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Comparative environmental analysis of waste brominated plastic thermal treatments

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ABSTRACT

The aim of this research activity is to investigate the environmental impact of different thermal treatments of waste electric and electronic equipment (WEEE), applying a life cycle assessment methodology. Two scenarios were assessed, which both allow the recovery of bromine: (A) the co-combustion of WEEE and green waste in a municipal solid waste combustion plant, and (B) the staged-gasification of WEEE and combustion of produced syngas in gas turbines. Mass and energy balances on the two scenarios were set and the analysis of the life cycle inventory and the life cycle impact assessment were conducted. Two impact assessment methods (Ecoindicator 99 and Impact 2002+) were slightly modified and then used with both scenarios. The results showed that scenario B (staged-gasification) had a potentially smaller environmental impact than scenario A (co-combustion). In particular, the thermal treatment of staged-gasification was more energy efficient than co-combustion, and therefore scenario B performed better than scenario A, mainly in the impact categories of "fossil fuels" and "climate change". Moreover, the results showed that scenario B allows a higher recovery of bromine than scenario A; however, Br recovery leads to environmental benefits for both the scenarios. Finally the study demonstrates that WEEE thermal treatment for energy and matter recovery is an eco-efficient way to dispose of this kind of waste.

1. Introduction

The demand for electric and electronic equipment (EEE) is continuously growing, thanks to the market expansion, to the development of new types of equipment, and to the increasingly rapid replacement of old technologies with newer ones. Plastics represent an increasingly important part of EEE, and flame retardants are particularly relevant in terms of complying with safety regulations. On average, 30% of the plastics used in EEE contain flame retardants (Vehlow et al., 2002a). Halogenated flame retardants have traditionally been used because of their efficiency and suitability with various types of plastics. Bromine is generally preferred over chlorine because it requires lower quantities of flame retardant and minimizes the impact of the additive on the polymer's performance. The high content of bromine, chlorine and heavy metals in waste electric and electronic equipment (WEEE) has led to the need for separate collection and recycling scheme for this type of waste, in order to reduce environmental impacts. As long as legislation is lacking, the industry will obviously look for the least costly solution. This, in many EU member states, is still represented by landfill: more than 90% of WEEE is currently landfilled (Tange and Drohmann, 2005). In January 2003, a specific European Directive (2002/96/EC) was issued in order to tackle this trend. WEEE can be disposed of in three different ways: reuse, mechanical treatment, and thermal treatment. Reuse is environmentally preferred but difficult to achieve because of the high quality requirements of the products. The mechanical treatment separates and partially recovers different fractions of the waste stream (plastic, metallic, ceramic). Some ECO-impact studies in The Netherlands and Germany have demonstrated that there is a limit of about 15% to the plastic waste that can be mechanically recycled ecologically (Boerrigter, 2000). Therefore, it is economically and environmentally advantageous to use plastic waste for energy recovery using thermal treatment, thus reducing the overall use of fossil fuels and the amount of greenhouse gas emissions, while avoiding landfilling. It is estimated that, if all of Europe's plastic waste that is not feasible to recycle were turned into energy, it would be equivalent to 5% of the EU's energy needs for power generation (Tange and Drohmann, 2005). Thermal treatment comprises different processes such as direct combustion, co-combustion with organic wastes, pyrolysis and gasification. In all of these processes, a minimal amount of bromine contained in the waste stream turns into ashes or char, while most turns into combustion gases or into syngas. Using suitable wet scrubbing systems, it is technically feasible to recover bromine, which can then be used to produce different types of com-

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Table 1
Characterization factors for HCl and HBr

Impact category	Emission	Unit	Characterization factor
Acidification/eutrophication	HCl (air)	PDF·m^2·year/kg	0.916
	HBr (air)	PDF·m^2·year/kg	0.413
Respiratory inorganics	HCl (air)	DALY/kg	2.84×10^{-4}
	HBr (air)	DALY/kg	2.84×10^{-4}

mercial bromine-based products such as bromine itself, hydrogen bromide, or sodium bromide (Tange and Drohmann, 2005). In 2001 two research bodies published the results of trials conducted at two different pilot-scale facilities treating the same WEEE test materials provided by EBFRIP (European brominated flame retardants industry panel). The results of these investigations were used in the present study, and two different thermal treatment scenarios were analyzed. Both of these achieve bromine recovery and electric power production. They are:

– co-combustion of WEEE and green waste in a municipal solid waste combustion (MSWC) plant;
– staged-gasification of WEEE and combustion of produced syngas in gas turbines.

The main goal of this study is to compare the environmental performances of these two processes of thermal treatment of WEEE using life cycle assessment (LCA). Mass and energy balances regarding the two scenarios were compiled, and a life cycle inventory (LCI) was created, which contains all of the inputs and outputs of the processes. A life cycle impact assessment (LCIA) was then conducted using the commercial software SimaPro 7.0.

2. Life cycle assessment

Life cycle assessment is a technique for assessing the environmental aspects associated with a product over its life cycle. According to the ISO normative on LCA (ISO 14040:2006 and 14044:2006), it consists of four phases: goal definition and scoping, inventory analysis, impact assessment, and interpretation.

2.1. Goal definition and scoping

The goal of the this study is to compare the potential environmental impact associated with two different scenarios of thermal treatment of WEEE, in order to provide the agencies responsible for environmental policy with criteria to choose between competing processes. LCA methodology was applied using SimaPro 7.0. The functional unit chosen for referring balances was 1 kg of the WEEE sample (and not of the total waste stream) fed to a plant. For the inventory analysis, it was not necessary to collect information about all the unit processes of the system considered. Indeed the data regarding processes such as the manufacture of major chemicals or electric power production from fossil fuels are available in several databases that have already been implemented in SimaPro. In this study the database Ecoinvent Data v1.2 (Frischknecht et al., 2005) was used, which contains recent data on Western Europe. The system boundary contained a series of unit processes: in addition to the thermal treatment of the waste brominated plastic stream, it included all the processes of energy and chemicals production, material transport and waste treatment associated with non elementary flows[1] entering or leaving the main process.

[1] In LCA an elementary flow is: (1) material or energy entering the system being studied, which has been drawn from the environment without previous human transformation; (2) material or energy leaving the system being studied, which is discarded into the environment without subsequent human transformation.

Table 2
Weighting factors for the method Impact 2002+

Damage category	Weighting factor
Human health	270
Ecosystem quality	270
Climate change	270
Resources	190

Due to the lack of data and the irrelevant associated impact, the construction and maintenance of means of transport and infrastructure such as roads and power, chemical and waste disposal plants were excluded. Moreover, also due to the lack of data, not all air pollutants were considered and balances were carried out only for the major ones: NH_3, CO_2, CO, HBr, HCl, NO_x, and SO_x. On the other hand, all possible emissions in soil and in water and the consumption of resources were taken into account.

2.2. Methods of impact assessment

In order to evaluate the reliability of the results, in this study LCIA was carried out using two different methods. The two methods selected, which both enable us to carry out the weighting step and achieve an impact single score, are Ecoindicator 99 (H) v2.03, with the normalization/weighting set "Europe EL 99 H/A", and Impact 2002+ v2.1. The standard method Ecoindicator 99 (Goedkoop and Spriensma, 2001) does not consider the emissions of HCl and HBr. These substances were added in two impact categories, and the respective characterization factors, reported in Table 1, were chosen according to the methods EDIP/UMIP 97 (Goedkoop et al., 2004) for "Acidification/eutrophication", and CML 2 baseline 2000 (Goedkoop et al., 2004) for "Respiratory inorganics".

Impact 2002+ (Jolliet et al., 2003) is a combination of the following methods: Impact 2002, Ecoindicator 99, CML and IPPC. The impact category of "Aquatic acidification", which may be important in the case study, is still under development and no damage factor is reported. A value of 1.04 PDF·m^2·yr/kg$_{SO_2}$ was chosen, which is the factor for "Terrestrial acidification/nutrification". For the same category, the normalization factor for HBr emission was set at 0.3965 kg$_{SO_2}$/kg. In addition, the method defines no weighting set, so that the one used was directly defined by us (see Table 2).

3. System definition and mass and energy balances

In this study, data on the thermal treatment of WEEE were taken from the results of two series of experiments conducted in the year 2001. The fuel samples used in both the series were the same WEEE test materials, provided by the EBFRIP. In this study the samples used are MIX 1 (WEEE shredder residues containing mixed polymers), TV 1 (shredded television housing) and PWB (shredded printed wiring boards) (Vehlow et al., 2002a; Boerrigter, 2001a). On the basis of the two series of experimentations, two flow-sheets were drawn up of analogous industrial-scale plants. Data from trials were used and some hypotheses were made on the basis of the literature, in order to compile mass and energy balances for these plants and to calculate all the inflows and outflows of the system.