Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Physico-chemical characterisation of material fractions in residual and source-segregated household waste in Denmark

R. Götze *, K. Pivnenko, A. Boldrin, C. Scheutz, T. Fruergaard Astrup

Technical University of Denmark, Department of Environmental Engineering, Miljoevej, Building 113, 2800 Kongens Lyngby, Denmark

ARTICLE INFO

Article history:
Received 15 February 2016
Revised 25 April 2016
Accepted 10 May 2016
Available online xxxx

Keywords:
Municipal solid waste (MSW)
Chemical composition
Recycling
Rare earth elements (REE)

ABSTRACT

Physico-chemical waste composition data are paramount for the assessment and planning of waste management systems. However, the applicability of data is limited by the regional, temporal and technical scope of waste characterisation studies. As Danish and European legislation aims for higher recycling rates evaluation of source-segregation and recycling chains gain importance. This paper provides a consistent up-to-date dataset for 74 physico-chemical parameters in 49 material fractions from residual and 24 material fractions from source-segregated Danish household waste. Significant differences in the physico-chemical properties of residual and source-segregated waste fractions were found for many parameters related to organic matter, but also for elements of environmental concern. Considerable differences in potentially toxic metal concentrations between the individual recyclable fractions within one material type were observed. This indicates that careful planning and performance evaluation of recycling schemes are important to ensure a high quality of collected recyclables. Rare earth elements (REE) were quantified in all waste fractions analysed, with the highest concentrations of REE found in fractions with high content of mineral raw materials, soil materials and dust. The observed REE concentrations represent the background concentration level in non-hazardous waste materials that may serve as a reference point for future investigations related to hazardous waste management. The detailed dataset provided here can be used for assessments of waste management solutions in Denmark and for the evaluation of the quality of recyclable materials in waste.

1. Introduction

Physico-chemical waste composition data are paramount for (i) quantifying substance flows of valuable and harmful components in the solid waste management sector, (ii) for assessing the quality of waste materials and recyclables, and (iii) for modelling emissions from waste treatment based on the composition of the incoming waste. For these purposes decision-support tools such as material flow analysis (MFA), substance flow analysis (SFA) and life cycle assessment (LCA) can be used. The fractional and physico-chemical waste composition has been shown to significantly affect the result of waste systems LCAs (Slagstad and Brattebø, 2013; Turconi et al., 2011). State-of-the-art environmental assessment of waste management systems should therefore comprise the tracking of material and substance flows in the modelled systems, a careful selection of waste composition data and an analysis of related uncertainties (Arena and Di Gregorio, 2014; Clavreul et al., 2012; Laurent et al., 2014). Thus, informed decisions on waste management strategies, e.g. the design of collection schemes or introduction of new treatment technologies, require reliable chemical waste composition data.

Several publications provide information on the physico-chemical composition of household waste material fractions (Gidarakos et al., 2006; Kost, 2001; Maystre and Viret, 1995; Riber et al., 2009; Rotter, 2002; Zhou et al., 2014). The physico-chemical properties of household waste are closely interlinked to the fractional waste composition, which is influenced by many varying aspects such as seasonal variation, regional customs and consumer behaviour, local waste collection schemes and their change with time (Boldrin and Christensen, 2010; Dahlén and Lagerkvist, 2008; Matsuto and Ham, 1990; Noehammer and Byer, 1997). But also the sampling point, the sorting of waste fractions, as well as mechanical sample preparation and analytical methods can affect the physico-chemical results (Brunner and Ernst, 1986; la Cour Jansen et al., 2004; Riber et al., 2009; Skutan and Aschenbrenner, 2012). As a consequence, the applicability of waste characterisation data is often limited by the regional, temporal and technical scope of the respective waste characterisation studies.

Physico-chemical waste composition data for Danish household waste materials can be found in Andersen et al. (2011), Boldrin and Christensen (2010), Fjelsted and Christensen (2007), Hansen et al.

---

* Corresponding author.
E-mail address: rmog@env.dtu.dk (R. Götze).

http://dx.doi.org/10.1016/j.wasman.2016.05.009
0956-053X/© 2016 Elsevier Ltd. All rights reserved.

Please cite this article in press as: Götze, R., et al. Physico-chemical characterisation of material fractions in residual and source-segregated household waste in Denmark. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.05.009

(2003), and Riber et al. (2009). The largest dataset is provided by Riber et al. (2009), who investigated 26 parameters in 47 waste material fractions in mixed household waste. For many years waste incineration with energy recovery has been the cardinal waste treatment technology for Danish household waste, but this is about to change as recent European legislation requires Denmark and all other EU member states to implement source-segregation schemes for the collection of recyclables in order to increase waste recycling rates (EU, 2008; The Danish Government, 2013). To ensure that source-segregation and recycling schemes do not shift environmental burdens to other parts of the waste management system, modelling and assessment of environmental impacts is becoming increasingly important. The definition of the waste material fractions in Riber et al. (2009) primarily reflected research questions focusing on waste incineration and energy recovery, which limits the applicability of these data in a recycling context. Thus data are needed for recyclable fractions distinguished by properties related to automated sorting and recycling processes (e.g. metals by ferrous and non-ferrous metals, and plastics by polymer resin).

The quality of waste materials may significantly affect recycling efficiencies, i.e. levels of the presence of contaminants and impurities may limit recyclability and substitution of virgin raw materials. When waste materials are collected mixed together, solid particles, moisture and dissolved substances can migrate from one waste material to another. This effect has been discussed in a waste management context as “cross-contamination” (Baeyens et al., 2010a; Edjabou et al., 2015; Miranda et al., 2013). Physico-chemical composition data for waste material fractions sampled from mixed waste collection may thus not appropriately represent the physico-chemical properties of the respective source-segregated materials. So far only organic waste materials from separate collection have been subject to physico-chemical characterisation in Denmark (Boldrin and Christensen, 2010; Hansen et al., 2003). Therefore, physico-chemical composition data for other source-segregated recyclables are needed.

The overall aim of this study is to provide a consistent dataset for the composition of individual material fractions in Danish household waste covering a wide range of physico-chemical properties, which can be used for future modelling and assessment of waste management systems and recycling chains. Based on waste samples from both residual and source-segregated household waste collected in the same area, the evaluation of the results of the physico-chemical characterisation focused on the following aspects: (i) physico-chemical differences between subfractions within the same material type, especially for potentially recyclable materials; (ii) potential differences between residual and source-segregated waste fractions, e.g. due to cross-contamination of materials. Based on this, conclusions on necessary levels of disaggregation of waste material fractioning are provided, to support the planning of future waste characterisation studies with similar purposes.

2. Material and methods

2.1. Collection area and sorting procedure

All household waste samples, were collected in 2013 as part of a waste sorting campaign in Aabenraa, Denmark. The full-service waste collection scheme in place included a residual waste bin and a two-compartment bin for the source-segregation of recyclables. One compartment was designated for the collection of paper, cardboard and plastic foil, and the other compartment for packaging and non-packaging items made of metal and rigid plastics, and glass packaging. Hazardous waste, bulky waste and large amounts of garden waste were excluded from the full service collection and instead delivered to central collection facilities by the residents. Additionally, the national refund system for beverage containers (made of glass, plastic and metal) was in place. Detailed information on stratification areas, sorting procedure and the resulting fractional composition of the waste are provided in Edjabou et al. (2015). Although the initially collected waste samples were derived from both multi and single-family housing areas, the waste from single-family housing areas was selected for further physico-chemical characterisation. The analysed samples were obtained from 1.5 tonnes of residual waste and 0.9 tonnes of source-segregated waste, which was generated and disposed of by 100 households within a period of two weeks in spring 2013. The waste for the sorting campaign was collected without compacting, and sorted into and temporarily stored in paper sacks. As described by Edjabou et al. (2015), the hand-sorting procedure followed a tiered approach; the entire amount of collected waste was first hand-sorted into 10 defined macro fractions followed by subsequent sorting into 37 material fractions (see level I and II in Edjabou et al., 2015) and finally into 50 material fractions (see Table 1 and more details in Appendix B). The same procedure was applied to the collected waste from source-segregation. Batteries, waste electronics and hazardous waste fractions were excluded from the physico-chemical analysis due to the small amounts found in the investigated household waste, which was not suitable to represent the extensive variety of products matching these fractions. Table 1 provides an overview of the material fractions investigated; in total 49 material fractions from residual and 26 material fractions from source-segregated household waste were obtained. A more detailed description of sorted fractions is available in Appendix B.

2.2. Mass and particle size-reduction

Following the sorting, the material fractions from residual and source-segregated household waste were prepared for physico-chemical characterisation (see an overview in Fig. 1). To homogenize the sorted material fractions each fraction was passed at least two times through a shredder (ARP SC2000, Brovst, Denmark) reducing the particle size and mixing the fractions’ components. The maximum amount of material processed in the shredder was about 40 kg. As the amounts of vegetable and animal derived food waste, and human hygiene waste were larger than 40 kg, mass-reduction prior to the shredding was necessary for these fractions, which was performed by selecting only some of the paper sacks the material fractions were sorted into. For all other fractions the entire amount was shredded. Each fraction was processed separately and between the processing of different fractions the shredder was cleaned with water and compressed air. For further mass-reduction of the samples after the shredding, the shredded material was spread on a plastic foil on the ground and arranged in an elongated flat pile simulating a one-dimensional lot. Splitting elongated flat piles has been reported to decrease sampling errors relative to other mass reduction techniques such as coning and quartering (Dahlén and Lagerkvist, 2008; Gy, 1998; Lagerkvist et al., 2011; Petersen et al., 2004), and has been previously applied for the sampling of waste materials by Boldrin and Christensen (2010). The flat pile was split into equally sized increments by means of a large plastic box and a shovel, and every second increment was discarded, so that the sample mass was reduced by half. This procedure was repeated until a mass of approximately 0.5–1.5 kg of wet material was obtained. Degradable fractions with high moisture content; i.e. food and gardening waste fractions, and tissue paper from residual waste were first processed and then temporarily stored at −18 °C until drying them for 72 h at 60 °C. All other shredded material fractions were temporarily stored in paper

Please cite this article in press as: Götze, R., et al. Physico-chemical characterisation of material fractions in residual and source-segregated household waste in Denmark. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.05.009