University of Belgrade
Technical Faculty in Bor

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and Industry of Serbia

XV International Mineral Processing & Recycling Conference

IMPRC
INTERNATIONAL MINERAL PROCESSING & RECYCLING CONFERENCE

Proceedings

Editors:
Jovica Sokolović
Milan Trumić

17-19 May 2023 | Belgrade SERBIA

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MOBILE PHONES – A VALUABLE COMPONENT OF E-WASTE STREAM

A. Radojević[#], S. Šerbula, T. Kalinović, J. Milosavljević, J. Kalinović
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ABSTRACT – As the fastest growing stream of waste, electric and electronic waste (e-waste) became one of the top priorities in the waste management policies in recent years. Since discarded mobile phones contain valuable metals such as gold, silver, platinum group of metals, copper, and nickel, as well as harmful ones, like lead and cadmium, the recycling should be considered both from the ecological and economical point of view. Metals in mobile phones are concentrated in printed circuit boards, as well as in batteries. Different technologies are being developed for the recovery of metals, plastic, and other components of the mobile phones.

Keywords: E-waste, Mobile Phones, Recycling, Environment Protection.

INTRODUCTION

The waste management data are critical in the process of creating policies for the treatment and disposal of all kinds of waste. Understanding the quality and quantity of generated waste, especially with the rapid urbanization and population growth, allow selection of a suitable management method. During 2016 more than 2 billion tonnes of municipal solid waste was generated in the world, on average 0.74 kg/person/day. The waste generation rates vary widely from 0.11 kg/person/day in Sub Saharan Africa to 4.54 kg/person/day in North America. In Serbia, the generation rate was at the world´s average, amounting to 0.72 kg/person/day. There is generally a positive correlation between the municipal waste generation rate and income level. The high-income countries (the gross national income – GNI, around US$12,500), account for 16% of the world's population and generate about 34% of the world's waste (683 million tonnes) [1]. Global consumption of materials such as biomass, fossil fuels, metals and minerals are expected to double in the next 40 years, while annual waste generation is projected to increase by 70% by 2050 [2], reaching 3.4 billion tonnes in 2050 [1].

Modern life is defined by various electronic devices and electrical equipment, from washing machines to smartphones. However, relatively short time of usage of some of the household appliances and portable devices, which cannot be easily reused, repaired, or recycled, is responsible for making it the fastest growing waste stream increasing at 3–5% per year in the European Union (EU). Electrical and electronic equipment type of waste is called WEEE or simply e-waste. The problem of fast-growing quantities of e-waste was recognized more than two decades ago, and the EU has made many improvements in waste management and legislative since the 1970s. The WEEE Directive 2002/96/EC was replaced with the Directive 2012/19/EU with the aim to

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prevent and reduce the negative environmental effects resulting from the resource use, generation, and management of e-waste through sustainable production and consumption, by supporting reuse, recycling, and other forms of recovery of such type of waste [2–4].

The generation of e-waste is strongly associated with the economic development, just like the generation of municipal waste. The high-income countries are generating 5 times the volume of e-waste generated by lower middle-income countries (the GNI US$1,026–4,035), that is 0.05 kg/capita/day compared to less than 0.01 kg/capita/day, respectively (on average 0.02 kg/capita/day). The share of recyclable materials from waste (paper, cardboard, plastic, metal, and glass), is also increasing with the economic development, ranging from 16% in low-income countries (US$1,025 GNI) to about 50% in high-income countries [1].

Considering all the categories of e-waste, smartphones are the most abundant electronic devices. As a result of the rapid technology development which simultaneously affects the improvement in the performances and the drop of prices, consumers replace their mobile phones more frequently [5]. The time of use of mobile phones is one of the shortest for all electronic devices, and lately it is getting shorter. Mobile phones are replaced after 3 years on average in developing countries, or in less than 2 years in developed countries [6]. However, compared to other electrical and electronic equipment, smartphones are more likely to be disposed of even if they are still in function, due to the reasons such as fashion trends and product obsolescence [7].

Discarded mobile phones should be considered from the ecological as well as from the economical point of view. They contain many harmful substances, such as Pb, Cd, and other chemicals with high potential to severely pollute the environment, and pose harm to the human health if not handled properly. On the other hand, many valuable materials such as Au, Ag, Cu, Ni, etc. can be recycled [5].

RESULTS AND DISCUSSION

In 2015, the European Commission started implementation of a new Circular Economy Action Plan (CEAP), with one of its priorities focused on the reduction of e-waste. In a circular economy, products, and the materials they contain are highly valued, unlike in traditional, linear economic model which is based on pattern “take-make-consume-throw away”. The CEAP is aimed to reduce the waste to minimum through reusing, repairing, refurbishing, and recycling of products. Benefits from implementation of the CEAP are numerous: reduced pressure on the environment, enhanced security of supply of raw materials, increased competitiveness, innovation, and opening new jobs. Between 2012 and 2018 the number of jobs linked to the circular economy in the EU grew by 5% reaching around 4 million jobs. One of the most effective environmental strategies of the CEAP approach is increasing product lifespan. For example, by repairing broken e-products, materials are kept longer in use. At the same time, by slowing down the production and consumption cycle, waste generation is prevented, as well as emissions from the production and transport are reduced, and energy is saved. Additionally, the measures such as introduction of a common charger for mobile phones/tablets are very simple to implement and yet could have big impact on the sum of e-waste generation worldwide [3,4]. The economic value of electronic products is lost when fully or partially functional products are discarded mainly because they are not reparable, the battery cannot be replaced, or the software is no longer supported. It should be noted that two types of lifespan exist. The "technical" lifespan refers to the products' technical abilities, while "social" lifespan is linked to the products' flexibility concerning social changes, changes in life situations, and changes in personal taste. Both aspects are a part of the sum quality of the product [7].

During 2012, out of 9 million tonnes of electrical and electronic products distributed on the EU market, 3.5 million tonnes were collected, of which 2.5 million tonnes were recycled or reused [3]. Large household appliances, such as washing machines and electric stoves, were the most collected ones, making 52.7% of all the collected e-waste. This is followed by consumer equipment (e.g. video cameras) with 14.6%, computer equipment (laptops, printers) with 14.1%, and small household appliances (vacuum cleaners, toasters) with 10.1% of the share. Other categories of electrical and electronic equipment make 8.4% of all the collected e-waste [8]. According to some estimation, an increase of 16–28% of e-waste for the EU region is going to happen every 5 years [6]. Due to the complexity of e-waste streams, the collected data need to be treated with caution, but still, represent a good reflection of the current situation in the EU [3].

During 2019, over 1.5 billion mobile phones were sold worldwide. The data from 2021 showed that China had the highest number of mobile phone users – 912 million. Although up to 80% of the materials in phones can be reused or recycled, the recycling rate of used phones in China is only 2%, and most of the phones end up with municipal waste or just "hibernate" [9]. Zhang *et al.* [5] showed that, approximately half of the respondents keep their last obsolete mobile phone at home because of stored personal information. 25% of respondents recycled their mobile phones through formal recycling channels. Also, recycling of packaging of mobile phones is important because it might also harm the environment since it contains plastic [9].

Laitala *et al.* [7] showed that among electric appliances included in the survey conducted in Norway, mobile phones were most frequently malfunctioning (28%), followed by dishwashers and laundry washing machines (12%), while 10% or less referred to malfunctioned refrigerators, freezers, and stoves. Out of all broken mobile phones, 55% were not repaired, for 19% the repairment failed, and only 16% of mobile phones were successfully repaired. The price and the availability of repair services, especially for mobile phones, are a crucial part of the circular economy. By increasing phone lifespan, better resource utilisation and less waste generation is obtained [7].

By the recycling technologies, materials are recovered and extraction of natural resources is avoided. Although recycling rate is globally low, amounting to 13.5%, it varies among countries with different income level. For example, in low-income countries the dominant disposal method is open damp with 93% of the total share, while recycling rate is less than 4%. On the other hand, in high-income countries, open dumps account only for 3% compared to recycling with 29% of the share. In Europe and Central Asia, the data showed similar share of unspecified landfilling and recycling (20.1% and 20%, respectively), with open dump (25.6%) as the preferred method. The data about Serbia (upper middle-income country, US$4,036–12,475 GNI), showed enormous gap between unspecified landfilling (73.9%) and recycling (0.8%) [1]. The average recycling rate of e-waste in the EU region is about 40% with some differences, for example, during 2016, the recycling rate of e-waste in Croatia was 81.3%, while in Malta was 20.8% [8].

Mobile phone producers, such as Apple [10], Huawei [11], and Samsung [12], and producers of other electronic devices [13,14] have already launched recycling programs, as measure for fulfilling an environmental corporate social responsibility. However, an effective recycling program of mobile phones must overcome the key barriers to consumers' participation, such as the lack of economic incentives and the inconvenience of return processes [9].

The precious metals (e.g. Au, Ag, and Pd) are widely used as contact materials or plating layers due to their electric conductivity and chemical stability. Moreover, e-waste contains about 10 times more precious metals than the corresponding natural minerals, providing a strong incentive for recycling it [15]. According to the data, 1 t of waste mobile phones contains 347 g of Au on average [16], while about 100 kg of Cu can be recovered from 1 t of used mobile phones [17], thus the recovery of materials has significant financial benefit other than environmental.

The typical recycling process of smartphones and tablets (Fig. 1) consists of separate processing of printed circuit boards and batteries [18]. Batteries incorporated in all kinds of e-waste should be collected, removed (manually, mechanically, chemically or in other way of handling) [4], and subjected to the recycling requirements of the Battery Directive 2006/66/EC.

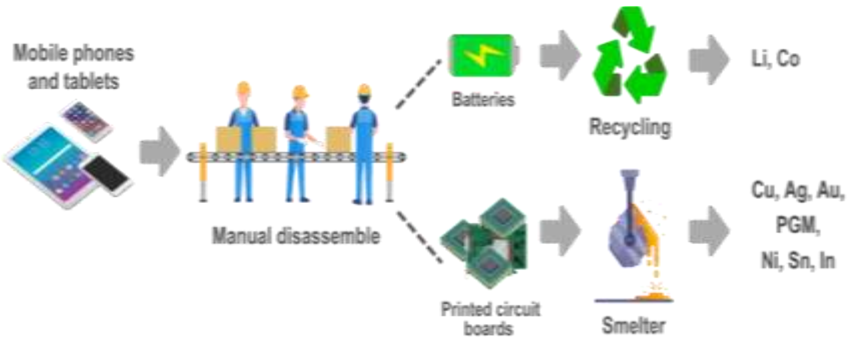

Figure 1 The end-of-life processes for smartphones and tablets (adopted from Schischke *et al.* [18])

However, recycling activities also have negative impact on the environment. Sugiyama *et al.* [17] estimated environmental impact of transportation and activities related to recycling of end-of-life mobile phones in Japan. According to simple mathematical model based on the total CO_2 emissions, a shipping transportation length has a biggest influence on environmental impact. Although shipping contributes only about 16% to the total fuel consumption of all traffic related sources, these emissions significantly contribute to emissions of pollutants from all transport modes, e.g. shipping emits approximately 1,200 times more particulate matter than aviation [19].

Printed circuit boards in mobile phones

Most of the printed circuit boards (PCBs), which are an essential subset of mobile phones, are incinerated or landfilled, causing pollution due to the emission of toxic compounds such as metals, dioxins, furans, polyhalogenated organic pollutants (POPs) and polycyclic aromatic hydrocarbons (PAHs). Heavy metals such as Pb, Cd, and Hg can leach on landfill sites, while gaseous compounds diffuse in the air. Within PCBs, Cu and Ni are the most abundant metals (Fig. 2), with 13–26 times higher content compared to natural resources, while the most valuable metal is Au, with almost 100 times higher concentration compared to ores. However, the main problem of metal recovery process is much lower concentration of Au compared to the base metals. The first step in recovering metals from PCBs is often selective dissolution of base metals in order to concentrate Au in a solid residue for subsequent recovery. The leaching of base metals is mostly carried out with strong acids (sulfuric, nitric or hydrochloric acid, or *aqua regia*) with adequate oxidant (H_2O_2, Cl_2, O_2, or even bacteria), since the metals are present in PCBs in their elemental forms [20]. Knowing the negative effects of strong acids, eco-friendly processes, compared to conventional methods, have been developed for recovery of base and other metals. Rao *et al.* [20] optimized the selective leaching process of Cu and Ni at lower temperatures (30 °C), in which energy consumption and effluent generation is reduced. However, under these conditions, Au cannot be dissolved. Yet, formed gold-rich residue (Fig. 2) is easy to manipulate with and could be subsequently used for the obtaining gold by hydrometallurgy.

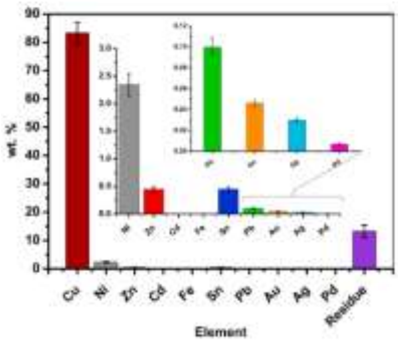

Figure 2 Composition (wt. %) of PCBs separated from mobile phones [20]

Batteries in mobile phones

The lead-acid, nickel-cadmium (Ni-Cd), nickel-metal hydride (Ni-MH), and Li-ion technologies are the most important battery systems used in electronic equipment today. The Ni-MH system was developed in 1989 for the replacement of portable Ni-Cd batteries, due to the toxic properties of Cd. Hence the newer batteries are based on the metals which have lower impact on the environment compared to Cd [21]. Lithium-ion batteries (LIBs) represent one of the biggest growth areas of the 21st Century since Li is preferred material among all metals because of the lightest, highest electrochemical potential, and the highest energy density. Spent LIBs usually contain 5–20% Co, 5–7% Li, 5–10% Ni and other metals (Cu, Mn, Al, Fe, etc.), 15% organic compounds, and

7% polymer separators. The composition differs depending on the producer and the type of the battery [22]. LIBs from mobile phones, other than plastics, contain about 15% Cu, 13% Al, 7.6% Fe, and 3% Ni, which all have high economic value. The total income of recycling of 1 tonne of LIBs could be more than US$3,200. Mobile phone batteries, have an average life span of 3 years, compared to batteries for electric vehicles, which have eight-year warranty, thus the recycling cycle of phone batteries is more than 2.5 times faster [23]. Recycling of spent batteries can be divided into three main processes: pre-treatment, metal extraction, and end-product preparation. Metal-extraction processes play the most important role in the entire recovery process and involve one of pyro-, hydro- or bio-metallurgical methods [21,22]. For example, Mennik *et al.* [23] showed that combination of flotation and magnetic separation could be a feasible technology with the recovery rate of 99% of metals and plastics from spent LIBs. However, hydrometallurgical methods have superiority because of industrial applicability, eco-friendly nature, high recovery rates and additional equipment is not required. The disadvantage of this method is the requirement of reagents such as strong acids used for leaching [22].

CONCLUSION

The environmental problems need to be resolved through sustainable resource management and circular economy in order to achieve zero-waste goal. As a fastest-growing stream of the e-waste, mobile phones, need to be properly managed and recycled due to the high content of hazardous components. The ecological benefit is equal to the economical, since two main components of the phones, printed circuit boards and batteries, contain valuable metals such as copper, nickel, gold, platinum group of metals, lead, cadmium, aluminium, etc. Importantly, the ongoing research studies are focused on the development of environmentally friendly recycling approach with the maximum recycling rate and minimum operating costs.

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