



Simple method for extracting gold from electrical and electronic wastes using hydrometallurgical process

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Abstract

Background: This research studied the feasibility of a simple method for extracting gold from central processing units (CPUs) of computer circuit boards without solvent.

Methods: Ceramic and composite CPUs of computer circuit boards were used. Gold was extracted using a hydrometallurgical method in six stages: grinding of CPUs, leaching in nitric acid, leaching in aqua regia, removing the excess nitric acid, extracting the gold, washing and purifying the gold deposits. Measurements of extracted precious metals were carried out by inductively coupled plasma (ICP).

Results: The results indicated that mean concentrations of gold in the first and second stages of leaching were 0.138 and 31.16 mg/L, respectively. Following the washing stage, the concentration of gold in the final deposit was 25 mg/L. The purity rate of the final deposit was 83.9%, and the final gold recovery yielded 82.3%.

Conclusion: The results of this study indicated there is a potential for extracting a high percentage of precious metals from e-wastes without solvent.

Keywords: E-waste, Gold extraction, Hydrometallurgical method

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Introduction

E-waste has been a major segment of the waste produced in the past decades (1, 2). The problem of e-waste began with the development of electronic-based industries (3, 4). E-waste comprises 2-5% of municipal solid wastes (MSW). These wastes include a wide range of discarded electronic products including computers, mobile phones, video players, copying devices and printers, tape recorders, microwaves, refrigerators, and freezers. The An estimated 50 million tons of e-waste was produced globally in 2014 (4). This is 1%-3% (1,636 million tons) of the total produced waste around the world (Organization for Economic Corporation and Development [OECD]). Second-hand computers, mobile phones, and televisions made up an estimated 9.8 million tons of e-waste in 2015. In some advanced countries, e-wastes account for over 80% of municipal waste. Scientific reports have shown that developing countries will produce twice the amount

of e-waste of developed countries by 2030 (4).

Recovering precious metals from e-waste through hydrometallurgical processes is more attractive economically than other methods (3). In recent decades, a large amount of research has been conducted on recovering metals from e-wastes, especially precious metals, using hydrometallurgical methods. In comparison with other pyrometallurgical methods, hydrometallurgical methods are more accurate and predictable (3,5). A hydrometallurgical process consists of first a set of operations including acidic or alkaline dissolution (leaching) of solids. The resulting solutions are then exposed to separation and purification methods including deposition, solvent extraction, adsorption, and ion exchange in order to isolate and concentrate the intended metals. Eventually, to recover the metals, the solutions are treated using the processes of electrolyte recovery, chemical recovery, and crystallization (3). Some



major problems of using a hydrometallurgical process are the unavailability and the prohibitive cost of effective extraction solvents.

The current research studied the feasibility of a simple hydrometallurgical method for extracting gold from ceramic and composite central processing units (CPUs) of computer circuit boards without special solvents.

Materials and methods

This research utilized composite (15 samples) and ceramic (15 samples) CPUs of computer circuit boards (Figure 1). The study process consisted of six steps (Figure 2). Step 1 (grinding of the CPUs): First, any dust or other particles were removed from the CPUs. This stage aimed to achieve the full contact of acid with the deepest parts and complete dissolution of its metals. The size of the grind pieces was 1 mm. Step 2 (leaching in nitric acid): Concentrated nitric acid (65%, Merck Co.) was added. Leaching time in this stage was 1 hour. The amount of acid utilized was based on the type of CPU-containing board. To prevent the loss

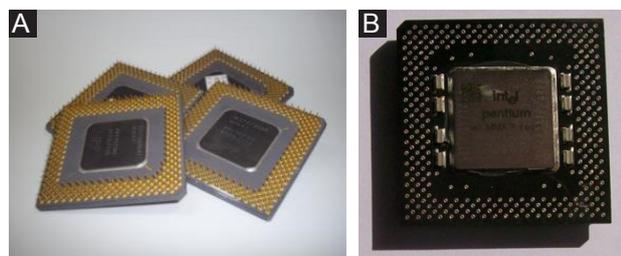


Figure 1. Ceramic (A) and Composite (B) CPUs of computer circuit boards used for gold extraction (Intel and AMD brands)

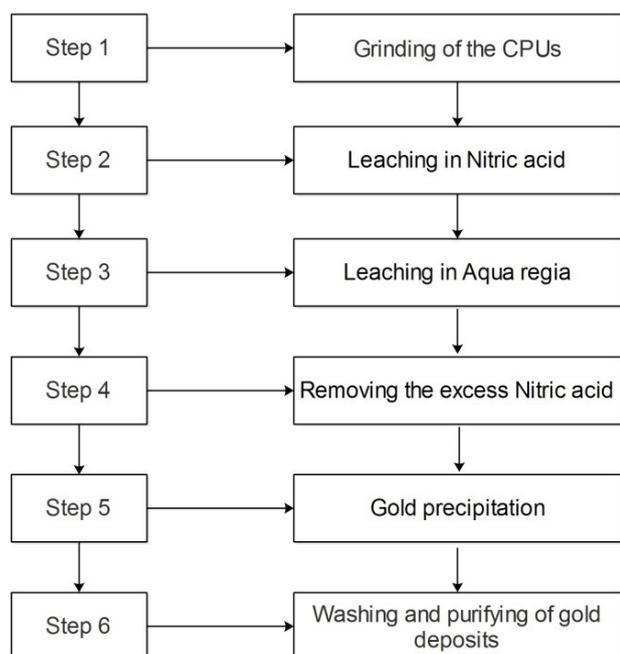


Figure 2. Six steps used to extract gold from computer circuit boards.

of gold, boiling was avoided (6). Step 3 (leaching in aqua regia): The aqua regia solution was obtained using three volumes of HCl plus one volume of HNO₃ (under the hood). Typically, the gold of composite CPU-containing boards is easily dissolved in 4-to-1 aqua regia. The reaction releases bubbles and is followed by sublimation of NO₂ brown gas. The solution was decanted, and the pieces were subsequently washed with 10 mL of concentrated HCl so that all of the gold content was fed into the solution. Step 4 (removing the excess nitric acid): Sulfuric acid was added to the solution to accelerate the removal of nitric acid and sedimentation of the lead as lead sulfate (if present). The time required for the complete removal of nitric acid from this solution was 45 minutes. At this stage, the solution's color was golden yellow and the solution's pH was around 0.5. If any deposit was observed (possibly related to silver chloride), it was separated by a filter. Step 5 (precipitation of gold): A certain amount of iron sulfate (per one gram of gold: 4.2 g of iron sulfate) was dissolved in warm water and gradually added to the gold-containing solution. For better dissolution of iron sulfate, some drops of HCl can be used. Step 6 (washing and purifying gold deposits): The deposit was coated with HCl and then boiled (to dissolve the excess copper sulfate). Following boiling, the acid was removed and the deposit was re-washed in HCl to ensure the cleanness of the gold powder. Eventually, the deposit was filtered and washed with large amounts of warm water. At this stage, the deposit was placed in an oven at a temperature of 100°C to dry (7). Sampling and measuring of precious metals were performed following the first and second stages of leaching, after the stage of gold extraction, and finally following the purification of deposits. The value of precious metals was measured by inductively coupled plasma (ICP-OES, Perkin Elmer, Optima 7300DV).

Results

Analysis results from the first stage leaching (nitric acid leaching) indicated that the average amount of gold metal was 0.138 mg/L. No platinum was found, but silver had the greatest amount (Figure 3A). ICP analysis values of the second leaching (aqua regia leaching) are presented in Figure 3B. As expected, the deposit washing stage should have had the lowest value of the investigated metals. The values of Ag, Au, Cu, and Pt were 1.174, 0.04, 3.668 (mg/L), and ND, respectively. These results show that a large amount of the metals were recovered in the previous steps. The results obtained from ICP analysis of the achieved deposit showed the weight of the final deposit following drying was 20.42 mg. The purity of the obtained deposit was 83.9%, and the recovery yield was 82.3%. The values are shown in Figure 3C.

Discussion

Different researchers have indicated that effective recovery of precious metals (especially gold) from e-wastes is

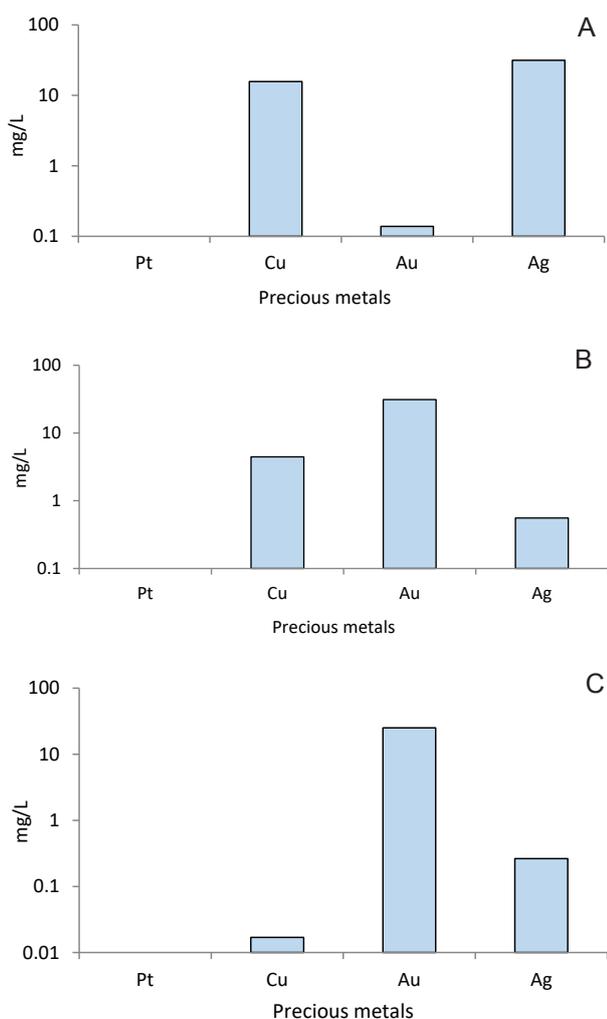


Figure 3. Average elements from first leaching step (A), Average elements from second leaching step (B) and Average elements from precipitation step (C).

feasible (7, 8). Optimum recovery in the present study was 82.3%. Other researchers achieved higher recovery rates using special solvent. Quinet et al managed to achieve 95% recovery of gold from a leaching solution (step one, oxidative sulfuric acid; step two, thiourea leach; step three, recovery of gold with activated carbon) in their proposed method (9). Kogan et al succeeded in extracting 98% gold from a leaching solution using a solvent extraction method (10). In the process presented by Biong et al, over 99.9% of gold was extracted from a leaching solution using solvent (*Dibutyl carbinol*) extraction method. Park and Fray indicated that using solvent extraction method (toluene as extraction solution and tetra-octyl ammonium bromide as phase transfer agent), gold with a purity of 97% can be extracted (6). The use of oxidant agents (electro-generated chlorine) and resin recovery (Amberlite XAD-7HP) of gold from mobile phones was found to achieve a maximum recovery of 95% (11).

Researchers who have achieved high percentages of gold recovery from leaching solution have based extraction

on solvent extraction methods. However, due to a lack of access to this type of special solvents, no solvent extraction stage was considered in the current study. Nevertheless, the results suggest that all percentages of gold recovery can be achieved by optimizing processes and fully implementing the proposed flowchart (Figure 2).

Conclusion

Electrical and e-wastes possess substantially important sources of different metals, especially precious metals. Extraction of these metals can both decrease the pressure on natural resources and reduce environmental contamination. The quantitative and qualitative investigation of precious metals extraction on a wider scale by considering technological aspects can bring about a direction for developing precious metals extraction technology.

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Ethical issues

The authors have completely observed ethical issues including plagiarism, misconduct, data fabrication, and redundancy.

Competing interests

The authors declare that no competing interests exist.

Authors' contributions

All authors contributed equally to the study, and all authors participated in data acquisition, analysis, and interpretation. All authors critically reviewed, refined, and approved the manuscript.

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