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ANALYSIS OF THE PRACTICES AND TECHNOLOGIES USED FOR THE TREATMENT OF BROMINATED PLASTICS OF WEEE IN GUADALAJARA CITY, MEXICO

Análisis de las prácticas y tecnologías utilizadas para el tratamiento de plásticos bromados de RAEE en la ciudad de Guadalajara, México

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Key words: flame retardants, electronic waste, waste management, recycling

ABSTRACT

The increase in waste electrical and electronic equipment (WEEE) has become an attractive waste for the recycling industry, mainly due to the high volume found in the waste flow that can be transformed into other products. The purpose of this study is to investigate the treatments applied to WEEE brominated plastics in companies of recycling in the Metropolitan Area of Guadalajara (MAG), Mexico, and the comparison with international guidelines. The information-gathering was obtained through interviews and visits; fourteen companies dedicated to the field of recovery, treatment and/or recycling of electronic waste were identified. Only seven companies allowed the study to be carried out, and only five companies provided plastics samples. Eighty-six samples of different kinds of plastics were obtained and analyzed using the Handheld X-ray fluorescence (HXRF) technique, and the atypical cases have undergone an analysis of X-ray photoelectron spectroscopy (XPS) and X-ray energy dispersive spectrometer (EDS). Bromine was the predominant element in the samples analyzed, which sometimes exceeded the permissible limits of the European Directive 4 to 10 times, meaning that the concentration ranges go from 10000 to 39500 mg/kg. It was identified bromine as a chemical precursor of flame retardants, which is prohibited by international agreements because they cause damage to the environment and public health. As a result, the companies dedicated to the treatment and/or recycling of plastics from WEEE do not follow the practices and technologies used internationally. However, considering the circular economy, this is relevant to establish limits of traces of contaminants in recycled plastics.

Palabras clave: retardantes de flama, residuos electrónicos, gestión de residuos, reciclaje

RESUMEN

El incremento de los residuos de aparatos eléctricos y electrónicos (RAEE) ha generado que estos sean un residuo atractivo para la industria del reciclaje, principalmente por el alto volumen en el flujo de residuos que pueden transformarse en otros productos. El propósito de este estudio es investigar los tratamientos aplicados a los plásticos bromados de RAEE en empresas de reciclaje en el Área Metropolitana de Guadalajara (AMG), México, y la comparación con lineamientos internacionales. La recopilación de información se obtuvo a través de entrevistas y visitas, se identificaron catorce empresas dedicadas al campo de la recuperación, tratamiento y/o reciclaje de residuos electrónicos. Siete empresas permitieron que se realizara el estudio y sólo cinco empresas proporcionaron muestras de plásticos. Se obtuvieron y analizaron 86 muestras de diferentes tipos de plásticos utilizando la técnica de fluorescencia de rayos X portátil (HXRF por sus siglas en inglés), y los casos atípicos se sometieron a un análisis de espectroscopía de fotoelectrones emitidos por rayos X (XPS por sus siglas en inglés) y espectrómetro de dispersión de rayos X (EDS por sus siglas en inglés). El bromo fue el elemento predominante en las muestras analizadas, que en ocasiones excedió los límites permisibles de la Directiva Europea de 4 a 10 veces, lo que significa que los rangos de concentración van de 10000 a 39500 mg/kg. Se identificó al bromo como un precursor químico de los retardantes de flama, lo cual está prohibido por acuerdos internacionales debido a que causan daños al ambiente y a la salud pública. Como resultado, las empresas dedicadas al tratamiento y/o reciclaje de plásticos de RAEE no siguen las prácticas y tecnologías utilizadas a nivel internacional. Sin embargo, considerando la economía circular, esto es relevante para establecer límites de trazas de contaminantes en plásticos reciclados.

INTRODUCTION

Technology in physical devices has allowed humanity to do simple until the most complex activities, faster and more efficiently. However, the improvement and evolution of these devices have caused an increase in the volume of this waste. Only in 2016, 44.7 million tons of waste from electronic and electrical equipment (WEEE) was generated worldwide (Baldé et al. 2017). Mexico was produced as for the year 2015 1310.52 kilotons of WEEE; this data does not include emissions related to exportation and importation of WEEE and post-consumer waste (SEMARNAT-PNUD 2017).

WEEE has become an attractive waste to the recycling industry, mainly due to the metals contained in these devices, hence concepts such as "urban mining" that refers to the extraction of raw materials from products in use and disuse, buildings, and waste (Cossu et al. 2015). This definition has been applied for the recycling of WEEE because they have recoverable materials such as printed circuit boards that contains valuable metals (iron, copper, aluminum, gold, silver, palladium). On the other hand, the technological evolution of electrical and electronic equipment (EEE) has followed a trend towards a decrease in their weight, which is intrinsically related to the type of materials used to manufacture EEE (Baldé et al. 2015).

From a mix of different types of EEE, the plastic is the second-highest weight with approximately 20 % of the total amount of the materials composition (Wäger et al. 2010), the first one is the iron and steel, which together represent 48 %, while printed circuit boards ranks sixth in the list with 3 % (Wang et al. 2014).

The plastics most used in WEEE are acrylonitrile butadiene styrene (ABS), high impact polystyrene (HIPS), polypropylene (PP), polycarbonate (PC), polystyrene chloride (PVC), polymethyl methacrylate (PMMA), among others. Three types of plastics represent 63 - 85 % by weight of the total plastic composition of WEEE (ABS, HIPS and PP) (Maris et al. 2015, UNEP 2017) which are from the thermoplastics group. These materials can be reheated, reshaped and frozen repeatedly.

Nevertheless, the waste from electrical and electronic equipment has more than 15 different plastics (UNEP 2017). These, in turn, contain substances considered dangerous for health and the environment, such as polybrominated diphenyl ethers (PBDE), listed in the Stockholm Convention for persistent organic pollutants (POPs), and heavy metals restricted by the European Directive (Restriction of Hazardous Substances (RoHS)) such as cadmium, hexavalent chromium, mercury, lead, among others, that, if not properly handled, it could cause serious impacts to health and the environment.

These substances were introduced into plastics as additives during their primary production, for example, cadmium is used in pigments, and polybrominated diphenyl ethers are used as flame retardants. Plastics containing brominated flame retardants can be influenced by various environmental processes such as chemical degradation, biodegradation, volatilization and photodegradation, determining their persistence, transport and last destination. Exposure to PBDEs can cause health effects such as carcinogenicity, neurotoxicity, and endocrine disruption. PBDEs have been detected in air, sediment, water, biological samples and human tissues (Akortia et al. 2016). Some routes of human exposure are emissions from electronics (i.e., televisions and computers), house dust, occupational, and consumption of contaminated food. High bromine compounds of PBDEs, like decabromodiphenyl ether (decaBDE), act differently in the body than low bromine compounds of PBDEs. If you breathe air containing PBDEs or eat food, water, soil, or dust contaminated with PBDEs, low-bromine congeners are more likely to pass into the blood through the lungs and stomach than decaBDE compounds (ATSDR 2015).

Studies of blood PBDE concentration have been carried out in Mexico. Pérez-Maldonado et al. (2009), evaluated PBDE exposure in Mexican children from the states of Chihuahua, the State of Mexico and San Luis Potosí. One conclusion is that the PBDE levels in a child living in an urban/industrial area is twice as high as that of a child in a rural area. Likewise, the most recent study was carried out in Jalisco and indicates that the concentrations are like the highest figures recorded in the world for children in North America, specifically for children living in Silicon Valley and nearby places in California, where it is considered one of the most severe problems due to environmental pollution associated with the electronics industry (Orta-García et al. 2018).

International initiatives have emerged to regulate the content of dangerous substances in different products, such as the Stockholm Convention on Persistent Organic Pollutants, which was adopted by the international community on May 22, 2001, and entered into force on May 17, 2004. The Convention has 178 countries and aims to protect human health and the environment against persistent organic pollutants by reducing or eliminating emissions to the environment. The signatory countries committed to develop a national plan for the fulfilment of their obligations, exchange of information on the reduction or elimination of the production, use and release of POPs and alternatives to POPs, public participation, and awareness-raising, to carry out research, development and monitoring activities and offer technical assistance to other countries.

In 2007 Mexico developed the National Implementation Plan (PNI for its initials in Spanish), in which the coordinated and transversal strategies are defined in the short, medium, and long term and these must be carried out in a co-responsible manner between the different government entities and other sectors of society. The PNI was the first national strategy for risk reduction of the first substances identified as POPs, mostly organochlorine pesticides, industrial chemicals, and secondary products. It considered other previous efforts, concretized within the work program of the Commission for Environmental Cooperation of North America, such as the formulation of regional plans of action on polychlorinated biphenyls (PCBs), chlordane, dioxins, furans and pentachlorophenol, which contributed to strengthening environmental policy in our country (SEMARNAT 2016). Furthermore, since 2004, the United Nations Development Program (UNDP) has supported eighty-four developing countries in their efforts to reduce and eliminate POPs and to achieve the objectives of the Stockholm Convention, including Mexico. Many of the challenges in reducing and eliminating POPs require good national capacities and greater availability of technical knowledge (PNUD 2015).

Different studies have detected PDBE in a variety of consumer products that do not require flame retardants or in insufficient concentrations to provide fire protection, including children's toys (Guzzonato et al. 2017), kitchen utensils (Kuang et al. 2017), bead garlands, among others. In many cases, recycled plastics from WEEE appear to have been used, in whole or in part, in contemporary non-compliant electrical or non-electrical products (Turner et al. 2017).

This paper aimed to observe compliance with international protocols, which will give a first approximation of the status handling WEEE plastics in recycling companies of the Metropolitan Area of Guadalajara, and to investigate the treatments available for these plastics in Jalisco, Mexico.

MATERIAL AND METHODS

Selection of recycling companies

In the Metropolitan Area of Guadalajara, we identified twenty-five authorized companies that were performing some stage of management for electronic waste.

Subsequently, companies were categorized according to the level of WEEE management, taking as reference those companies dedicated to the treatment and recycling of WEEE; that is, those that carry out selective separation activities of recoverable components and materials (i.e. plastic, ferrous and non-ferrous metal, cables and printed circuit boards), including the disposal or treatment of toxic materials through an authorized service provider (i.e., batteries, lamps and displays), and/or reconditioning and repair of electronic equipment. Finally, seven out of fourteen companies within this level of WEE management, participated in the present study

Survey design for gathering information in the field

A survey was designed to collect field information, which provides elements to know the activities, practices and technologies used to recycle and dispose of brominated plastics in companies at the Metropolitan Area of Guadalajara. The survey was divided into nine topics: 1) general data and information on activities, 2) reception of the material, 3) classification, 4) selective separation, 5) treatment of plastics, 6) recycling of plastics, 7) identification of retardants of flame, 8) trade-in materials, and 9) occupational health. The survey had thirty-one open questions.

Collection of plastic samples

We collected at least three plastic samples per company (seven companies participated) by separation category at the time of the visit, which was provided by the workers of the companies. Eighty-six samples of different kind of plastics were obtained.

Detection of bromine in plastics

We measured all the collected pieces with the handheld Portable X-Ray Fluorescence (HXRF) technique (Genius 3000 Skyray instrument) and reference material ERM-PE1 # 509. The samples were measured without any preparation and scanned for 100 seconds at five random points in the sample. We weighed each sample, and information was included on the type of EEE from which the piece or crushed material came, as well as color aspects of the sample.

The Restriction of Hazardous Substances (RoHS) of the Directive of the European Union 2002/95/EC was considered as a reference; the atypical cases have undergone an analysis of X-ray photoelectron spectroscopy (XPS) (Phoibos 150, Specs. Berlin, Germany) and X-ray Scattering Spectroscopy (EDS).

RESULTS AND DISCUSSION

Fourteen companies are dedicated to the treatment and recycling of WEEE; that is, those that carry out selective separation activities of recoverable components and materials were at this level, equivalent to 56 % (**Fig. 1**). We requested to visit their facilities, where only seven companies were agreed to be part of the study and to provide information through interviews.

Reception of WEEE

The visited e-waste management companies commented that approximately 90 % of their raw material is from companies dedicated to the generation of products and services. The WEEE that is most frequently

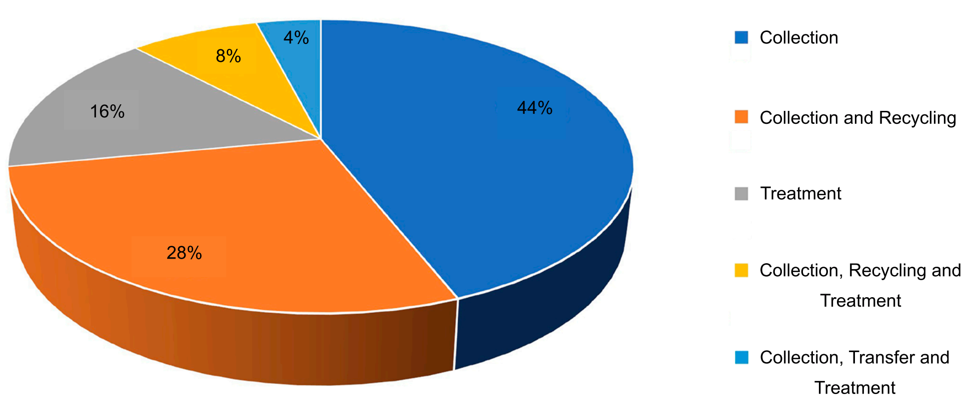

Fig. 1. Companies with authorized stages for some stage of WEEE management in the Metropolitan Area of Guadalajara, 2018.

processed are computers and telecommunications equipment and to lesser extent household appliances and toys (video game consoles). The refurbish is not practiced by all the companies visited, and it is carried out if the client authorizes it.

Selective separation

This work is carried out manually, and consists of removing the fasteners from the WEEE, using screwdrivers, which can be manual or electrical, the separation of the shells, electronic card, cables, glass and metals is performed.

Use cardboard boxes (known as gaylord boxes) as containers to facilitate the classification of materials, as well as their subsequent handling to storage areas. Sometimes EEE contains packaging that is removed prior to disassembly.

Recovery materials

Printed circuit boards are classified according to the number of components it contains, their quality and the size of the card. The cables are sorted by type of output like USB, VGA, HDMI, among others. It should be noted that no mechanical or chemical procedure for separating the plastic fraction from the cable was identified in any of the companies visited.

Plastics are classified according to the generic identification and marking of plastics products (ISO 11469 and 1043) that is placed by the manufacturers, and in some cases based on the experience gained by the workers. A lighter is used to burn the plastic, and according to the smell it gives off, the type of flame and its deformation, it is classified.

Although 43 % of the companies interviewed argued that they have experience in detecting brominated flame retardants, however we do not identify processes or laboratory tests like evidence. Likewise, all the companies interviewed are familiar with the name of "flame retardants". However, 86 % do not associate that a flame retardant can be toxic compounds contained in WEEE plastics, as is the case of some brominated compounds.

On the other hand, all companies visited and dedicated to e-waste management, they separate the plastic according to the indications of the downstream vendor, who is, in this case, the company that provides treatment to the plastic in its plant. Among the companies dedicated to the treatment of plastics, we identify this kind of companies that receive plastics from different industrial sectors, and the main criterion for processing plastics is that they belong to the same type of polymer. In the case of WEEE plastics, the detection of the plastic components that are collected from the disassembling companies of EEE may require a manual process to extract metals or labels, before being crushed through industrial mills, where the particle size is determined in turn by the target market, whether national or international.

Plastic materials are commercialized in the national (25 %) and international market (75 % in countries such as China, United States, India, Thailand, Brazil, Guatemala, and Indonesia). The companies commented that some of the applications of plastics are in: i) the electronics industry, ii) the automotive industry, iii) the footwear industry, and iv) the plastics industry. However, it was not possible to verify which products the recovered plastics are transformed.

The rest of the materials that failed to be recoverable, because these couldn't be identified according to the type of polymer, are disposed of as special handling waste in sanitary landfills. During the interviews, a company commented that they were designing a pilot project for energy recovery from the WEEE plastics, like an alternative fuel in cement kilns with the company Geocycle located in Tecomán, Colima, Mexico (**Fig. 2**).

So, the current model identified for the handling of WEEE plastics is as follows: the WEEE disassembly companies sell their plastic fractions to a company dedicated to the treatment of plastics (also known as "downstream vendor"). The plastics processing companies, mainly carry out crushing processes, and if the client requires them, carry out pelletizing processes. Then, the flakes or pellets are commercialized; after this step, the traceability of the plastic fraction is lost (**Fig. 3**).

The companies visited consider the following as risks for workers and the environment: i) mishandling of materials and hazardous waste (batteries, lamps, lead-tin solders, toners, cadmium, and flame retardants, among others), ii) generation of dust and iii) poisonings and fires.

Economic aspects

Companies commented that mixed plastics do not have market value and represents a disposal cost for the company of approximately $1.50 - 2.00 Mexican pesos per kilogram. While a plastic that is properly separated, its market price ranges from $5.00 - 15.00 Mexican pesos per kilogram, they also commented that the economic value of plastics is related with the quality of the material, purity and quantity, as well as the price of oil.

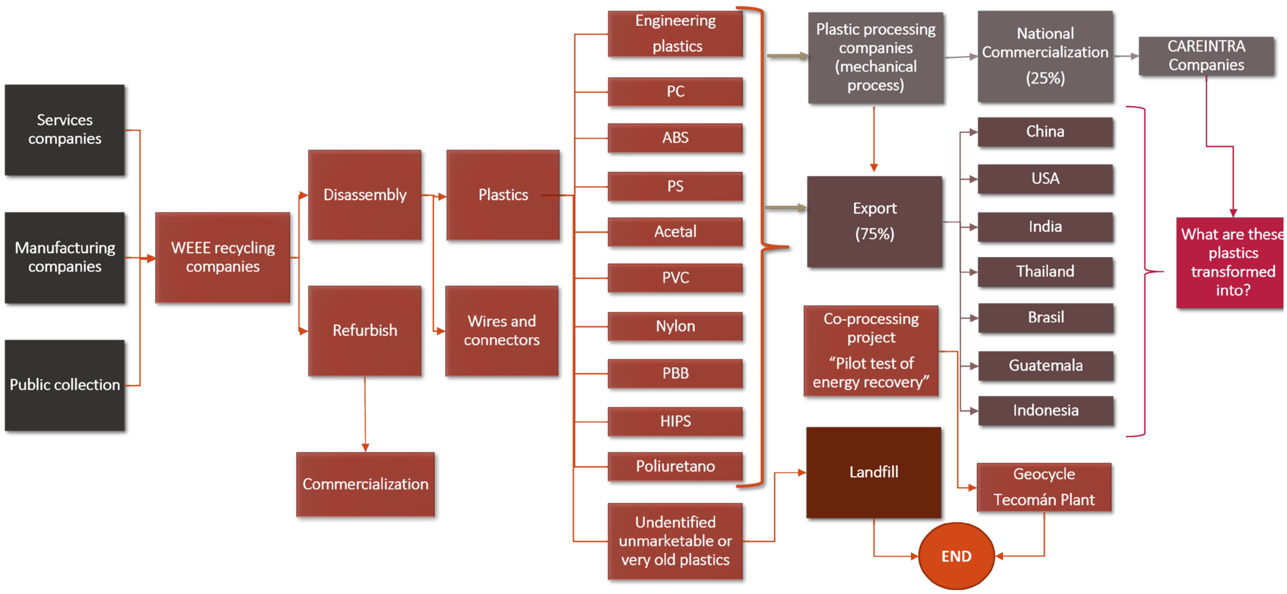

Fig. 2. General traceability of WEEE plastics in Jalisco, based on companies visited. Note: Pilot project for energy recovery applies only to one company, it has not been explored by the rest of the companies.

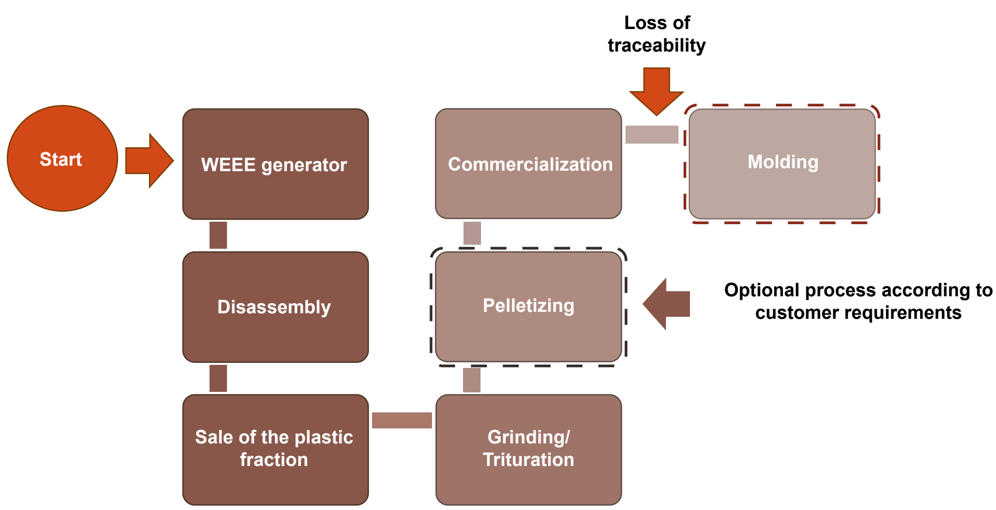

Fig. 3. Identification of processes for handling WEEE plastics in Jalisco.

Plastic samples collected and characterization

Eighty-six samples of different kind of plastics were obtained, companies engaged in the disassembly of electrical and electronic equipment, were provided with plastic parts. In contrast, for plastics treatment companies, samples of crushed plastic were provided.

They were categorized into 11 groups according to the generic identification and marking of plastics products (ISO 11469 and 1043). In the case of samples that are crushed, the company provided the samples identified by the type of polymer. The types of plastics that have the highest percentage of representation in the samples received are ABS, PC, and the combination of these with 15.11 and 12.79 %, respectively. Likewise, the third place is occupied by samples of unidentified plastics and polystyrene with a 9.3 % representation. PVC and HIPS were found in moderate amounts. PP, PMMA, ABS-PS mix, and PC-GF mix are found in less quantity (4, 3, 1 and 1 samples, respectively).

Chemical analysis of plastic samples with HXRF, XPS and EDS equipment for bromine identification

In the measurement of the pieces with the HXRF equipment, the following chemical elements were detected: arsenic, bromine, cadmium, chromium, mercury, and lead. The reported value is the average of the five measurements taken.

The results were compared with concentration limits established by RoHs, to identify which samples were above (**Table I**). These results should be used with caution since they cannot be used to draw conclusions about PBB, PBDEs or Cr (VI) because the scope of the measuring equipment was according to chemical elements, but not to chemical compounds.

In this first analysis, we studied the concentration of different contaminants; however, it is important to consider that samples present different characteristics such as type of polymer, the origin of the pieces, color, crushed and uncrushed, weight (variable) and size (variable).

Due to that in some cases the elemental rates installed in the HXRF equipment are significantly different with the calibration standards, and metal standards are limited for different plastic matrices of electronic products, the results obtained were confirmed with another lab techniques (Dimitrakakis et al. 2009). HXRF was considered as a useful tool for the first screening of elemental concentration.

For which, complementary analyzes were performed using X-ray photoelectron spectroscopy (XPS) and X-ray energy dispersion spectroscopy (EDS) techniques. The results obtained through both techniques are described in the following section.

Four samples were analyzed by X-ray photoelectron spectroscopy (XPS): the three samples that presented concentrations that exceeded the RoHS limits (#36, #51 and #52) and an additional sample (#35) that also presented high values without reaching RoHS maximum limits, in order to have an additional value that reinforces the data analysis. According to the elemental analysis using this technique, other elements such as fluorine, silicon, calcium, and chlorine are presented in addition to bromine; in concentrations of 25 750-43 380 mg/kg; 22 180 - 30 000 mg/kg; 28 750 mg/kg and 123 670 - 198 490 mg/kg, respectively. Presenting in higher concentrations fluorine and chlorine, whose substances also belong to the group of halogenated substances. Bromine concentrations occurred in the range of 1360 - 14 650 mg/kg.

An analysis of five samples was performed employing X-ray energy dispersion spectroscopy (EDS) analysis: the three samples that presented concentrations that exceeded the RoHS limits (#36, #51 and #52) and two additional samples (#34 and #35), which they also presented high values without reaching the RoHS maximum limits, to have two additional values that reinforce the data analysis. The bromine concentrations detected by this technique are in the range of 100 to 39 500 mg/kg.

Through this technique other traces of elements such as copper in the range 400 - 500 mg/kg were detected; iron in the range 900 - 19 000 mg/kg; magnesium with the concentration of 400 mg/kg;

TABLE I. HEAVY METAL CONCENTRATION RANGES FOUND IN SAMPLES THROUGH THE HXRF TECHNIQUE.

Chemical element	Amount of pieces	Range (mg/kg)	Median (mg/kg)	Limit RoHS/ CENELEC (mg/kg) (ppm)	Data above the limit
As	65	0.02 - 189.68	0.22	-	-
Br	74	0.02 - 6094.65	5.33	2000	3
Cd	77	0.06 - 1246	1.72	100	1
Cr	78	0.14 - 2125.92	16.52	1000*	11
Hg	85	0.44 - 97.86	3.22	1000	0
Pb	38	0.02 - 5456.08	4.83	1000	4

*Note: RoHS limit refers to hexavalent chromium.

titanium in the 900 - 6600 mg/kg range and zinc in the 300 - 1300 mg/kg range.

Comparison of bromine chemical analysis results between HXRF, XPS and EDS techniques

Based on the previous results, the predominant pollutant is bromine. On the other hand, it was observed that different elements were detected through the different techniques, firstly, due to the material is not homogeneous in all the surface, because when the plastic extrusion processes are carried out, there are temperature fluctuations in processing them (speed and pressure) (Abeykoon et al. 2014), which affect the homogeneous distribution of the composition of a plastic piece; and this determines the quality of a plastic and therefore its homogeneity; secondly, the samples analyzed were crushed, so there may be variations in molecular weight as a consequence of exposure to high processing temperatures and mechanical stresses relevant (Capone et al. 2007).

The HXRF and XPS equipment measurements yielded similar data regarding ABS and PC plastics pieces. On the other hand, through the EDS technique, more traces of contaminants were detected in the samples. The average of the three techniques indicates that the bromine concentration ranges between 2 and 20 g/kg of plastic (**Fig. 4**).

The concentration of heavy metals in WEEE plastics, especially bromine, increases concern considering that bromine exceeds on average four to ten times the limits established by the European Union, as well as the management that is given to it as it is recycling, of which the type of product they will be converted into is unknown and, on the other hand, considering that those plastics that were not able to be marketed are sent to landfill.

Cesaro et al. (2017) performed toxicity tests under the NOAEL method, which consisted of contacting leachate tests (1: 1 dilution) with daphnia, in the case of plastics started with a concentration of 100 g/L confirming that the elements found in the plastics of WEEE (Al, As, Cd, Cu, Cr, Ni, Pb, Sb, and Zn), are highly toxic, where 80 % of daphnids were immobilized after 24 hours. The mean observed level of toxicity effect for WEEE plastics was estimated to be 50 g/L and at approximately 20 g/L no toxicity adverse effects were observed.

On Jalisco, one hundred forty-five landfill sites have been registered by The State Attorney's Office for Environmental Protection (PROEPA by its initials in Spanish), fifteen sites correspond to landfills and only twelve are currently authorized.

PROFEPA had found irregularities in eight out of ten inspections that it carried out in landfill sites

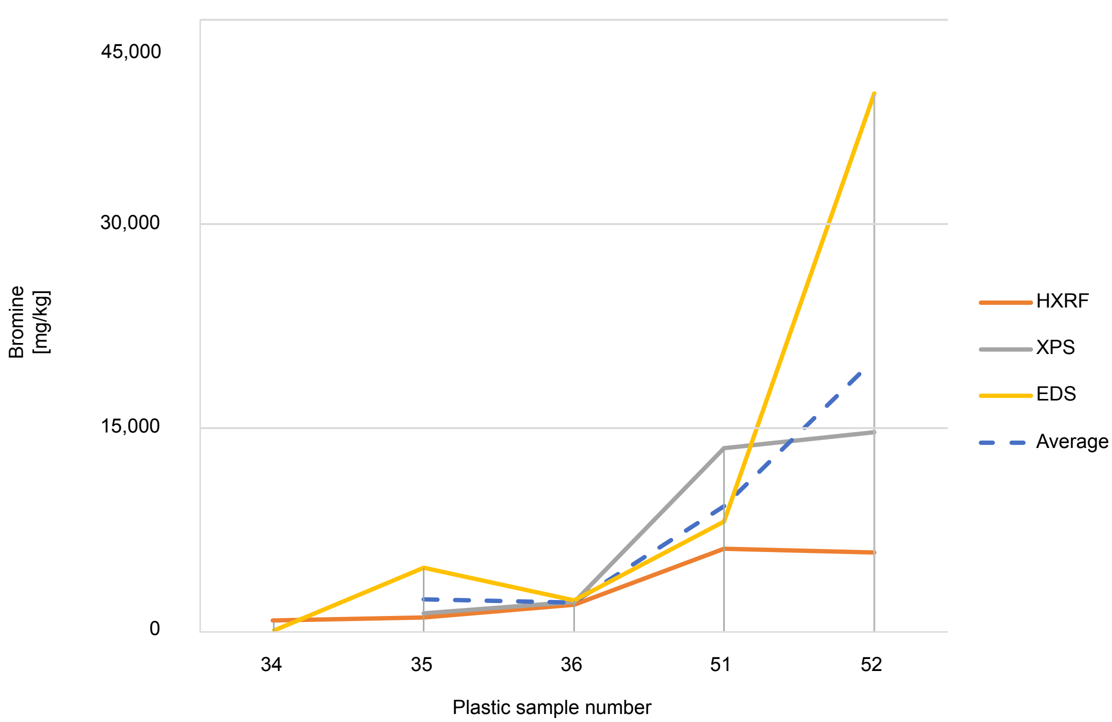

Fig. 4. Comparison of bromine concentrations in selected plastic samples among the different techniques used.

of urban solid waste and special management waste located in Jalisco, which does not comply with environmental normativity, such as perimeter fence, geomembrane placement, presence of infectious and dangerous biological waste, cover the waste, extraction, collection, conduction and control of the generated biogas, a system that guarantees the collection, conduction and removal of the generated leachate, presence of scales, medical services, services of surveillance, among others aspects.

The above, reveals an incorrect waste management increasing the risks of fire generation and causing emissions of toxic compounds into the atmosphere and ash with heavy metals left in the soil. Only since 2016 to 2019, twenty-eight fires have been registered in landfills. The fires took between five days and two weeks to be extinguished by the Civil Protection and Fire departments of the State and the municipalities. In the first half of 2019, nine claims occurred in two of the largest landfills of the state located in Tonalá and Zapopan (El Informador 2019).

Separation methods for plastics with brominated flame retardants

Due to methods and techniques were not identified for the identification of brominated plastics, according to the literature, 10 methods are potentially effective for the identification of brominated flame retardants in WEEE plastics (Haarman et al. 2016, Zhao et al. 2018, Beigbeder et al. 2013, Gent et al. 2011):

- Visual separation
- Separation at the source
- Beilstein's test
- Sliding Spark Spectrometry
- X-ray fluorescence
- Laser-based methods
- X-ray transmisión
- Separation by infrared spectroscopy (NIR)
- Sink and floatation
- Magnetic levitation

Types of treatment for plastics with brominated flame retardants

Chemical treatment refers to the treatment of plastic waste through physicochemical processes, in which the molecules of the plastics are broken in order to obtain from them monomers or products of any value to the petrochemical industry and convert them again into raw materials (López et al. 2017). Different techniques have been applied in plastics with brominated flame retardants, such as:

- Pyrolysis
- Hydrolysis
- Metanolysis
- Glycolysis
- Hydrogenation
- Gasification
- Creasolv method

They are considered complementary processes to mechanical treatments and offer the possibility of solving their limitations. Its application may be viable for mixed plastics; However, all plastics conversion technologies have to face the problem of variability in feed quality and composition.

Thermal treatments refer to processes of combustion under proper conditions. Persistent organic pollutes are destroyed during incineration at temperature above 1 100 °C with a residence time greater than two seconds in the combustion chamber. Also, processes of incineration with energy recovery and co-processing in cement kilns (SRI 2016) are suggest by Stockholm Convention on Persistent Organic Pollutants.

Analysis of the WEEE plastics treatment practices in the Metropolitan Area of Guadalajara

Based on the guidelines of Stockholm Convention on Persistent Organic Pollutants, brominated plastics should be separated from the recycling chain, so the route that these should follow is shown in **figure 5**. Plastics must be identified through one or the combination of previously mentioned techniques. Subsequently, those plastics that are free of brominated flame retardants can continue in the recycling chain. In contrast, those that were identified with flame retardants must be separated from the recycling chain and subjected to other types of treatments to eliminate the polymer bromine or, where appropriate, be subjected to a type of heat treatment or final disposal site that prevents its release into the environment.

Likewise, it is important to have the waste traceability manifest, to give certainty of its treatment, recycling, and destination.

In this sense, one of the proposals where Jalisco could start with the separation of contaminants in plastics is using an automated machinery based on X-ray transmission sensors for the separation of plastic fractions with heavy metals above of RoHs standards. One of the brands that design this type of machinery used in other countries is the English company Steinert, which has different models under the same separation principle.

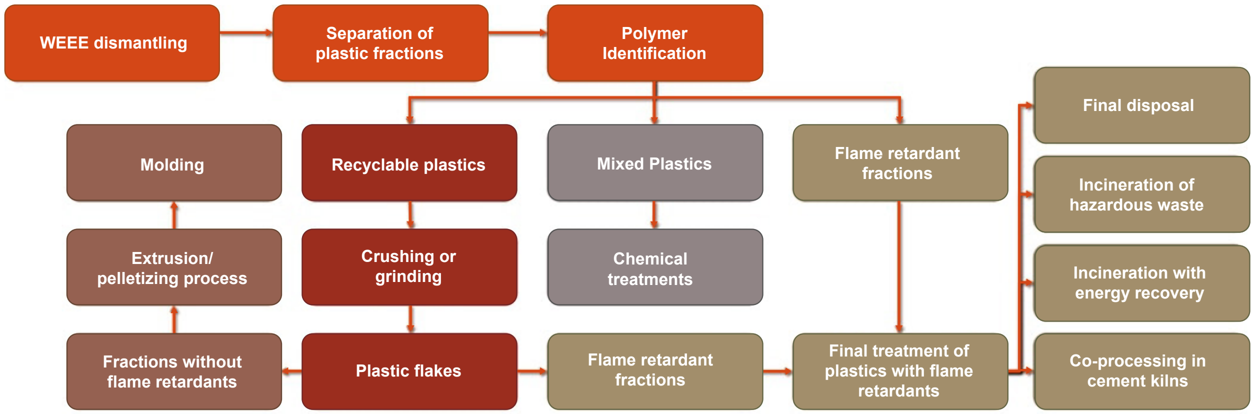

Fig. 5. Flow chart for handling WEEE plastics.

On the other hand, sending the WEEE plastics to landfills is not the best environmental option, due to their current conditions of those, in addition the world trend is to improve the handling of plastics. The European Union, in its strategy for plastic in a circular economy, includes the reduction of plastics in landfills through the promotion of economy improvement of and the quality of plastic recycling.

Likewise, industrial-scale plants were not identified for chemical treatments of brominated plastics so that chemical recycling could have potential from an energy, environmental and economic point of view; being convenient to continue with the research on chemical recycling towards the development of a pilot plant for this type of plastics. So, due to the disadvantages in the quality of the products and control of variables of a pyrolysis process on a laboratory scale, the processing of these plastics in refineries, whose characteristics of equipment and procedures are more robust, can also be explored. It is important to consider that there is no documented experience in the implementation of this type of treatment for plastics on a large scale, so it would be a challenge to ensure that the polymers arrive clean for processing (López et al. 2017).

While developing and implementing new technologies for the treatment of said waste, another proposal for those contaminated plastics is to store them in a landfill that fully complies with NOM-083-SEMARNAT-2003, and which is also exclusive for this type of waste.

This leads to a series of actions that involve the application of the principles of clean production, such as improving the design to make EEE, including its plastics, easier to recycle; expand, equip and technical capacity treatment and disposal of WEEE plastics; creation of viable markets for recycled and renewable plastic and lastly, develop and improve the management of WEEE and its plastics, to guarantee the quality of inputs for the recycling industry.

It is necessary to establish a management system for WEEE, including the participation of the companies dedicated to the manufacture of EEE in the Metropolitan Area of Guadalajara and the promotion of complete recycling, including plastics, based on international experiences. Establishing schemes of rates for transport and recycling of WEEE that allow incorporating processes of controlling hazardous emissions from recycling plastics in a pilot plant will represent a step towards optimal management in the framework of the circular economy of plastic for this waste stream. Finally, this encourages investment to establish treatments and expand disposal options for WEEE plastics. Still, suppose it continues absent beyond having a robust regulatory framework for WEEE. In that case, there will be no compliance, leading to an environmental deterioration that goes against a human right: a healthy environment.

CONCLUSION

Companies do not use any other technique combined with manual separation for the dismantling of waste electrical and electronic equipment, so an efficient separation of plastics with flame retardants is not achieved, which becomes a risk for health, since the disassembling companies are the first filter for the recovery of plastics. Therefore, the companies dedicated to the treatment of plastics require to be equipped with technology (controls) for the identification of traces of contaminants, as well as to develop a quality system based on the ability to verify the history of the residue, location, or application of plastic, through the supply chain, in order to monitor the general and real conditions of the type of treatment that will be given to the waste. WEEE plastics require differentiated treatment due to the presence of heavy metals.

The current model for handling WEEE plastics in the Metropolitan Area of Guadalajara is as follows: generation, dismantling, commercialization of the plastic fraction, grinding/crushing, pelletizing, marketing, and molding. In the commercialization stage, the traceability of WEEE plastics, which may contain significant amounts of flame retardants, is lost because adequate technologies are not used to identify them.

The e-waste that is processed more frequently in the selected companies are computers and telecommunications equipment and, to a lesser extent, household appliances and toys (video game consoles).

Of the companies in the study, it was estimated that each year they treat approximately 8928 tons of plastics.

The average concentration of heavy metals in WEEE plastics, and halogens such as bromine, increases concern considering that bromine exceeds on average four to ten times the limits established by the European Union in two samples (9225 and 20 003 ppm); as well as the management that is given to it, such as recycling, the type of product in which WEEE plastics will be converted is unknown and, those plastics that were not able to be marketed are sent to landfill, which due to inadequate management of the final disposal site, periodically suffer fires.

Although HXRF is not as accurate as the other techniques used, this technique proves to be a quick, easy-to-use, and inexpensive option for estimating the concentration of heavy metals in WEEE plastics. The use of other techniques should be applied according to the needs of the company being evaluated, since the XPS and EDS techniques turn out to be much more expensive.

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