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Elemental balance of SRF production process: solid recovered fuel produced from municipal solid waste

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Abstract

In the production of solid recovered fuel (SRF), certain waste components have excessive influence on the quality of product. The proportion of rubber, plastic (hard) and certain textiles was found to be critical as to the elemental quality of SRF. The mass flow of rubber, plastic (hard) and textiles (to certain extent, especially synthetic textile) components from input waste stream into the output streams of SRF production was found to play the decisive role in defining the elemental quality of SRF. This paper presents the mass flow of polluting and potentially toxic elements (PTEs) in SRF production. The SRF was produced from municipal solid waste (MSW) through mechanical treatment (MT). The results showed that of the total input chlorine content to process, 55% was found in the SRF and 30% in reject material. Of the total input arsenic content, 30% was found in the SRF and 45% in fine fraction. In case of cadmium, lead and mercury, of their total input content to the process, 62%, 38% and 30%, respectively, was found in the SRF. Among the components of MSW, rubber material was identified as potential source of chlorine, containing 8.0 wt.% of chlorine. Plastic (hard) and textile components contained 1.6 and 1.1. wt.% of chlorine, respectively. Plastic (hard) contained higher lead and cadmium content compared with other waste components, i.e. 500 mg kg^{-1} and 9.0 mg kg^{-1}, respectively.

Keywords

Solid recovered fuel, municipal solid waste, household energy waste, elemental balance, polluting and potentially toxic elements

Introduction

Solid recovered fuel (SRF) can be a practical and environmentally safe outlet for recovering value from the non-sustainably recyclable waste fraction (Velis and Copper, 2013), substituting fossil fuels (Beckmann et al., 2012; Thiel, 2007; Weber and Gehrmann, 2007). In comparison with pure disposal, the use of waste-derived material for recycling and energy recovery is a preferable waste management option in terms of climate change impact (Dehoust et al., 2010; Friege and Giegrich, 2008). In a new virtuous cycle, the potential of recovered fuels prepared form solid waste materials enforces us to consider their position in the emerging landscape of resource efficiency (Velis and Copper, 2013).

SRF is prepared from non-hazardous waste to be utilized for energy recovery in incineration/co-incineration plants and meeting the classification and specifications requirements laid down in European Committee for Standardisation (CEN) standards (EN 15359). SRF is a product of mechanical treatment (MT) or mechanical biological treatment (MBT) plants processing unrecyclable waste. Mechanical processing concentrates suitable waste components into a prepared combustible fraction stream of SRF, and separates out recyclables (metals), polluted (reject material and fine fraction streams containing comparatively higher concentration of polluting elements and PTEs than other output streams) and non-combustible waste components (inert such as stone/building material and glass etc.) into separate small streams (Nasrullah et al., 2014a, 2014b, 2015a). Quality and yield of SRF is affected by the type of input waste material and production technology (Nasrullah et al., 2013; Wilén et al., 2002). In Finland, SRF is currently produced from various types of waste streams such as commercial and industrial waste (C&IW), construction and demolition waste (C&DW) and municipal solid waste (MSW) in MT-based SRF production plants. The SRF is being utilized in cement kilns, lime kilns, coal-fired power plants and combined heat and power (CHP) plants for the production of energy (power and heat), reducing the amount of waste going to

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landfill and replacing the fossil fuels to a significant extent. Due to the developments in the field of waste-derived alternative fuels, the use of SRF as fuel/co-fuel has increased significantly in Finnish waste-to-energy technology, especially fluidized bed combustion and gasification could handle such fuel.

SRF referring to a fuel, meeting defined quality specifications, is a possible energy recovery option in industrial facilities (Rotter et al., 2011). The chlorine content in SRF is key to fuel quality because of the concern that high concentrations could severely increase ash deposition in the convective part of boilers (Wu et al., 2011). The European Committee for Standardisation (CEN) selected residual chlorine content as the key technical performance indicator of SRF quality (EN 15359). The composition of ash is affected by the trace and major elements in fuel (Konttinen et al., 2013). From an emission point of view, generally in SRF, concentration of heavy metals plays its part in defining that how 'clean' the SRFs are. Therefore, as general rule, concentration of heavy metals in SRF is to be kept low (Gawlika et al., 2007).

In MT/MBT plants, the quality and yield of SRF stream is directly linked with the proper sorting of input waste stream's components into the relevant output streams. The sorting of input waste stream's components into the relevant output streams is found significantly affected by their physical properties or appearance (e.g. particle size, shape, weight/density and moisture content of waste components) (Nasrullah et al., 2014a, 2014b, 2015a). In SRF production, the quality of SRF could be very well understood through a comprehensive elemental analysis of input and more importantly the output streams (Nasrullah et al., 2015b; Velis et al., 2013). There are very few published studies (Nasrullah et al., 2015a, 2015b; Rotter et al., 2004; Velis et al., 2013) that considered the chemical characterization and elemental flows in output streams of SRF/RDF production process. In particular, there are hardly any published studies available (Nasrullah et al., 2015a, 2015b) that describe the mass flow of polluting and potentially toxic elements (PTEs) and chemical characterization of the input and output streams of SRF production, and present the link between elemental concentration and mass flow of waste components from input to the output streams.

The objective of this paper is an in-depth examination and detailed evaluation of the mass flow of polluting elements and PTEs in SRF production. The SRF was produced from MSW through MT. This research work examined in detail the concentration of inorganic elements in the input and the output streams of SRF production. The link between SRF quality and mass flow of types of waste components in the output streams is presented here. In this paper also, the sources of polluting elements and PTEs are traced and identified.

Materials and methods

In an industrial-scale experimental campaign, SRF was produced from a batch of 30 tonnes of MSW. The stream of MSW used to produce SRF was household energy waste (fraction) collected from the metropolitan area of Helsinki region. This household energy waste stream was not subject to recycling but to energy recovery. Energy waste was source separated at the household level containing about 75 wt.% of energy-related waste components, for example paper and cardboard, plastics, textile, wood, rubber, foam material and a small proportion of non-energy waste components such as inert materials (metals, glass, stones) and food waste (Nasrullah et al., 2015a) due to false sorting.

In an SRF production plant, a series of unit operations was used, such as primary shredding, screening, magnetic/eddy current separation, air classifiers, near-infra-red (NIR) sorting units and secondary shredding, to sort/classify the input waste stream's components into the relevant output streams. The input waste stream was further divided/classified into various output streams of material, i.e. SRF, ferrous metal, non-ferrous metal, fine fraction, heavy fraction and reject material. Sorting of input waste components into the output streams was based on material properties, e.g. particle size (screening), density/weight (air classifier), magnetic properties (magnetic separation) and NIR spectra sorting. Input and output streams were sampled according to standard sampling methods for SRF (EN 15442). Sampling of streams was performed by using the static lot method, static conveyor belt method and manual drop flow method (EN 15442). Sample preparation of streams for their laboratory analysis was performed according to standard sample preparation methods for SRF (EN 15443). According to EN 15443, the methods for particle size reduction and sample division (i.e. mass reduction) were used at each stage of sample preparation for laboratory analysis. Elemental analysis of process streams and waste components was performed by using standard analysis laboratory methods, which are briefly described in the previous study (Nasrullah et al., 2015b). The SRF production process, sampling of process streams and their sample preparation for laboratory analysis are described and published in detail in the previous study (Nasrullah et al., 2014a).

The composition of input and output streams of SRF production was determined and presented in the previous research (Nasrullah et al., 2015a). The input stream was MSW, i.e. household energy waste, and was source separated at the households. The composition of MSW (i.e. energy waste collected from households) is representative of the said waste stream in the metropolitan area of the Helsinki region. Waste material was collected through trucks/lorries from their respective collection locations. The composition of household energy waste may vary to a certain (small) extent with location compared with other cities of Finland. The composition of input and output streams of SRF production from MSW (household energy waste) is given in Table 1.

The mass balance of SRF production from MSW (household energy waste) described and presented (Nasrullah et al., 2015a) i.e. the flow/distribution of mass from the input waste stream into the output streams. In the SRF production, of the total input MSW (household energy waste), 72 wt.% was recovered as SRF, 12 wt.% was separated as fine fraction, 11 wt.% as reject material, 2 wt.% as heavy fraction and 3 wt.% as metals (ferrous/non-ferrous).

Table 1. Composition of process streams produced in SRF production from MSW (energy waste collected from households, wet basis of material) (Nasrullah et al., 2015a).

Component	MSW[a] wt.%	SRF wt.%	Reject material wt.%	Ferrous metal wt.%	Non-ferrous metal wt.%	Heavy fraction wt.%	Fine fraction wt.%
Paper and cardboard	24.5	30.0	8.6	1.2	1.4	0.4	5.4
Plastic (hard)	12.0	13.0	16.0	2.3	1.6	6.4	2.8
Plastic (soft)	16.6	19.6	5.4	–	2.0	–	5.2
Textiles	8.8	10.0	11.0	0.3	1.8	–	2.6
Wood	6.5	8.2	4.5	2.0	–	3.0	3.8
Bio waste	5.0	0.4	10.0	–	–	–	20.0
Rubber	4.8	2.2	24.0	–	–	–	2.5
Metal	4.6	0.5	1.0	92.0	90.0	10.0	3.0
Foam	1.8	2.6	0.5	0.8	0.6	–	6.5
Glass	3.2	0.7	7.8	–	–	–	22.2
Stone	2.6	–	6.0	–	–	78.2	16.8
Fines	9.6	12.8	5.2	1.4	2.6	2.0	9.2

[a]MSW: energy waste collected from households. MSW, municipal solid waste; SRF, solid recovered fuel.

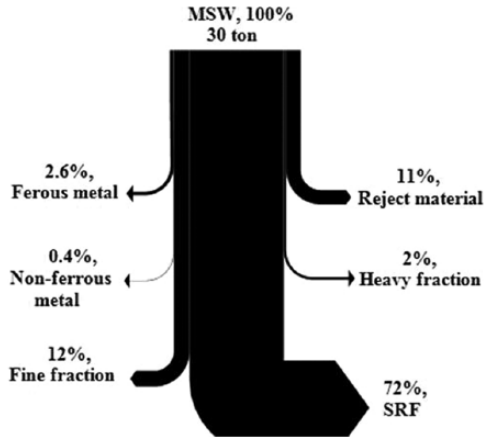

Figure 1. Mass flow balance in process streams of SRF production process: SRF produced from MSW (household energy waste, wet basis) (Nasrullah et al., 2015a). MSW, municipal solid waste; SRF, solid recovered fuel.

The mass balance of SRF production from MSW (household energy waste) is shown in Figure 1.

In the process, the input waste material of MSW was subjected to mechanical separation/sorting only and no material transformation took place. Moreover, there is no material accumulation in the process and the input waste material was recovered in the form of output streams. In waste treatment processes, the whereabouts of hazardous chemicals can be determined only by an exact accounting of all substance flows (Rotter et al., 2004). The elemental balance of the SRF production process was calculated based on the elemental analysis of output streams (given in Table 3) produced in the process and mass balance of SRF production (given in Figure 1). Based on the law of mass conservation; the input mass balance of element (s) was calculated from the sum of its mass in output streams. The total mass/concentration of element (s) in the output stream (s) was calculated by multiplying the concentration of element (s) in stream (given in Table 3) with total mass of stream (s) (given in Figure 1). The elemental balance calculations were performed according to material flow analysis (MFA) methodology by using Equation 1. The MFA methodology was described in detail (Bruner and Rechberger, 2004; Rechberger, 2001). The SRF production process evaluated to establish elemental balance by using MFA is shown in Figure 2. Configuration of the MT-based SRF production plant in terms of unit operations/sorting techniques used and their arrangement in the process have a profound effect on the outcome of the process. The unit operations used and their functions that characterize the evaluated MT process are described and presented (Nasrullah et al., 2014a).

$$X_{input}(s) = M_{input} * C_{input}(s) = \sum_{i=1}^{k} M_{pi} * C_{pi}(s) \quad (1)$$

where X is the load of element; c is the concentration of element; M refers to the mass of stream; P_i refers to the output $_i$; (s) refers to the element; and k number of outputs.

The specific load of various elements in unsorted input waste stream was determined based on the elemental analysis of waste components (Table 2) and composition of the input waste stream (Table 1). The specific load of an element in components of the input waste stream was calculated by multiplying the mass fraction of that component in the input waste stream with the concentration of element in that component. The sources of polluting elements and PTEs among the waste components of MSW were traced and identified based on the elemental analysis of waste components (Table 2).

Determination of the uncertainty aspects in sampling (sampling of streams from SRF production plant) and sub-sampling (sample preparation of streams for laboratory analysis) required very extensive sampling quantities, their treatment and analysis of all the streams (input and output), and was almost not feasible at this scale of research. The precision of the sampling and sub-sampling methods for SRF was presented in detail in QUOVADIS

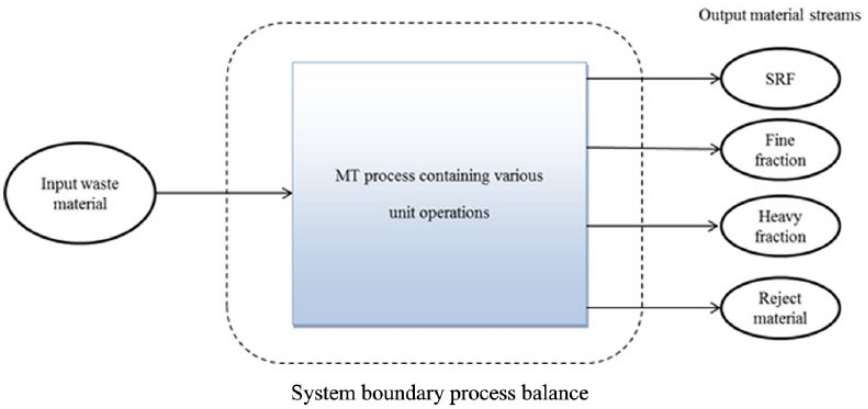

Figure 2. Flow balance of MT process to produce SRF. MT, mechanical treatment; SRF, solid recovered fuel.

Table 2. Elemental analysis of components of municipal solid waste (MSW) (energy waste collected from household) (mean value of three laboratory sub-samples test).

#	Element	Unit	Paper & cardboard	Plastic (hard)	Plastic (soft)	Textiles	Rubber	Foam	Wood	Food waste
1	Cl	wt.%, d	0.15	1.6	0.83	1.1	8.0	0.75	0.05	1.2
2	F	wt.%, d	0.002	0.003	0.004	0.004	0.001	<0.001	<0.001	0.002
3	Br	wt.%, d	0.001	0.001	0.001	0.008	0.001	0.001	0.001	0.001
4	Na	mg kg^{-1}, d	1400	570	1300	3700	980	800	220	11200
5	K	mg kg^{-1}, d	940	440	1200	1500	420	670	710	7600
6	Mn	mg kg^{-1}, d	32.0	25.0	37.0	42.0	30.0	25.0	49.0	58.0
7	Cr	mg kg^{-1}, d	15.0	67.0	41.0	5300	87.0	37.0	7.0	37.0
8	Cu	mg kg^{-1}, d	31.0	24.0	37.0	77.0	1400	40.0	4.7	140
9	Ni	mg kg^{-1}, d	6.0	26.0	18.0	31.0	32.0	17.0	3.3	14.0
10	Zn	mg kg^{-1}, d	47.0	170	160	310	3800	3800	20	110
11	Sb	mg kg^{-1}, d	3.0	56.0	5.0	62.0	170	2.8	1.8	3.4
12	As	mg kg^{-1}, d	0.43	0.61	1.0	2.4	0.6	0.5	0.1	0.8
13	Cd	mg kg^{-1}, d	1.2	9.0	0.50	3.1	1.5	0.5	0.12	0.1
14	Co	mg kg^{-1}, d	1.0	2.0	1.4	2.4	4.8	1.6	<0.5	1.4
15	Pb	mg kg^{-1}, d	12.0	500	19.0	63.0	370	38.0	3.0	120
16	Mo	mg kg^{-1}, d	0.9	1.6	21.0	4.0	2.2	1.3	0.5	1.8
17	Se	mg kg^{-1}, d	0.84	1.2	0.8	1.0	1.0	1.6	<0.53	1.1
18	Tl	mg kg^{-1}, d	<0.5	<0.5	<0.5	0.5	0.5	<0.5	<0.5	–
19	V	mg kg^{-1}, d	4.1	2.2	6.5	6.2	4.3	5.0	0.98	4.3
20	Hg	mg kg^{-1}, d	0.05	0.05	0.1	0.2	0.2	0.1	0.05	0.05

document (QUOVADIS). For this research work, the confidence in the measured and calculated values (for elemental analysis of waste components, specific load contribution calculations and elemental balances of SRF production) was based on the fact that the entire methodology of the research work was based on standards: CEN standard methods for SRF (EN 15442, EN 15443) and laboratory analysis methods (Nasrullah et al., 2015b).

Results and discussion

Elemental analysis of components of MSW

Among the waste components of MSW, rubber was found to be a major source of chlorine containing 8.0 wt.% of it. Rubber material also contained rubber shoes (rubber material contained various types of rubber components and rubber shoes were one of them). Among the components of waste, rubber was reported (Nasrullah et al., 2015b, 2015c) to contain higher concentration of chlorine. Among the components of SRF, rubber shoes were one of those reported to bear high chlorine content (Velis et al., 2012) and were recommended to be directed away from the SRF stream (Velis et al., 2013). Rubber material was also measured to contain higher copper (Cu) than other waste components. Components of rubber and foam were measured to contain considerably higher zinc (Zn) content compared with other waste components. Food waste in MSW was measured to contain 1.2 wt.% of chlorine. The chlorine content could be due to the salt containing food in the food waste components. Textiles were measured to contain higher concentration of bromine compared with other waste components. In textiles, flame retardant textiles

were reported one of the potential source of bromine (Vainikka and Hupa, 2012; Vainikka et al., 2011; Wua et al., 2014). Plastic (hard) was measured to contain higher concentration of lead and cadmium than other components of input waste stream. In the previous studies (Nasrullah et al., 2015b, 2015c) and this study the components of hard plastic (PVC-plastic) and rubber were found to be potential sources of chlorine and textiles (synthetic and flame retardant) a source of bromine. In these studies (Nasrullah et al., 2015b, 2015c), the component of rubber was measured to contain a higher content of copper compared with other components of various waste streams. The elemental analysis of components of MSW is given in Table 2.

The specific elemental load contribution by waste components identified the specific waste components, which contributed to the high load of polluting elements and PTEs in unsorted MSW. The specific load calculations were based on the concentration of elements in the component and the mass fraction of the component in the unsorted stream of MSW. Concentrations of various elements in waste components of MSW and their elemental specific load contribution are shown in Figure 3.

In unsorted MSW, the major load of chlorine was contributed by rubber material and plastic (hard). Rubber and plastic (hard) carried 40% and 20%, respectively, of the chlorine load in MSW. This was due to the considerable mass fraction of plastic (hard) and rubber in MSW and high chlorine content in these components. In previous research (Nasrullah et al., 2015b, 2015c), components of rubber and plastic (hard) were found to carry most of the chlorine load in C&IW and C&D waste. In waste-derived fuel, plastics carried a higher load of chlorine (Rotter et al., 2004; Velis et al., 2012). Rubber was also found to carry a higher load of antimony, zinc and copper in unsorted MSW compared with other waste components. The load of bromine in MSW was mainly influenced by the textile component, i.e. 50% of the total bromine load. The textile component was also found to carry about 35% load of arsenic in the input waste stream. The higher loads of bromine (Br) and arsenic in MSW were due to their higher concentration in textiles compared with other components and considerable mass fraction of textiles in MSW. In textiles, flame retardant textile components were measured to contain high bromine (Br) concentration. Among the waste components, rubber, plastic (hard) and textiles carried a higher load of antimony in MSW, i.e. 38%, 32% and 25%, respectively. In the input waste stream, the load of lead and cadmium carried by plastic (hard) was 60% and 58%, respectively, of total load. Plastic (hard) carried exclusively higher loads of lead and cadmium in MSW compared with other components. Among the waste components, plastic (hard) was measured to contain higher concentrations of lead and cadmium (Table 2) and in MSW the mass fraction of plastic (hard) was 12% (Nasrullah et al., 2015a). The specific load of mercury in MSW was mainly carried by textiles and plastic (soft), i.e. about 50% of the total load. Among the waste components, rubber was measured to carry exclusively a high load of copper (Cu) in MSW, i.e. about 70% of the total load. The higher load of copper (Cu) carried by rubber compared with other waste components was reported in C&IW and C&D waste (Nasrullah et al., 2015b, 2015c).

Among the waste components of MSW, rubber, plastic (hard) and textiles (to a certain extent, especially the synthetic type) were identified as the most critical in terms of affecting the elemental quality of the SRF, and their distribution in the output streams was recommended to be monitored carefully. On the other hand, paper and cardboard, wood and plastic (soft) were identified as the least containing polluting elements, and PTE components and their maximum recovery in the SRF stream could enhance the yield and effectively reduce the concentration of polluting elements and PTEs in the SRF.

Elemental balance of SRF production from MSW

The mass flow of polluting elements and PTEs was examined from input waste stream into the output streams in terms of elemental balance of SRF production process. The elements investigated for their balance were: chlorine, arsenic, cadmium, lead and mercury. These elements were reported (Nasrullah et al., 2015b, 2015c) as polluting elements and PTEs, which might get concentrated in the SRF stream. In the RDF production test runs chlorine, lead and cadmium were reported (Rotter et al., 2004) to be found often concentrated in the fuel product. The elemental analysis of input and output streams of SRF production from MSW (energy waste collected from households) is given in Table 3.

In the SRF production process, higher mass fraction of input chlorine and cadmium content was found in the SRF stream compared with other output streams, whereas higher mass fraction of input arsenic and mercury content was found in the fine fraction stream compared with other output streams. Lead was found to be comparatively homogenously distributed among SRF, fine fraction and reject material streams. The elemental balance of SRF production from MSW (energy waste collected from household) is shown in Figure 4. The elemental balance (shown in Figure 4) was based on elemental analysis of output streams (Table 3) produced in SRF production and the mass balance of the SRF production process (Figure 1), and was calculated by using an MFA approach (see section 2). The difference in the measured (laboratory measurement, Table 3) and calculated (calculated by using MFA method on output streams previously described, see section 2) values of the input element concentration is described here and shown (in Figure 4) as the balance error. Different colours in Sankey diagrams indicate the extent to which the stream is polluted, for example a red colour indicate the highest polluted stream, after that yellow and blue colours, respectively, and a green colour indicates the least polluted stream.

Among the unit operations in SRF production, the air classifier and NIR sorting units were noticed as the most influential and mainly responsible for determining the composition of the SRF stream and therefore the quality and yield of the SRF. The air classifier sorts the lightweight components (especially paper and cardboard, plastic, wood and textiles) and put them into the SRF stream, and the NIR sorting unit separates waste components based on their infra-red/spectral properties and sorts the combustibles (paper and cardboard, wood, non-PVC plastics and

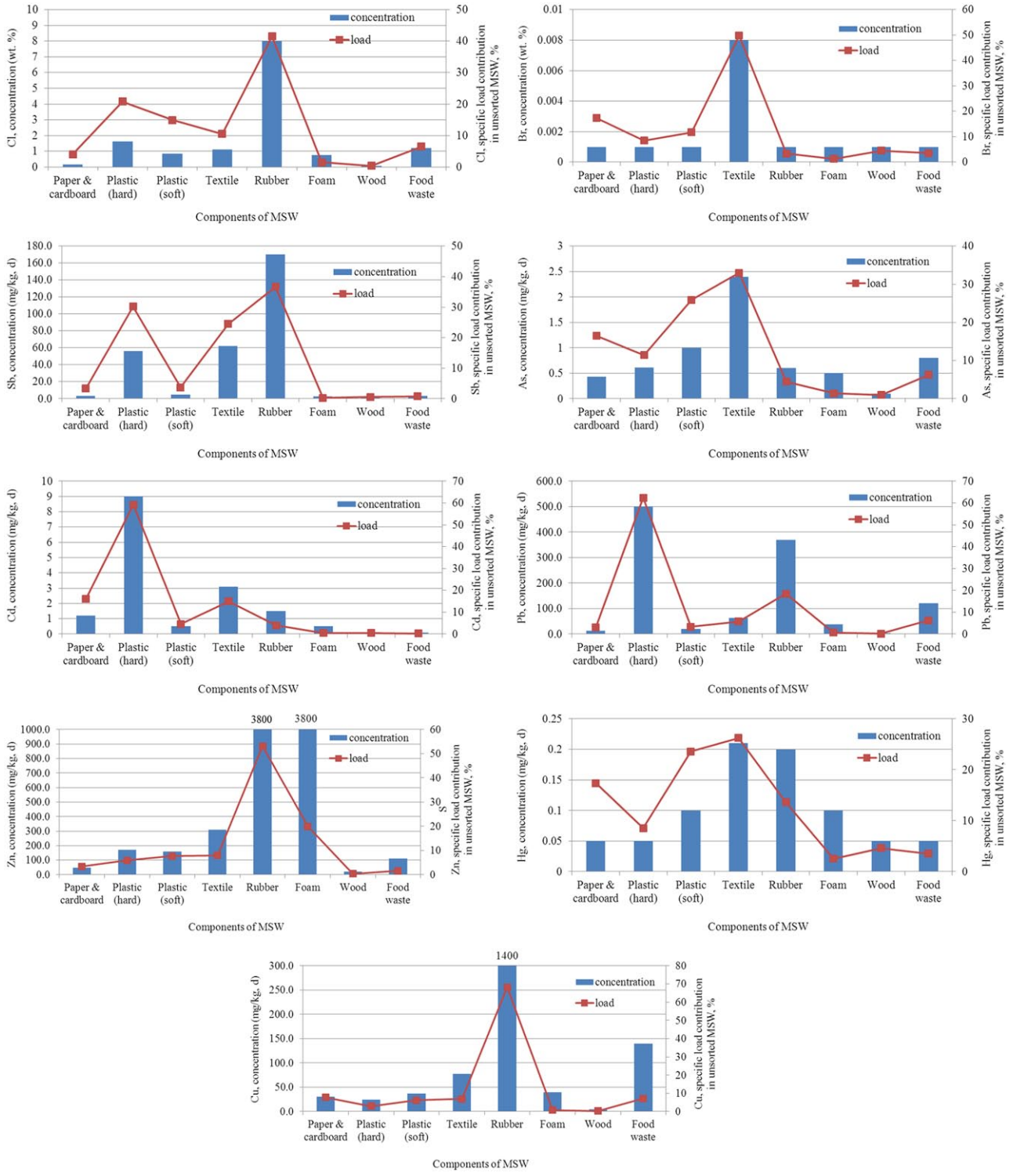

Figure 3. Concentrations and specific load contributions of individual elements to the waste components in unsorted MSW (energy waste collected from household). MSW, municipal solid waste.

textiles etc.) into the SRF stream, whereas non-combustibles (especially high chlorinated rubber and plastics and inert, i.e. stones, metal etc.) ended up in the reject material stream. The mechanical process/unit operations used and their function in MT-based SRF production process are briefly discussed (see section 2) and presented in detail in the previous study (Nasrullah et al., 2014a).

The elemental analysis of components of input waste stream showed that rubber material and plastic (hard) components were potential sources of chlorine and to some extent textiles as well. In the case of cadmium, plastic (hard) measured to contain a higher cadmium content compared with other components of input waste stream. To some extent, the components containing high chlorine and cadmium content were not directed away from making their way into SRF stream. Even though the maximum mass fraction of input rubber and plastic (high chlorinated) was found in the reject material, there could still be certain

Table 3. Elemental analysis of various streams produced in solid recovered fuel (SRF) production from municipal solid waste (MSW; energy waste collected from households) (mean value of three laboratory sub-samples test).

#	Element	Unit	Input waste (MSW)	Reject material	Fine fraction	Heavy fraction	SRF
1	Cl	wt.%, d	1.5	2.7	1.1	0.04	0.6
2	F	wt.%, d	0.01	0.05	0.03	0.002	0.01
3	Br	wt.%, d	0.002	0.01	0.01	0.001	0.004
4	S	wt.%, d	0.2	0.5	1.0	0.1	0.2
5	Na	mg kg^{-1}, d	7918	9187	18880	7112	1590
6	K	mg kg^{-1}, d	3530	4474	8496	13872	924
7	Ca	mg kg^{-1}, d	30623	36604	56262	82356	28925
8	Mg	mg kg^{-1}, d	2957	3142	6419	4566	1390
9	P	mg kg^{-1}, d	382	976	1227	307	338
10	Al	mg kg^{-1}, d	12402	15994	23320	48114	6262
11	Si	mg kg^{-1}, d	41499	40412	54752	32486	9244
12	Fe	mg kg^{-1}, d	6678	3760	11610	8341	1392
13	Ti	mg kg^{-1}, d	2480	2570	2738	4390	1988
14	Cr	mg kg^{-1}, d	153	452	208	77	368
15	Cu	mg kg^{-1}, d	1240	3865	689	711	268
16	Mn	mg kg^{-1}, d	105	413	236	176	55
17	Ni	mg kg^{-1}, d	48	249	104	29	12
18	Zn	mg kg^{-1}, d	563	1380	736	53	229
19	Sb	mg kg^{-1}, d	73	138	81	2.2	537
20	As	mg kg^{-1}, d	3.4	4	7.8	4.4	0.7
21	Ba	mg kg^{-1}, d	468	490	1510	360	278
22	Cd	mg kg^{-1}, d	1.1	1.1	2.2	0.2	0.7
23	Co	mg kg^{-1}, d	3.6	6	8.5	4.4	3.4
24	Pb	mg kg^{-1}, d	280	162	179	25	31
25	Mo	mg kg^{-1}, d	12.4	8	19	1.8	3.2
26	Se	mg kg^{-1}, d	1.2	1.4	2.2	3.8	0.5
27	Tl	mg kg^{-1}, d	0.5	0.5	0.5	0.4	0.5
28	Sn	mg kg^{-1}, d	26	67	41	8	12
29	V	mg kg^{-1}, d	20	11	25	54	8.0
30	Hg	mg kg^{-1}, d	0.15	0.5	0.8	0.1	0.1

lightweight waste components (rubber, plastic or textile) that might contain a high chlorine and cadmium content classified by the air classifier (due to their lighter density/weight) and put into the SRF stream. The other reason might be that some waste components containing high chlorine and cadmium content were picked up by the NIR sorting unit during its positive sorting and added into SRF stream. This issue might be related to the lack of capacity or proper maintenance checks of the NIR sorting unit (especially air nozzles) or non-steady flow rate of waste material (sometimes there could be sudden peaks of material flow from sorting units due to non-steady material feeding at the start of process) passing through the NIR sorting unit on conveyor belt. In newly built SRF production plants, NIR sorting technology is being increasingly installed, which is capable of removing highly chlorinated plastic polymers (Roos and Peters, 2007; Schirmer et al., 2005) but improvements in this sorting technology are necessary for full operational scale (Pieber et al., 2012). In the case of mercury and arsenic, higher mass fraction of their respective input content were found in fine fraction stream. This might be linked with the fact that waste components in the input waste stream containing mercury and arsenic content were shredded to a smaller particle size (<15 mm) in the primary shredding and screened out as a fine fraction.

Conclusion

In this research, the elemental quality of SRF produced from MSW was examined in detail. The stream of MSW used to produce SRF was energy waste collected from households. The quality evaluation was based on the elemental analysis of waste components, the input and output streams, and the elemental balance of the SRF production process.

In the SRF production process, a higher mass fraction of the input chlorine and cadmium was found in the SRF compared with the other output streams. Of the input of chlorine and cadmium to the process, 55% and 62%, respectively, was found in the SRF. In case of arsenic and mercury, of their input content to the process, higher mass fraction was found in the fine fraction compared with the other output streams. Of the input arsenic and mercury content, 45% of each was found in fine fraction. Lead was found to be comparatively homogenously distributed among the SRF, fine fraction and reject material.

Among the components of MSW, rubber, plastic (hard) and textiles (synthetic type) were identified as the potential source of polluting elements and PTEs and their distribution in the output streams of SRF production played a decisive role in defining the elemental quality of the SRF. In particular, the sorting of rubber

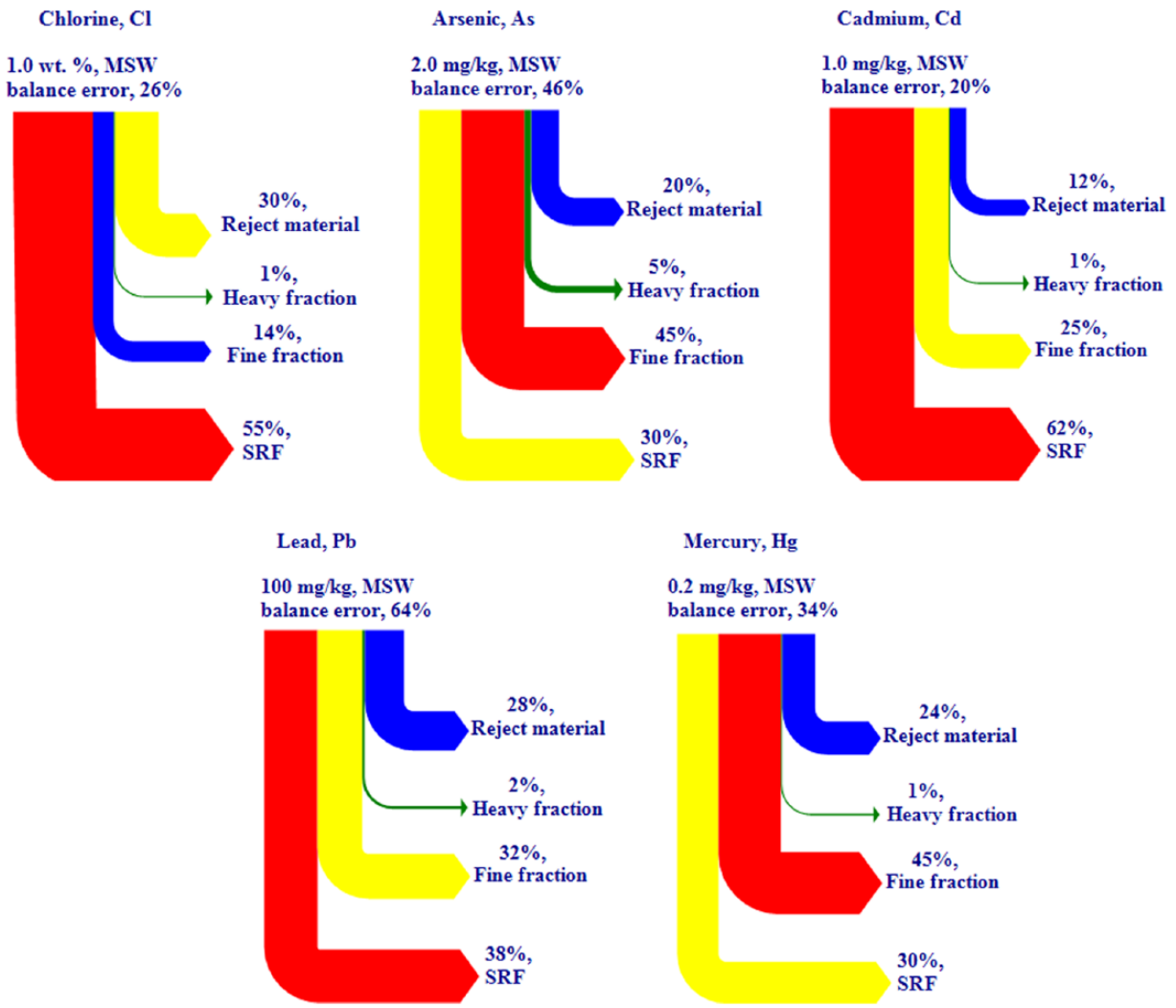

Figure 4. Elemental balance of SRF production process: SRF produced from MSW (energy waste collected from household). MSW, municipal solid waste; SRF, solid recovered fuel.

and hard plastics (PVC-plastic) from the input waste stream into the output streams was recommended to be monitored very carefully. On the other hand, paper and cardboard, wood and plastic (soft) were identified as the least containing of the polluting elements and PTEs, and their maximum recovery in the SRF stream effectively reduced the content of polluting elements and PTEs, and enhanced the yield of SRF.

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