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THE RECOVERY OF METALS FROM ELECTRONIC WASTE: A REVIEW

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The scarcity of precious metals in the earth's crust necessitates finding secondary sources to fulfil the increasing demand for these metals. For example, a secondary source of precious metals can be made available through the metallurgical recovery of metals from electronic waste. However, conventional commercialized methods have limitations and can result in potential harm to the environment. Flotation, ionic liquids and chelating are the latest developments in this research area. This concise review entails the following:

- The worth of metals in e-waste,
- The current methodologies of recovering metals from the e-waste,
- Current research on the efficiency of environmentally friendly reagents

Keywords: metal recovery, e-waste, chelating, flotation, hydro/pyro metallurgy

INTRODUCTION

As the world's population is growing exponentially, the demand for natural resources is surging, and driving prices up, while deposits are diminishing [1]. The reserves of minerals are becoming uneconomical and technically difficult to extract due to low-grade deposits or the practicality of mining. The future supply of critical metals is thus concerning [1, 2]. Energy critical elements are critical resources for supporting emerging or transformative energy technologies, critical raw elements are high risk and supply-high economic importance materials. Platinum group metals are amongst this list, i.e. Ir, Pt, Rh, Ru, Pd, Os as well as Au, Ag and Cu [2, 3] A plot for element abundance in the earth's crust versus the price of elements is shown in Figure 1.The least abundant metals include Ag, Au, In, Pd, Pt, Re, Se, and Te at less than 1 ppm per ton of the earth's crust. Au, Pd and Pt appear to be the most expensive metals also. Ag, Au and Pd are used in printed circuit boards (PCBs), and Pt is mostly used in auto catalysts [3, 4]. Given the scarcity of these four metals in the earth's crust and their cost, it is worth finding secondary sources to supply these metals. Energy critical elements are circled in the graph in Figure 1 [2]. PCBs are a component within many waste electrical and electronic products. End of life electronic devices have far more valuable metals than natural deposits of precious metals. For instance, ewaste contains up to 26 times more Cu and up to 50 times more Au content compared to ores.

The metallic content of the PCBs may vary based on the manufacturer, the device, the year of manufacturing, and its origin [1], [3 – 7]. PCBs can have the following metals in %: Au (2,5), Ag (7,2), Al (19,7), Cu (34,5), Sn (8,8), Pb (5,5), and others (Fe, Ni, Si, Pt, Pd) 29 % [5, 7 - 12].As the precious metal content in PCBs is higher than in ores, recycling e-waste for economical and environmental benefits is gaining more attention. Using secondary metal resources can replace the primary metal resources in future and relieve the supply risk for critical metals [3 - 6, 9, 10]

THE METALLURGY OF E-WASTE

E-waste processing entails disassembling (removal of hazardous inorganic substances), upgrading (improving metal content), and refining (extraction of final products). Upgrading can be achieved by electrostatic, magnetic or gravity separation. Refining is where recovered materials are processed to produce the final metals [5, 9, 11, 13, 14]. Recent research in metal extraction processing involve the use of non-toxic lixiviants such as ionic liquids, amino acids and chelators.

Ionic liquids, amino acids, chelating

Ionic liquids are liquids which consist of ions at ~100 °C or lower. Some attributes of ionic fluids include; low melting point (<100 °C), negligible volatility, negligible vapor pressure, high conductivity, and high stability, [3, 15, 17]. Ionic liquids can either be hydrophilic or hydrophobic. Hydrophillic ionic liquids can be used for leaching metals from powders, whereas hydrophobic ionic fluids can be applied in metal extraction from leachates. 1-Butyl-3-methylimidazolium hydrogen sulphate is a hydrophilic, acidic ionic liquid which is less toxic and reusable. It is reported to effec-

BM Thethwayo (bkanyane@uj.ac.za), University of Johannesburg, Department of Metallurgy, Doornfontein, Johannesburg, South Africa

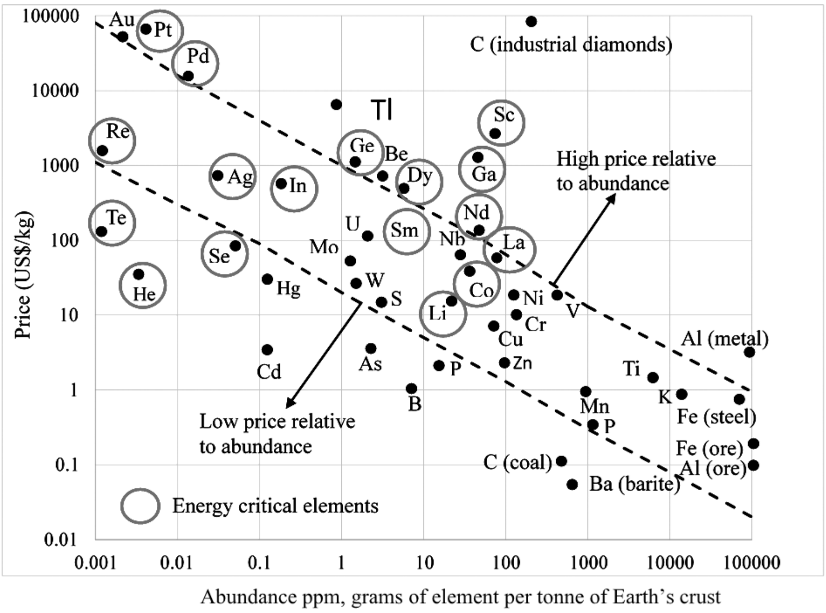

Figure 1 Price–abundance plot for many elements, specifically those for which there is a market. Energy-critical elements are circled in red [2]

tively leach metals (Au, Fe, Sc, Ti, Al and other precious metals) with-Fe_2O_3 or $H_2O_2/KHSO_5$ as oxidizing agents [17]. Examples of hydrophobic ionic liquids are 1-Butyl-3-methylimidazolium [hexafluorophosphate and bis (trifluoromethylsulfonyl)imide] and Cyphos 101 [Trihexyl (tetradecyl) phosphonium chloride]. These can effectively extract Ag, Au, Pd, Pt and Cu from chloride media, but Cyphos 101 was not effective for extraction from glycinehistine leach liquors [3, 17].

Amino acids: Glycine is an amino acid that is non-toxic, non-volatile, eco-friendly and has high metal affinities. It was successfully tested as a lixiviant for leaching of Cu, Pb and Zn from powdered PCBs. Glycine leach requires an alkali environment with oxidants such as (O_2, H_2O_2 or Cu^{2+}) and a catalyst [15, 16].

Chelating is a novel leaching method, where chelators/ligands are used which are more environmentally friendly than the current lixiviants. The research on the use of chelating agents in extracting metals from PCBs is ongoing. Reported research cites successful leaching of Cu, Zn and Ni [15, 18]. However, methods to precipitate or extract the chelated metals out of solution have not been reported. The advantage of chelating is that the lixiviant can be recycled; the drawback is lack of research on the topic [15]. None of the above methods are commercialized, conventional PCB treatments are highlighted below.

The flotation of e-waste

Recovery of metals from e-waste using flotation is said to be the most economical and environmentally friendly process [9]. Metals from e-waste can either be recovered by direct flotation [12] or reverse flotation [9]. Reverse flotation of ewaste can be easily achieved since metallic particles are hydrophilic, dense, have high surface energy and will therefore sink. On the contrary, fine plastic components are expected to float because they are naturally hydrophobic and lighter in weight [9]. Reverse flotation of metals from PCBs was demonstrated by [9] where Au and Pd were successfully recovered. Natural hydrophobic response was observed, without using frothers or collectors [9]. Recovery of metals from PCBs using direct flotation was demonstrated by [12]. Corflot was the best frother, while xanthogenates (sodium-amyl and ethyl), and X-23 were the best collectors. The optimal parameters that were the stirrer speed, air flow rate [9], and a pH [12].

Hydrometallurgy of e-waste

Typical lixiviants in precious metal leaching are cyanide, halides, thiourea and thiosulfate. Cyanide is widely used for gold recovery in industry, it is efficient and economical, however due to its toxic nature, alternative lixiviants are being considered. In halide leaching, chlorination is industrially applied. Its disadvantage over cyanide is the corrosiveness of the acids and the high toxicity of Cl_2 gas. Thiourea and thiosulfate are environmentally friendly but have low recovery rates, high consumptions and are more expensive than cyanide. Precious metals (Ag, Pd and Pt) in PCBs can be leached with the same chemicals and conditions used for Au. Metal recovery is achieved by electrowinning or cementation [3, 5, 6, 11, 14, 15]. Other metals (Al, Tn, Pb and Zn) can be leached with $HCl/MgCl_2/HNO_3$, while Cu and Ni can be leached with $H_2SO_4/MgCl_2/H_2O_2$ and the NH_3/NH_4^+ solution [4, 5, 11, 15, 16]. In bioleaching, the most prominent microorganism is thiobacillus ferrooxidans. Metals that can be extracted by bioleaching include Al, Au, Cu, Co, Mo, Ni, Pb and Zn. However, only Cu and Au are commercially extracted using bioleaching [6, 11, 19].

The pyrometallurgy of e-waste

Pyrometallurgical processes used to recover metals from e-waste include plasma smelting, blast furnace, submerged arc, top submerged lance, chlorination, volatilization, sintering, and incineration. Ewaste scrap is added as part of a feed blend in existing copper smelters (Miranda process) and zinc fuming processes. The Pb, In, Se, Te, Fe, Zn and other elements form a slag, a metal is made of 99,1 % Cu and 0,9 % (Au, Ag, Pt, Pd and Ni). The extract is electrorefined to recover the metals. Chlorination of gold containing scrap can recover up to 99,9 % Au [11, 13].

ADVANTAGES AND DISADVANTAGES OF E-WASTE PROCESSING

Hydrometallurgy is preferred over pyrometallurgy for e-waste treatment. Pyrometallurgy has high energy requirements, formation of toxic volatiles and gases, high slag volume, and potential loss of precious metals to the slag. The advantages of hydrometallurgy includes: No dust production, low energy consumption, high recovery rate and easy working conditions. The disadvantages of hydrometallurgy are the toxicity of the chemicals used, high acidity and high consumption of reagents which create potential environmental [3, 4, 11, 13, 15]. Bioleaching is greener and provides a safer and environmentally friendly process, with reasonably good and faster leaching kinetics compared to chemicals. However, it is slower and less efficient [5]. Flotation promises to be the future of metal recovery from e-waste given more developments and investments in this process.

Mining from ore can cost up to 13 times more than e-waste recycling. E-waste recycling can generate revenue, create income, and can be far more profitable than traditional mining [20]. Other benefits include reduction in demand for virgin ores, reduction in environmental impact of ewaste, hazardous materials and water consumption [1, 3, 20].

CONCLUSIONS

Due to the fast depletion of critical resources in the earth's crust, secondary sources of critical elements need urgent attention. Substantial research on metallurgical methods to recover metals from PCBs is widely reported, but very few of these methods are commercially operated. Given the toxicity and potential hazards of some of the currently used methods more research is needed to find alternative or improved methods. It is envisaged that establishing commercial operations for metal recovery from e-waste can benefit the environment, reduce the demand for metals, create jobs, and reduce amounts of waste disposal to landfills.

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REFERENCES

[1] Park JK, Clark T, Krueger N, Mahoney J, A review of urban mining in the past, present and future, Advances in Recycling and Waste Management 2 (2017) 2, 2475–7675.

[2] Hurd AJ, Kelley RL, Eggert RG, Lee MH, Energy-critical elements for sustainable development, MRS Bulletin 37 (2012) 4, 405–410.

[3] Paiva, AP, Nogueira, CA, Ionic Liquids in the Extraction and Recycling of Critical Metals from Urban Mines, Waste and Biomass Valorization, (2020)

[4] Ding Y, Zheng H, Li J, Zhang S, Liu B, Ekberg C, et al. Recovery of platinum from spent petroleum catalysts: Optimization using response surface methodology, Metals 9 (2019) 3, 354.

[5] Akcil A, Erust C, Gahan CS, Ozgun M, Sahin M, Tuncuk A, Precious metal recovery from printed circuit boards using cyanide and non-cyanide lixiviants-a review, Waste Management 45 (2015), 258–271.

[6] Woollacott LC, Eric RH, Mineral and Metal Extraction, An overview, Southern African Institute of Mining and Metallurgy (1994), (Monograph series)

[7] Balde CP, Forti V, Vanessa G, Ruediger K, Paul S, The global e-waste monitor 2017: Quantities, flows and resources, International Telecommunication Union, and International Solid Waste Association, Bonn, Geneva, and Vienna: United Nations University (2017), 116.

[8] Bidini G, Fantozzi F, Recovery of precious metals from scrap printed circuit boards through pyrolysis, Journal of Analytical and Applied Pyrolysis 111 (2015), 140–147.

[9] Ogunniyi IO, Vermaak MKG, Groot DR, Chemical composition and liberation characterization of printed circuit board communition fines for beneficiation investigations, Waste Management 29 (2009) 7, 2140–2146.

[10] Ogunniyi IO, Vermaak MKG, Investigation of froth flotation for beneficiation of printed circuit board comminution fines, Minerals Engineering, 22 (2009) 4, 378–385.

[11] Cui J, Zhang L, Metallurgical recovery of metals from electronic waste: A review, Journal of Hazardous Materials 158 (2008), 228–256.

[12] Oleksiak B, Siwiec G, Blanch-Grzechnik A, Recovery of precious metals from waste materials by the method of flotation process, Metalurgija 52 (2013) 1, 107–110.

[13] Matinde, E, Simate GS and Ndlovu S, Mining and metallurgical wastes: a review of recycling and re-use practices, Journal of the Southern African Institute of Mining and Metallurgy 118 (2018) 8, 825-844.

[14] Zhang Y, Liu S, Current status on leaching precious metals from waste printed circuit boards, Procedia Environmental Sciences 16 (2012), 560–568.

[15] Li H, Eksteen JJ, Oraby EA, Hydrometallurgical recovery of metals from waste printed circuit boards (WPCBs): Current status and perspectives–A review, Resources, Conservation and Recycling 139 (2018), 122–139.

[16] Oraby EA, Li H, Eksteen JJ, An alkaline glycine-based leach process of base and precious metals from powdered waste printed circuit boards, Waste and Biomass Valorization 11 (2019), 3897–3909.

[17] Masilela, M.D., Application of ionic liquids in the leaching and extraction of precious metal from electronic waste (2018), (Masters dissertation)

[18] Verma A, Hait S, Chelating extraction of metals from e-waste using diethylene triamine pentaacetic acid. Process Safety and Environmental Protection, 121 (2019), 1-11.

[19] Sethurajan M, van Hullebusch, ED Leaching and selective recovery of Cu from printed circuit boards, Metals 9 (2019) 10, 1034.

[20] Wu R, Chen TI, Gold recovery from eresources. Advances in Recycling and Waste Management 3 (2018), 16–17.

Note: The responsible for English language is: Dr Neil Barnes, South Africa