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Recycling of waste electrical and electronic equipment

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ABSTRACT

Purpose: This paper describes the current status of waste electrical and electronic equipment recycling and disposal in Europe, and its impact on the environment, human health and the economy.
Design/methodology/approach: The production of electric and electronic equipment is one of the fastest growing areas. This development has resulted in an increase of WEEE. Increased recycling of WEEE is supposed to limit the total quantity of waste going to final disposal.
Findings: Based on comprehensive bibliography, this article reviewed the implementation of strategies of WEEE treatment and the recovery technologies of WEEE.
Research limitations/implications: Further studies should be undertaken in order to develop integrated WEEE recycling and disposal systems.
Practical implications: In view of the environmental problems involved in the management of WEEE, many countries and organizations have drafted national legislation to improve the reuse, recycling and other forms of recovery of such waste so as to reduce disposal. Recycling of WEEE is an important subject not only from the point of waste treatment but also from the recovery of valuable materials. The study of WEEE properties is important for a further recycling and eventual reuse.
Keywords: Environmental management; Recycling; Waste treatment; Electronic scrap

1. Introduction

The importance of waste electrical and electronic equipment (WEEE) recycling has become more evident over the last ten years. It is expected that quantities of WEEE will increase rapidly in the near future. Actually, WEEE constitutes 4% of municipal waste in EU [1].Germany has a yearly electronic scrap waste stream of about 1.8 million Mg. In Austria the total WEEE amounts 85000 Mg per year with a tendency to rise, whereas 5000 Mg are declared as hazardous waste [2]. In Poland, 30000 Mg of WEEE were generated in 2005, the amount of WEEE is expected to increase by at least 3÷5% per year [3].

Due to their hazardous material contents, WEEE may cause environmental problems during the waste management phase if it is not properly treated. Many countries in the world have drafted legislation to improve the reuse, recycling and other forms of recovery of such wastes to reduce disposal. The European Parliament has adopted on 13th February 2003 two directives, the Directive on the Waste from Electrical and Electronic Equipment (WEEE) [4] and the Directive on the Restriction of Hazardous Substances (RoHS) [5]. The Polish WEEE legislation came into force in October 2005 [6], requiring producers to start take back and recycle electronic and electrical appliances. The Polish WEEE legislation and activity of recycling systems in Poland are expected to reduce the amount of electronic waste going to landfills by up to 80% significantly reducing the overall impact these products have on the environment [7]

Recycling of WEEE is an important subject not only from the point of waste treatment but also from the recovery of valuable materials. WEEE is non-homogenous and complex in terms of materials and components. In order to develop a cost effective and environmental friendly recycling system, it is important to identify and quantify valuable materials and hazardous substances to understand the physical characteristic of this waste stream [8].

2. Characteristic of WEEE

In the WEEE Directive, electrical and electronic equipment is defined as being equipment that is dependent on electric current or electromagnetic field to function, and equipment for the generation, transfer or measurement of such currents and fields. The voltage rating to which that applies ranges from 0÷1000 V for AC and 0÷1500 V for DC [4].

The WEEE Directive has ten categories of electrical and electronic equipment and they are categorized as follows [4]:

- Large household appliances (e.g. refrigerators);
- Small household appliances (e.g. coffe machines);
- IT and telecommunications equipment (e.g. computers);
- Consumer equipment (e.g. radio and TV sets);
- Lighting equipment (e.g. fluorescent lamp);
- Electrical and electronic tools with the exception of large scale stationary industrial tools (e.g. drills and saws);
- Toys, leisure and sports equipment (e.g. video games);
- Medical devices with the exception of all implanted and infected products (e.g. X-ray equipment);
- Monitoring and control instruments (e.g. smoke detectors);
- Automatic disperses.

The composition of the WEEE depends strongly on the type and the age of the equipment. For example WEEE from IT and telecommunication systems contain a higher amount of precious metals than scrap from household appliances (Fig. 1). In older devices the content of valuable metals is higher but also the content of hazardous substances than in newer devices [2].

Generally, WEEE are composed of metal (40%), plastic (30%) and refractory oxides (30%) [9]. As shown in Figure 2, the typical metal scrap consists of copper (20%), iron (8%) tin (4%), nickel (2%), lead (2%), zinc (1%), silver (0.02%), gold (0.1%) and palladium (0.005%) [10]. Polyethylene, polypropylene, polyesters and polycarbonates are typical plastic components [9].

One of the important problems in the treatment of WEEE is the content of substances such as heavy metals and organic compounds. In combination with halogens in the plastic fraction they can form volatile metal halides but they also have a catalytic effect on the formation of dioxins and furans [10].

3. Processes for the recycling of WEEE

Actually, existing processes for the recycling of electronic scrap focuses on separation of ferrous metals, nonferrous metals, and precious metals [11]. Figure 3 illustrates a typical recycling process of waste electrical and electronic equipment [8]. Incoming electronics are manually sorted to the product groups or directly transferred to another recycling entity. Products may be transferred if they are still functional, or exceed the recycler's capacity, capabilities, or permits. Products accepted for processing are sorted and staged for disassembly [11].

Generally, the following methods for the treatment of electrical and electronic scrap are applied [2]:

- mechanical separation;
- thermal treatment;
- hydrometallurgical treatment;
- electrochemical treatment.

Fig. 1. Waste electrical and electronic equipment

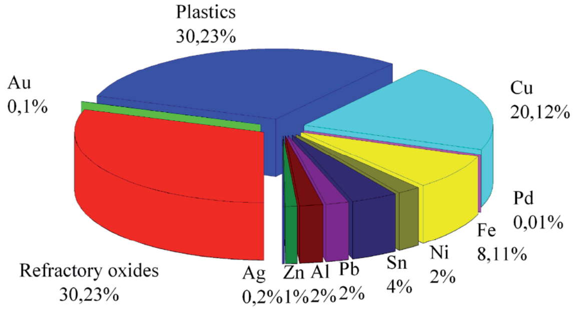

Fig. 2. Characteristic material composition of WEEE [10]

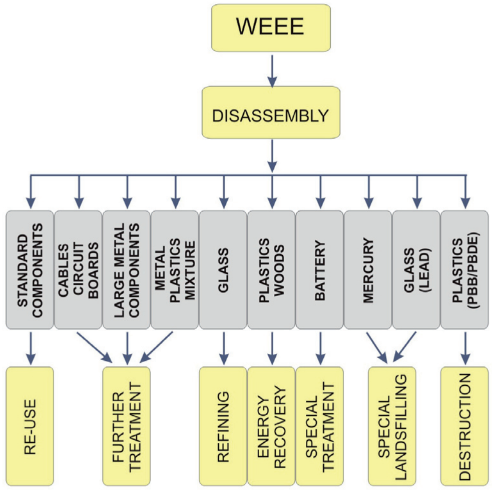

Fig. 3. Typical recycling process of WEEE [8]

3.1. Mechanical separation

The different components and devices can be separated in a first mechanical step into various fractions such as metals (iron, copper, aluminium etc.), plastics, ceramics, paper, wood and devices such as capacitors, batteries, picture tubes, LCDs, printed circuit boards etc. These fractions can then be further treated. Plastics are disposed off because of the high halogen content and the metallic fractions are further treated in different metallurgical processes. Printed circuit boards can cause problems because the metallic and non-metallic phases are highly crosslinked [2].

After hand sorting and the removal of the contaminants (mercury switches, PCP containing capacitors etc.) the material undergoes a first size reduction step [12]. Material separation may be based on magnetic, electrostatic, density, visual, or other characteristics. A series of magnets may be used to remove ferrous metals from conveyors. The use of permanent magnets instead of traditional electromagnets can significantly reduce energy consumption [11]. Reprocessing, multiple passes through the shredder and magnets, may increase the ferrous metals recovered [13]. Following the removal of ferrous metals, pieces may be slowly conveyed past pickers to remove large pieces of designated materials such as glass or plastics. Grinders and screens to separate pieces by size often precede nonferrous metal separation processes based on eddy currents, electrostatics, air, float-sink, or centrifugal force [11, 14]. Size reduction may also include subsequent shredding, grinding, or hammer milling processes connected by conveyors [11]. The range of devices in usage depends strongly on the composition of the scrap. The obtained fractions are enriched in certain materials and have to be further processed using other treatment methods such as pyrometallurgy or hydrometallurgy [2].

3.2. Thermal treatment

Pyrometallurgical processes include incineration, smelting in a plasma arc furnace or blast furnace, drossing, sintering, melting and reactions in a gas phase at high temperatures [10]. Incineration is a common way of getting rid of plastic material and other organics to further concentrate the metals [15]. The crushed scrap can be burned in a furnace or in a molten bath to remove plastics, leaving a molten metallic residue. The plastic burns and the refractory oxides form a slag phase [2].

In smelting reactions a collector metal such as copper or lead can by used. But also impure alloys can be made by smelting the crude metal concentrates. Silver and gold containing scrap materials can be treated in a copper smelter, but silver as well as other noble metals are tied up in a process for a long period. The majority of secondary copper and a main part of the electronic scrap is processed pyrometallurgically in a copper smelter, which include steps as reduction and smelting of the material, blister or raw copper production in the converter, fire fining, electrolytic refining and processing of the anode mud. In a modern secondary copper smelter, many different kinds of copper containing materials are recycled. Figure 4 illustrates a typical recycling process of waste electrical and electronic equipment containing copper [2]. Besides copper, WEEE materials contain nickel, lead, tin, zinc, iron, arsenic, antimony and precious metals amongst many others. The materials (e.g. electronic scrap) are fed into the process in different steps depending on their purity and physical state. The anode composition and the quality of the dust and slag fluctuate significantly due to the heterogeneity of the input materials. This is also the case with the anode slime which results from electro-refining [2]. Another possibility to recover base and noble metals form electronic scrap is the recovery via lead smelting processes.

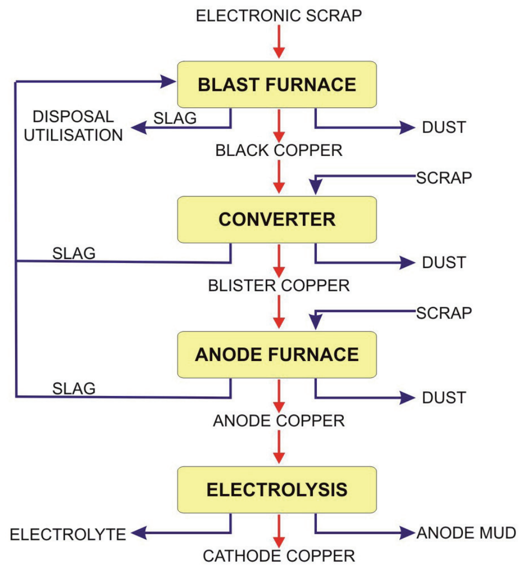

Fig. 4. Recycling process of WEEE containing copper [2]

Pyrolysis is a process where the material is heated up in an inert gas atmosphere. At certain temperatures the organic fractions (plastic, rubber, paper, wood etc.) decompose and form volatile substances which can be used in the chemical industry or for the generation of energy by combustion of the gases or oils. At the present there exists no process which uses this method in industrial scale [2].

3.3. Hydrometallurgical treatment

In hydrometallurgical treatment the main steps are acid or caustic leaching of solid material. This process normally requires a small grain size to increase the metal yield. From the solutions the metals of interest are then isolated and concentrated via processes as solvent extraction, precipitation, cementation, ion exchange, filtration and distillation. Leaching solvents are mainly H_2SO_4 and H_2O_2, HNO_3, $NaOH$, HCl etc. [2].

3.4. Electrochemical treatment

Most of the electrochemical treatment methods are usually refining steps and they are carried out in aqueous electrolytes, sometimes in molten salts. Only a few processes can be found in literature which uses shredded scrap directly in electrolysis. Examples are the iodide electrolysis where an aqueous KI/KOH solution is used to recover gold, silver and palladium from plated or coated metal scrap. Another process is the Fe-Process where copper based scrap is leached in a solution of sulfuric acid in the presence of trivalent iron. The leach solution is the electrolytically regenerated [10].

4. Discussion

All the mentioned methods have advantages and disadvantages. Using the mechanical separation there is an important advantage, that uncomplicated devices can be used to obtain different fractions, e.g. iron, nonferrous metals, light fractions (plastics etc.). The disadvantages are noise and dust formation. The recycling steps depend on the material and because of the high shear forces the temperatures increase and gas emissions (dioxins, furans etc.) can occur due to pyrolysis and other reactions. The obtained fractions have to be treated further in other processes or have to be landfilled as it is done at present with plastic fractions. In thermal treatment existing plants are available and high purity of metals can be obtained – often more than one metal, e.g. in a copper plant nickel is also a product as well as the noble metals. Composite materials are no problem because they are destroyed during the melting process [2].

Disadvantages are the waste gases and flue dusts. The halogen content can lead to dioxin problems, and the off-gas system has to be adapted. Noble metals stay for a long time in the metallurgical process and are obtained at the very end of the process. Enrichment of the metals is necessary because an increase in oxides increases also the slag content which further increases the metal losses. Less noble metals cannot be regained with this method (e.g. aluminium). On the contrary, aluminium has influences on the slag properties which are in most cases not wanted [16-20]. Hydrometallurgical methods also lead to high purity of the metals with the possibility to a selective leaching of the metals in various steps using different solvents. Disadvantages are the high volumes of leach solutions. Furthermore solutions can be corrosive and toxic. Metal losses occur due to composite materials. One problem is also the high amount of waste water.

5. Conclusions

Due to the Directive on the Waste from Electrical and Electronic Equipment (WEEE) and the Directive on the Restriction of Hazardous Substances (RoHS), the importance of WEEE recycling has become more evident. Nowadays, the pyrometallurgical treatment in copper smelters is the common process for the recycling of electronic scrap. But the treatment of electronic scrap especially material with high contaminations or amount of plastic needs always a combination of different steps, i.e. mechanical, thermal and hydrometallurgical, whereas the environmental regulations have to be considered. But the costs of sampling and analysis of base and precious metal scrap are quite high and they are often higher than the economics of processing. Furthermore the quantity and composition of the scrap changes continuously and therefore also the market value. Environmental restrictions on processing and disposal of the scrap are to be considered, for example the removal of mercury switches and capacitors. Large metallurgical plants, e.g. copper or lead smelters, may be able to charge high amount of WEEE but due to the decreasing quality and higher amount of plastic it will be more difficult in the future.

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