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Process simulator and environmental assessment of the innovative WEEE treatment process

N. Menad [a,*], N. Kanari [b], Y. Menard [a], J. Villeneuve [a]

[a] BRGM, 3 av. C. Guillemin, BP 36009, 45060 Orléans Cedex 2, France
[b] Université de Lorraine, UMR 7359 CNRS, CREGU, GeoRessources Laboratory, 2 rue du Doyen Roubault, TSA 70605, Vandoeuvre-les-Nancy Cedex, F-54518, France

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A B S T R A C T

The Waste Electrical and Electronic Equipment (WEEE) is one of the fastest growing residual materials as a result of huge production of the Electrical and Electronic Equipment (EEE), its market expansion and technological progress in its conception. The complex compositions of WEEE (precious, strategic and rare elements, ferrous and non-ferrous metals, plastics, hazardous substances…) and its often miniature design lead to the technical and environmental difficulties to propose an efficient and viable flow-sheet for WEEE treatment and for the recovery process.

In this context, this study deals with delivering a predictive simulation tool (simulator) for the WEEE physical treatment (size reduction and sorting) useful for coherent matter balance calculation. Calculated material flows are then available for further environmental assessment.

The simulator approach is based on combining the flow-sheets, the phase model, the mathematical models and a set of algorithms to get a representation of a given situation in terms of material flows circulating between processes. Data optimization and assessment of the simulator output led to the establishment of an enhanced and innovative process for the WEEE processing.

Further, this study provides a methodology to assess the impact of the implementation of a WEEE recycling technology that takes into account economic, social and environmental consequences. Results linked to the chosen examples for aluminum and ABS plastic recycling from WEEE by the established process and their use instead of virgin products showed an important profit for these recycled materials from economic and environmental points of view. In this paper, a developed REWARD process was simulated by using a tool based on the USIMPAC™ software architecture.

1. Introduction

The worldwide production of Waste Electrical and Electronic Equipment (WEEE) is estimated to about 20–50 Mt per year, making up 1–3% (8% in rich countries) of municipal waste (Robinson, 2009; Widmer et al., 2005). EU countries have generated some 9.6 Mt of WEEE in 2011. The resulting WEEE deposit is expected to grow from around 8.5 Mt in 2005 to 10.5 Mt in 2014. The volume of WEEE will increase in the coming decades with an expected rate of at least 3% to 5% per year, about three times higher than the growth of municipal waste production (Gramatyka et al., 2007). Currently only 25% of small appliances and 40% of larger appliances are recycled in Europe. A large part is incinerated or exported outside Europe (Africa, China and India) where it is disassembled under inadequate working conditions (Zoeteman et al., 2010). WEEE needs increasing recycling to generate materials of high added value. Therefore, a high rate of recycling will be necessary. End-of-life WEEE production also increases with a yearly rate of 2.5%. As shown in Fig. 1, the plastic components constitute between 5% and 70% of the weight of WEEE (Anonymous, 2007). An overall composition of the WEEE is also given in Fig. 1.

WEEE contains a large amount of different engineering plastics that need further separation to produce high added value plastics. WEEE also contains large quantities of recoverable metals such as steel, stainless steel, brass, Al, Zn, precious metals (Au and Ag), platinum group metals (Pt, Pd, Rh, Ir, Os, Ru) and rare earth metals (Sm, Eu, Y, Gd and Dy), which are currently hardly recycled (Menad and van Houwelingen, 2011). The prices of these metals are expected to increase by 15% annually due to increased demand, quotas, supply shortages and limited numbers of suppliers. The "Waste Electrical and Electronic Equipment" contains also hazardous materials such as PCB (PolyChloroBiphenyl), cadmium, and mercury.

The literature review revealed that a good number of investigations are recently devoted to correlating the composition complexity, material design and typology of residual streams with the efficiencies of the physical and metallurgical recyclability based on simulation and modeling developments. The work performed by van Schaik and Reuter (2010) linked product design and liberation modeling in order

* Corresponding author.
E-mail address: n.menad@brgm.fr (N. Menad).

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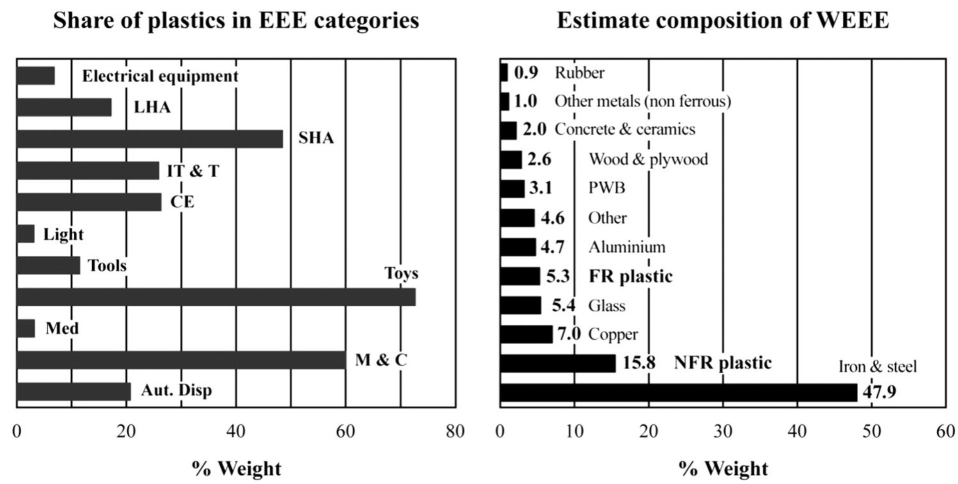

Fig. 1. Average plastic in each of the E&E categories (left) and its overall content in WEEE (right).

to predict and monitor e-waste recycling technologically, economically and environmentally. The simulation process, including metallurgical processing and environmental analyses as well as the developed models, are also used for the recycling of light emitting diode lamps (Reuter and van Schaik, 2015). Another report (Reuter et al., 2015) gave a comprehensive methodological description digitalization of the whole system using simulation tools from the primary minerals and metallurgical processing industry to capture the destination of all materials as a function of techno-economically design of the system.

A dynamic-model-based analysis established by Reuter and van Schaik (2012) tends to describe the opportunities and limits of recycling of complex, multimaterial products, specifically cars and electronic wastes, as well as wastewater and surface-water systems. This is an extension of the work performed previously by (Reuter et al., 2006) regarding the fundamental limits for the recycling of end-of-life vehicles and those deeply overviewed and developed with respect to design for recycling and 'sustainability' (Reuter, 2011).

This paper will present some results of simulation of the innovative processing of WEEE taking into account the environmental aspects.

2. Materials

In order to develop and implement both environmentally friendly and economically viable recycling processes, in-depth characterization of this specific material stream, oriented towards mechanical separation amenability, is imperative. It has been proved that it is worthwhile to recycle electronic scrap in spite of the fact that the content of precious metals (Au, Ag, Pd) steadily decreases. It is realized, though, that conventional recycling techniques which are oriented towards precious metal recovery is being faced with challenges in terms of the economic reward. Alternatively, a full material recovery involving ferromagnetic, nonferrous metals, precious metals and non-metallic, through mechanical separation, may be applicable both economically and technically.

The WEEE sample taken from the Smasher process shown in Fig. 2 was characterized by the combination of different separation techniques, such as classification, sink float analysis, hand held NIR and XRF devices, magnetic and eddy current separators (Menad et al., 2013).

The results obtained show that more than 60% of the WEEE sample is larger than 20 mm. It contains more than 50% plastics which are predominantly in the size fraction +20 mm. The printed circuit boards represent about 5% and most of them are in the coarse fraction. It contains more than 12% ferrous metals and most of them are in the coarse fractions. The same estimation is made for non-ferrous materials. This sample contains around 5% fine particles (−2 mm). The majority of electric wires are concentrated in the size fraction +20 mm (8%).

3. Method and components of a simulator

3.1. Simulation based approach

In the industrial production field, a simulator is basically aimed at helping process engineers and scientists to model plant operation with available experimental data and to determine optimal treatment configurations that meet production targets. The simulator can also

Fig. 2. Aspects of investigated sample of WEEE.