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Elemental balance of SRF production process: Solid recovered fuel produced from commercial and industrial waste

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HIGHLIGHTS

- Concentration of inorganic elements in waste components is examined.
- Concentration of inorganic elements in streams of SRF production process is examined.
- Sources of pollutant and potentially toxic elements in input waste are identified.
- Elemental balance of commercial scale SRF production process is established.
- Parameters affected the quality of SRF and yield of SRF process are highlighted.

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ABSTRACT

In order to study the mass flow of pollutant and potentially toxic elements (PTEs) in the output streams of solid recovered fuel (SRF) production process, the various streams produced in commercial scale SRF production process are characterized chemically and, the elemental balance of SRF production process is presented. The SRF is produced from commercial and industrial waste (C&IW) through mechanical treatment (MT). The elements investigated for their mass balance in SRF production process are chlorine (Cl), arsenic (As), cadmium (Cd), lead (Pb) and mercury (Hg). The results showed that of the total input chlorine 60% was found in the SRF stream and 35% in the reject material stream and rest of 5% was in fine fraction and heavy fraction streams. Of the total input arsenic content 42% was found in the reject material and 32% in the SRF stream and rest (i.e. 26%) was found in the fine fraction stream. In case of cadmium, lead and mercury of their total input content to the process 46%, 58% and 45% respectively was found in the SRF stream. Among the waste components of C&IW, rubber and plastic (hard) were measured to contain the highest content of chlorine i.e. 8.0 wt.% (dry basis) and 3.0 wt.% (dry basis) respectively. Rubber was also found to contain higher content of cadmium as compared to other waste components. Plastic (hard) was measured to contain higher content of lead (i.e. 400 mg/kg, dry basis) than other components of input waste stream. The distribution of waste components (mainly plastic (hard), rubber and to some extent textile) was found significantly more important than other components of input waste stream in defining the concentration of pollutant and potentially toxic elements in output streams of SRF production process.

1. Introduction

Production and use of solid recovered fuel (SRF) represent a sustainable alternative for waste material that cannot be used for recycling due to economic inefficiency [1,2]. To recover value from the non-sustainably recyclable waste fraction, SRF can be a practical and environmentally safe outlet [3]. Use of SRF is significantly beneficial in terms of its utilization as an alternative energy source and a potential incorporation of the biogenic content of initial waste stream which is carbon dioxide (CO_2) – neutral [4,5]. To save primary fuels energy intensive industries are looking for alternative fuels, which encourage the sustainable development [6–10].

Use of SRF as fuel in coal fired power plants, cement and lime producing industries requires high quality standards in order to replace fossil fuels and so as not to cause operative and technical problems. The reliable quality standards in terms of fuel characteristics (chemical and physical) are one of the quality criteria that have to be ful-

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filled by SRF [1]. Thus, SRF is subject to stringent quality standards. In 2003, CEN (European Committee for Standardization) TC 343 was established to develop standards and technical specifications for solid recovered fuels for European markets. European standards for SRF have been established, the standardisation process took some ten years in which a lot of information on SRF has been generated [11–13]. The classes and specifications of SRF have been described and evaluated based on various parameters (such as net calorific value, chlorine content and mercury content) in CEN standards for SRF [6,14]. Technical prospects for the production and use of SRF have improved due to decades of profound experiences in cement and power plant industries. The production and use of SRF is an area where 'science meets practice' [15].

By the early 1990s, an initial disaster cycle for refuse-derived fuels (RDF) was effectively closed and the term ended up denoting a low-quality fuel or absence of quality checks [3]. RDFs could not create sufficient demand because of the high concentrations of chlorine and heavy metals in it. The non-homogeneous distribution of elements like chlorine, cadmium and mercury in waste components leads to varying fuel qualities [16,17]. As chloride salts they have significant influence on corrosiveness of deposits on the superheater tubes. From an emission perspective, SRFs can be considered "clean" fuels, if their content of heavy metals is below certain levels. Therefore, as a general rule heavy metals concentrations need to be kept as low as possible [18]. Zinc, lead and tin lower the melting temperature of deposits on the superheater tubes amplifying corrosion [19]. Trace elements that can be volatized in the combustion processes, with insufficient additional flue gas cleaning they can be released as gaseous emissions. Trace and major elements affect the composition of ash [20].

Commercial and industrial waste (C&IW) [21] possesses a significant potential in terms of energy fuel to be utilized for energy recovery [22]. C&IW contains a very high mass fraction of combustibles (such as paper and cardboard, plastic and textile) along with considerable mass fraction of impurities (such as PVC plastic, highly chlorinated rubber material and inert material). In the previous research [21] most of the combustibles in C&IW were recovered in the form of SRF by sorting out the impurities in separate small streams.

Input waste material and production technology affect significantly the quality of SRF [23,24]. The phenomenon of peak concentration in fuel product is reduced by mechanical processing of waste material. However, variability in fuel properties is unavoidable [25]. Based on the unit operations/sorting techniques used in an SRF production plant, various streams of material are produced in the process. Highly pollutant and low quality waste components are concentrated separately in small streams to produce relatively less polluted and quality controlled stream of fuel product [16,21,26]. Proper sorting of input waste stream's components into output streams ensures high quality of SRF stream. Chemical characteristics of output streams of refuse derived fuel (RDF) production processes are evaluated in a previous research [16]. There are only very few published studies [16,27–29] which cared about chemical characteristics and elemental material flow in output streams of SRF/RDF production processes.

The objective of this paper is to study the mass flow of pollutant and potentially toxic elements into various output streams of SRF production process produced from commercial and industrial waste (C&IW). This research examined in detail, the concentration of inorganic elements in various streams and components produced in commercial scale SRF production process produced from C&IW. Based on the elemental analysis of process streams, the elemental balance of SRF production process is established by using material flow analysis (MFA) approach. In this paper also, source components of pollutant and potentially toxic elements are identified based on the elemental analysis of components of input waste stream (i.e. C&IW).

2. Materials and methods

A commercial scale experimental campaign was conducted to produce SRF from C&IW. A batch of 79 tonnes of C&IW was collected from the metropolitan area of Helsinki region was treated on MT waste sorting plant to produce SRF. Based on the unit operations and sorting techniques used in MT plant, input waste material was further divided into various output streams of material; SRF, ferrous metal, non-ferrous metal, fine fraction, heavy fraction and reject material. All the process streams were sampled and treated according to CEN standard methods for SRF: EN15442 [30]. As per EN 15442, sampling of streams from SRF production plant was performed by using static lot method and manual drop flow method. Sample preparation of process streams for their laboratory analysis was performed as per CEN standard methods for SRF: EN 15443 [31]. As per EN 15443, methods of particle size reduction and sample division (mass reduction) were applied at every stage of sample preparation of streams for laboratory analysis. Standard analysis methods used for the elemental analysis of waste components and process streams in laboratory were; SFS-EN ISO 10304-1:2009 (mod.) for halogens, SFS-EN ISO 11885:2009 (mod.) for major elements/heavy metals and SFS-EN ISO 17294-2:2005 (mod.) for minor/trace elements. Laboratory analysis of major elements, minor elements and halogen was based on elementary analysis inductively coupled plasma optical emission spectrometry (ICP-OES), inductively coupled plasma mass spectrometry (ICP-MS) and liquid chromatography of anions and ion chromatography methods respectively. Details about description of SRF production process (unit operations/sorting techniques), sampling of process streams from SRF production plant and their sample preparation for laboratory analysis are published in a previous study [21].

Here, the elemental balance of SRF production process are based on the elemental analysis of various streams produced in this process and are calculated by using material flow analysis (MFA) method. MFA is a systemic assessment of material flows within a system defined in space and time. In waste treatment processes, whereabouts of hazardous chemicals can be determined only by an exact accounting of all substance flows [16]. The methodology on MFA is published [32,33].

The configuration of SRF production plant (in terms of unit operations used) and their arrangement in the process have profound implications on the outcome of the process. Unit operations/sorting techniques used in the SRF production process were primary shredding, screening (jigging and drum screens), metal separation (magnetic/eddy current separators), air classifiers, near-infra red (NIR) sorting units and secondary shredding. Input waste stream (i.e. C&IW) passed through series of these unit operations in which components were sorted out into various output streams based on material properties e.g. particle size (screening), density/weight (air classifier), magnetic properties (magnetic separation) and IR-spectra (NIR sorting). Detailed description of unit operations used in SRF production process and their functions is presented in a previous study [21].

Concentration of thirty elements in various process streams (input and output) was measured in laboratory (see Table 2). The elements investigated for their balance in SRF production process were; chlorine (Cl), arsenic (As), cadmium (Cd), lead (Pb) and mercury (Hg). These are potentially toxic elements which could be found in fuel product. It is reported [16] that in the RDF production test runs chlorine, lead and cadmium have been often found concentrated in fuel product. The SRF production process evaluated in order to establish elemental balance by using MFA is shown in Fig. 1. In the given MT process, incoming waste material stream i.e. C&IW is subjected to mechanical separation to produce SRF. This process only does the mechanical separation of the incoming