Extracting Gold from Obsolete Printed Circuit Boards

Gjergj DODBIBA*, Kouji YABUI, Josiane PONOU and Toyohisa FUJITA

The University of Tokyo, Tokyo 113-8656, Japan

Abstract

Japan is a major consumer of precious metals. Nevertheless, it imports most of its required amount of precious metals. In order to ensure a stable supply of precious metals as well as deal with the increasing global demand, it is important to develop cost effective and environmental-friendly technologies that are able to recover the precious metals from electronic waste, known as e-waste.

Generally speaking the conventional method for recovering gold (Au) from printed circuit boards (PCB) involves the incineration of scarp, followed by acid leaching. In an attempt to improve the Au extraction process, the authors are putting forward a new method. The sample was first subject to carbonization in N₂ atmosphere, followed by flotation in order to reduce the amount of sample subject to acid leaching as well as reduce the acid consumption. The sample recovered by flotation was then treated with aqua regia to dissolve Au. After investigating the effect of the carbonization temperature, a Cost-Benefit Analysis and a Life Cycle Assessment (LCA) were carried out in order to compare the efficiency of both conventional and suggested methods.

Key words: Gold, Extraction, Carbonization, Flotation, Process evaluation

1. Introduction

Computers and electronics are becoming more and more common as a result of price decline, planned obsolescence and higher data processing capabilities required by businesses. In addition, rapid advances in technology and an expanding demand for new features are increasing the amount of the discarded computers and electronic devices. The result is a growing challenge for businesses, and local governments to find ways to dispose of this equipment and recycle their components that pose an environmental issue if not disposed correctly. The aim of this paper is to find alternatives for extracting gold (Au) from printed circuit boards of obsolete electronic equipment, protecting the environment and saving the resources at the same time.

Urban Mining is the process of reclaiming compounds and/or valuable elements from obsolete products, or waste. There are many different types of printed circuit boards. A ball grid array (BGA) is a type of surface-mount chip carrier used to permanently mount devices such as micro-processors. BGA is made up of many overlapping layers that can contain up to a million multiplexers, logic gates, flip-flops or other circuits. It uses a grid of solder balls or leads to conduct electrical signals from the integrated circuit board. In addition, BGA boards contain a relatively large amount of Au. Broadly speaking, the conventional process for Au leaching from obsolete printed circuit boards starts with the incineration of the sample, followed by a size reduction process prior to acid leaching.

In an attempt to reduce the amount of sample subject to Au leaching, which in turn would reduce the amount of acid required for leaching, the authors are putting forward a new method that employs carbonization of obsolete BGA boards in N₂ atmosphere, followed by froth flotation in order to remove carbon-based particles prior to acid leaching. In other words, the objective of this work is to investigate if the carbonization process followed by flotation can improve the efficiency of Au leaching from obsolete BGA boards. The efficiency of the conventional process is also compared with that of the novel process in context of environmental impact assessment, and cost-benefit analysis.
2. Experimental

Two different methods or options were tested for leaching Au from obsolete BGA boards. The first method involves the incineration of BGA sample at 800°C for 3 hrs. Then, the size of the sample was reduced by using a cutter mill. The time allowed for the size reduction process was kept constant at 3 min. Next, the sample was subject to acid leaching by using aqua regia, keeping the leaching time at 30 min. and temperature at 20°C (Fig. 1).

Fig. 2, on the other hand, shows a novel method, which starts with the carbonization of the BGA boards for 3 hrs. at 400°C, 500°C, 650°C or 800°C. Then, as in the previous method, the size of the sample was reduced by using a cutter mill. Next, the sample was subject to froth flotation in order to float or remove carbon-based fraction, which was formed as a result of carbonization. The flotation was carried out for 20 min., using MIBC as frother (dose of MIBC: 8 kg/t) and kerosene (32 kg/t). During the flotation the pulp density was kept constant at 2 wt%. Finally, only the sink fraction, exiting the flotation process, was subject to acid leaching by using aqua regia.

In all cases, the concentration of Au in the dissolved sample was analyzed by using ICP-OES.

3. Methodology of Environmental and Economic Assessment

Environmental Assessment is a conventional method for evaluating the environmental performance of a product or process, starting from raw material extraction, through manufacture and final disposal. These methods are generally carried out in four steps:

1. goal definition and scope, which consists of: (a) defining and describing the subject of the study; (b) determining the so-called “functional unit” (fu) i.e. the unit of comparison that assures that the options to be compared provide an equivalent level of function or service; (c) specifying the processes required in the manufacture, use and eventual disposal of the products or materials; (d) developing a flow diagram of the system to be evaluated; (e) identifying the boundaries and environmental effects to be reviewed for the assessment;
2. inventory analysis, i.e. identifying and quantifying energy, materials usages and environmental releases (e.g. atmospheric emission, waterborne emissions, etc.) for the entire life-cycle;
3. impact assessment, i.e. assessing the human and ecological effects of energy, materials usages and the environmental releases identified in the inventory analysis;
4. interpretation and reporting, i.e. (a) evaluating the results of the inventory analysis in order to select the most suitable option; (b) conducting a sensitivity analysis in order to find alternatives for lowering the environmental burden.

In addition, a cost-benefit analysis was also carried out in order to calculate the possible economic surplus generated by implementing either method.

In this work, two pre-treatment options or
methods prior to Au leaching from BGA boards were considered:
Option 1: incineration at 800°C (Fig. 1);
Option 2: carbonation (at 650 or 800°C) in N₂, followed by froth flotation (Fig. 2).

The assessments were therefore carried out in order to evaluate the potential environmental impacts and economic benefit of each option and select the most suitable treatment. The functional unit \( f_u \) was defined as treatment of 1 t obsolete BGA boards for Au leaching.

4. Results and Discussions

4.1. Leaching of Au from BGA boards

The experimental results indicated that the amount of leached Au (kg-Au/t-BGA), when the conventional method was employed (Option 1) was 0.967 kg/t. In addition, Table 1 shows the experimental results when novel method (Option 2) was employed.

The experimental suggested that the amount of leached Au [kg/t-BGA] was relatively higher, when the novel process (i.e. Option 2) was employed. This was due to the fact that Au-containing particles were better exposed to acid leaching, because carbon-based particles were already removed by flotation. It was also found that the higher the carbonization temperature, the higher was the amount of leached Au (Table 1).

4.2. Environmental and Economic Assessment

The inventory analysis was the one of the most important steps of the assessment. It consisted of quantifying energy and raw material requirements, atmospheric emissions, solid wastes, and other releases for the entire life cycle. Following are the steps for performing the inventory analysis:

- (a) collect data, and
- (b) evaluate the environmental loads and costs, related to each option under investigation.

The diagram shown in Figs. 1 and 2 provided the road map for data to be collected. The data were obtained from IDEA database and the MiLCA software was used for the assessment.

In this work, the following impact category indicators have been calculated:
1. depletion of abiotic resources (ADP), expressed in “kilogram-antimony-equivalent” (kg Sb eq.);
2. global warming potential (GWP), expressed in “kilogram carbon-dioxide equivalent” (kg CO₂ eq.);
3. acidification potential (AP), expressed in “kilogram sulfur-dioxide equivalent” (kg SO₂ eq.).

These impact category indicators were chosen on the basis that they were the most relevant to the treatment options undergoing comparison and data availability.

Fig. 3 shows that the estimate of the environmental burden was higher for Option 2, regardless the carbonization temperature. It was found that the environmental burden was primarily linked with the depletion of abiotic resource (ADP indicator). Fig. 4, on the other hand, shows the results of the cost-benefit analysis. The economic surplus for Option 2 was higher due to a higher amount of Au leached out from BGA boards. It should be noted that both the processing cost and the price of gold were considered in this analysis.

In order to compare all pre-treatment options taken under the consideration, both the results of

---

Table 1 Results of Au leaching as a function of the carbonization temperature (Option 2)

| Carbonization temperature (°C) | 500 | 650 | 800 |
|-------------------------------|-----|-----|-----|
| Au distribution (%)           | 95.89 | 97.54 | 98.88 |
| Froth                         | 4.11 | 2.46 | 1.12 |
| Leached Au (kg-Au/t-BGA)      | 0.975 | 1.010 | 1.031 |

---

Fig. 3 Results of the environmental impact assessment.
environmental assessment and cost-benefit analysis were considered. Fig. 5 shows the increase of the environmental burden as a function of the increase of benefit, when compared with the oxidation at 800°C (Option 1) that is the reference value. It was found that even though the novel process (regardless the temperature at which the carbonization was carried out) increases the environmental burden, carbonization at 800°C prior to Au leaching ensures a higher economic surplus.

4. Conclusions

In this work Au leaching from BGA boards was investigated. It was found that carbonization of obsolete BGA boards at 800°C, followed by flotation increased the amount of Au leached out, because Au-containing particles were better exposed to acid leaching after carbon-containing particles were first removed by flotation. In addition, the results of environmental and economic assessments indicated that both the economic surplus and the environmental impact were higher when carbonization and froth flotation were employed as pre-treatment processes. Although both environmental impact and economic surplus increased with increasing carbonization temperature, the economical surplus outmatched the environmental burden, when temperature was kept at 800°C, because the higher the carbonization temperature, the greater the amount of Au being leached out. The authors believe that the carbonization of obsolete BGA boards, followed by flotation is a feasible and effective method since it facilitated the leaching of Au and ultimately would increase its recycling rate.

References

1. M.A. Curran: Environmental Life-Cycle Assessment. New York: McGraw-Hill, 1996.
2. U.S. Environmental Protection Agency (USEPA). Office of Research and Development: Life Cycle Assessment: Inventory Guidelines and Principles. EPA/600/R-92/245, 1993.