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Design and construction of an industrial mobile plant for WEEE treatment: Investigation on the treatment of fluorescent powders and economic evaluation compared to other e-wastes

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ABSTRACT

The main objective of this manuscript is the description of a mobile demonstration plant designed and built for the recovery of metals from waste of electrical and electronic equipment and other waste such as spent batteries and exhausted industrial catalysts. The plant was designed within the European FP7 framework HydroWEEE-demo (2012–2016) and can offer an effective proposal to addressing the problem of the electronic waste, reducing the environmental impact of their not correct disposal, recovering critical materials as rare earths and precious elements, and giving economic benefits, moreover by it, it is possible to overcome the problem of moving hazardous wastes from one country to another one.

Details about the process to recover rare earths from fluorescent materials are presented. Two alternative treatments are showed with and without recirculation of the residual solutions. Economic analysis shows that with the actual product price (14 €/kg) only the process, in which solution recirculation is present, provides a return on the investment. Positive gain is possible if the plant works at its highest capacity and if the price growths up to 20 €/kg the gain increases about 20% of operating costs (process with recirculation, 2 batch/day). In the process without recirculation of the solution, to obtain the same ratio between gain and operating cost it is necessary that the price increases up to 26 €/kg. About other e-wastes, economic analysis has shown that the highest gain is provided from the PCB treatment.

1. Introduction

The issue of waste, especially of Waste Electrical and Electronic Equipment, WEEE, is becoming much more important within of recycle of special waste, given their large consumption. The interest of the countries in respect to these waste is gradually growing, despite only a small fraction of them is collected, treated and recycled. WEEE represent a source of metals, which have been extracted from ore minerals, where they are often present at low concentrations: indeed, these are included at higher concentrations as the pure metals or metallic alloys in electrical and electronic equipment.

Many institutions from different countries have enacted laws to improve the reuse, the recycling and the recovery of metals, plastics and other parts from WEEE with the aim to reduce disposal, start research activities and construct the first treatment plants.

The European directives related to WEEE are: Directive on the Waste from Electrical and Electronic Equipment (Directive 2002/96/EC), the Directive on the Restriction of Hazardous Substances (RoHS) (Directive 2002/95/EC) and more recently the Directive 2012/19/EU that encourage the recycle of the waste and set the recycling standard to reach in the future [1–3].

The metals from WEEE can be recovered by mechanical, pyrometallurgical and hydrometallurgical processes which depend on the subsequent use. The first step, for a typical WEEE process, is the dissemble of the waste to obtain glass, plastics, and metal components that are separately treated: to product energy, refine the several parts by further treatments, or take to the special landfill [4]. Representative reviews about this topic were reported various authors [5–8].

Many scientific works described the processes to recover metals from these equipment at the end of their useful life. Table 1 reports a resume of the state of art about WEEE treatment.

The cited articles showed as the interest about the WEEE recycling is continuously in growth, in this scenario two important European Projects were born: HydroWEEE projects. In the first project the hydrometallurgical processes for the recycling of

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Table 1
WEEE treatment—state of art.

WEEE	Method	Process	Aim	Reference
Li–ion battery	Mechanical	Crushing, sieving, magnetic separation, fine crushing and classification	Materials separation	[9,10,16]
	Chemical	Melting by heated ionic liquid	Materials separation	[14]
	Thermal	Calcinations	Alloy recovery	[10]
	Chemical	Acid leaching, precipitation, solvent extraction, Bioleaching, alkali leaching, leaching by organic compound, supercritical leaching	Metal recovery	[9–11,13,34,40]
	Electrochemical	Potentiostatic electrolysis, electrowinning	Metal recovery	[12]
Printed circuit boards	Mechanical	Electrostatic separator, magnetic separator, floatation, milling, crushing, grinding	Materials separation	[42]
	Thermal	Pyrolysis, gasification	Plastic degradation, metallic materials and glass separation	[42]
	Chemical	Acid leaching, ammonia—ammonium leaching, chloride leaching, solvent extraction	Cu recovery	[15,19,21,35,36,41,42]
	Chemical	Leaching with: acid, cyanide, halide, chlorine, thiourea or thiosulfate, bioleaching, solvent extraction, cementation, ion exchange, precipitation, adsorption, electrowinning, cementation	Precious metal recovery	[18,20,36,42]
	Chemical	Supercritical fluids depolymerization and hydrogenolytic degradation	Non-metallic conversion	[17]
Liquid cristal display	Chemical	Chloride-induced vaporization, acid leaching, solvent extraction	Indium recovery	[22–25,43]
Lamps and CRT	Mechanical	Crushing, grinding, brushing	Materials separation	[29]
	Chemical	Acid leaching, solvent extraction, super critical solvent extraction, selective precipitation, ionic-exchange	Rare earths recovery	[5,26,27–33]

fluorescent lamps, CRTs, LCDs, PCBs and Li–ion spent batteries (LiB) were developed; in the second one the processes were implemented and two industrial demonstration plants were constructed. Hence this manuscript is addressed at presenting a successful example of urban mining, achieved within EU-FP7 funded projects: the details of the projects and the results mainly focused on the description of the experimental data from laboratory to industrial scale for the rare earths recovery from fluorescent materials.

2. Design and construction of an industrial mobile recycling plant

2.1. Background: HydroWEEE and HydroWEEE demo projects

The two important European Projects were found, HydroWEEE projects (Innovative Hydrometallurgical Processes to recover metals from WEEE including lamps and batteries), with the goal to develop hydrometallurgical processes to treat WEEE and other types of waste for the recovery of metals. In the first project, HydroWEEE 231962 (2009–2012), the hydrometallurgical processes for the recycling of fluorescent lamps, CRTs, LCDs, PCBs and Li–ion spent batteries were developed. In this phase the research activities were mainly focused on the laboratory scale and the work included a characterization of the initial materials, leaching tests to define the best reagents to dissolve the metals of interest and finally the experiments to recover the metals from leaching solutions. The results of the tests were used to describe the flow sheets and the mass balances of the processes that are tested in the pilot scale using portable prototype plant. Moreover in this phase a preliminary economical analysis was performed. The same processes were implemented in the second phase of the project, HydroWEEE demo 305489. The optimizations were especially focused on the reduction of the reagents with particular attention to water consumption. The wastewater treatment and recirculation of the treated water were integrated to the processes, in this manner the water consumption and the amount of the wastewater were reduced. Other implementations were focused to increase the total recovery and purity of the final products. The initial characterization and preliminary tests of the WEEE residues have showed that fluorescent powder of lamp contains 5–10% of Y, as oxides with other REs (mainly Eu and Tb), the CRTs' powder has 10–15% of Y and traces of Eu, the ground electrode material contains 23–25% of Li and 2–3% of Co, the LCDs material contains around 200 g/t of In, and finally PCBs material has around 25–28% of Cu, 400–800 g/t of Au, and 1400–1900 g/t of Ag. These materials are the initial powders feed to leaching step. The dissolution is carried out with sulfuric acid and in presence of hydrogen peroxide only for Li–ion spent batteries and PCB powders. In the case of PCBs, this is followed by a thiourea leaching step (for Au and Ag dissolution). Metal recovery from the leach liquor is carried out by selective precipitation operations, according to each of the specific metals to be recovered. The products are recovered with extraction efficiencies of around 95% for Y and Eu (lamp and CRT powders treatment), 90% for Cu, Au, Ag (PCB treatment), 93% for Li, and >97% for Co (LiB treatment) and In (LCD treatment), with respective purities of 97% (yttrium oxide from lamp), 95% (yttrium oxide from CRT), 95% (cobalt carbonate from LiB after solvent extraction), 18% (indium from LCD), 93% (Cu) and 80% (Au + Ag from PCB). These products are not suitable for direct commercialization given their purity but can be sold to companies that could be refined them and commercialized. The main results of the research activities were summarized in several articles [26,31–38]. In one of the above mentioned articles, a life cycle analysis of the treatments was described. The results of this preliminary analysis showed that the processes appear beneficial for the environment in terms of CO_2 emissions, especially for fluorescent lamps and CRTs [38].

Moreover the activities of the second part of the European project were also focused on the design of two industrial plants, one stationary and one mobile, to treat lamps, CRTs, PCBs, LCD and Li–ion spent batteries, in order to test the performance and prove the viability of the processes from an integrated point of view (technical, economical, operational, social) including the assessment of its risks (including health) and benefits to the society and the environment.

In literature another scientific work was found that deals the design of an integrated mobile recycling plant [39]. In this article the authors described a mobile plant constructed in two containers

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