assessment of resource recovery from SR was undertaken in order to develop a method to assist industry and society in selecting the appropriate management and utilization of resources contained in it. The identified stakeholders are the shredding companies, landfill sites and policy makers whose role and interests in the decision making process will be discussed.

In order to judge the feasibility of recovering the resources from SR and to select recovery technologies, knowledge of its composition is necessary. The composition and properties of SR varies a lot due to a number of different factors – e.g. heterogeneity of shredder feed material, different shredding companies with differences in the shredding process and post-shredder materials recovery technologies and their effectiveness; all together making it difficult to quantify and generalize on the composition of the SR waste stream (Ambrose et al., 2000 and Morselli et al., 2010). Several studies have been undertaken for characterizing and identifying the management options for SR. Many of them are delimited to describing the composition of ASR only; others were carried out on specific point sources such as samples collected from one shredding company or one landfill site only. This has led to a huge disparity found among the reported data on the composition of SR (Vermeulen et al., 2011; Nielsen et al., 2006; Zevenhoven and Saeed, 2003; Jody and Daniels, 2006; Force Technology Report, 2011 and Cramer et al., 2006). A comparison has been presented in the Appendices highlighting the different composition and characteristics of ASR/SR from other studies referred to in the literature review and the total composition of the entire samples analyzed here. The referenced studies included in this comparison do highlight the calorific value of the waste and include substances that would cause potential environmental impacts (Mancini et al., 2010; Hjelmar et al., 2009; Saxena et al., 1995; Gendebien et al., 2003; Day et al., 1999; Zolezzi et al., 2004; Vigano et al., 2010 and Osada et al., 2008). However, none of the referenced studies have had the aim of a full characterization of the resource potential in the SR. The present study, thus, distinguishes itself by providing full mass and calorific balances. No other study in found in literature comprised of all the essential metals and other elements and allowed, thereby, for justifying the composition and revealing e.g. the state and oxidation degree of metals. The composition of SR in this study may be significantly influenced by the shredding process and post-shredder material recovery at the shredding companies before SR was landfilled. The main aim of this study was to carry out representative sampling and analyses of SR as it is generated today and SR already landfilled in order to present a detailed characterization of this entire waste stream in Denmark. The results from this study will constitute an exhaustive data platform for determining the resource potential of the waste and assist in evaluating the feasibility of recovering resources contained in SR.

2. Methods

From the literature review conducted, it was observed that SR was very heterogeneous in composition. Therefore, in order to carry out a comprehensive characterization of SR in Denmark, samples were collected from the three largest landfill sites receiving SR from three different shredding companies. The SR deposited in these sites represented approximately 85% of the total SR generated and deposited in Denmark. After conducting site visits and based on historical information on where and how SR was deposited, sampling plans were made for each of the respective sites in accordance with the European standard EN 14899:2005 (standard for Characterization of waste – sampling of waste materials – framework for the preparation and application of a sampling plan). The detailed information on the each of the sites and the respective sampling carried out is given in the Appendices.

2.1. Sampling from landfill sites

Two main types of sampling procedures were used – for SR already landfilled (deposited before 2009), samples were collected from different depths (between 1 and 8 m depths) at the landfill sites using an excavator and for SR received at the landfill sites (in the period of 2009–2010), monthly samples were collected which were later combined to get one composite sample. Fig. 1 illustrates the process flow followed from the sampling step to the preparation of samples for chemical analysis. It also provides an overview of the samples collected and the period of time they present.

2.2. Pretreatment of samples

As shown in Fig. 1, the samples (approximately 100 kg each) brought to the laboratory were further sub-divided at least three times using the long pile principle into individual laboratory samples of approximately 10–20 kg each to be used subsequently for further composition analyses. The long pile principle also termed the long pile-alternate shovel method is a method where the sample is laid out in a long pile, this pile is then separated into two equal piles by using a shovel and placing alternate shovel loads to either side to form two new long piles. Then one pile is randomly selected and the process is continued to reduce the sample size (EU Technical Report, 2004). Each of the 10–20 kg laboratory samples were initially dried at 40 °C for 24 h. The samples were dried only till the moisture content was low enough to allow for size fractionation. The samples were fractionated based on particle size by sieving into four size fractions –>10 mm, 10–4 mm, 4–1 mm and <1 mm. The largest size fraction of >10 mm size was then manually sorted into 12 different material fractions – metals, plastics, rubber, foam/fluff, wires, electronics, wood, textile, paper/cardboard, glass/ceramics, stones and miscellaneous/mix. Fig. 2 gives an overview of the pretreated samples.

2.3. Preparation of samples for physical and chemical analysis

The metals that were sorted from the >10 mm fraction were not included in the samples prepared for the chemical analysis. For each sample, the four different size fractions were then shredded, cut and crushed down to a particle size less than 4 mm. The shredded fractions were split using a riffle splitter. Using these split fractions, four samples for chemical analysis representing the four different size fractions were prepared along with a sample termed as "entire sample" consisting of all the size fractions for each of the samples as shown in Fig. 1. Approximately 2 kg each of these were further size reduced to <1 mm by using a hammer mill. These