

## Leaching of gold, silver and accompanying metals from circuit boards (PCBs) waste

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*Au-Ag noble metal wastes represent a wide range of waste types and forms, with various accompanying metallic elements. The presented leaching strategy for Au-Ag contained in circuit boards (PCBs) aims at gaining gold and silver in the metallic form. Application of the proposed ammonium thiosulphate leaching process for the treatment of the above mentioned Au-Ag containing wastes represents a practical, economic and at the same time an ecological solution. The ammonium thiosulphate based leaching of gold and silver from PCBs waste, using crushing as a pretreatment, was investigated. It was possible to achieve 98 % gold and 93 % silver recovery within 48 hours of ammonium thiosulphate leaching. This type of leaching is a better leaching procedure for recovery of gold and silver from PCB waste than the classical toxic cyanide leaching. 84 % Cu, 82 % Fe, 77 % Al, 76 % Zn, 70 % Ni, 90 % Pd, 88 % Pb and 83 % Sn recovery of the accompanying metals was achieved, using sulphuric acid with hydrogen peroxide, sodium chloride and aqua regia. A four steps leaching process gave a very satisfactory yield and a more rapid kinetics for all observed metals solubilization than other technologies.*

**Key words:** waste, gold, silver, accompanying metals, leaching

### Introduction

A mass of electrical and electronic waste is building up throughout Europe. Every European consumer generates on average 16 kilograms of this waste a year, producing 6 million tonnes of waste each year. This is a huge waste of resources. It is also a major environmental hazard: electrical appliances and electronic equipments contain highly toxic heavy metals and organic pollutants [1].

The problem of recycling secondary resources containing noble metals is in the centre of interest of all developed economies of the world. There, this problem is being tackled as one that is not only a technological, legislative or economical problem, but also one related to environmental protection. Winning these metals from waste materials and lowering the environmental load by recycling is a very complex issue that requires an all-round strategy and the application of a number of methods [6].

Noble metals, and specially gold, silver as well as platinum, palladium and rhodium have properties that ensure a wide range of industrial applications. From the pattern of global gold and silver consumption it is evident, that apart from jewellery, the greatest consumption of these metals can be observed in electronic industry. Photographic industry also consumes a significant amount of silver. Medicine and cosmetics industry is a big consumer of both Au and Ag. Platinum and rhodium is used mostly in the production of catalysts. Palladium is used predominantly in electrical engineering [7, 8].

Waste material containing Au and Ag occurs in a number of forms, where the proportion of noble metals varies greatly. Therefore their processing can be done by a number of technologies and their combinations. The choice of technology is determined by the noble metal content, the type of accompanying elements and by the character of the material they are embedded in. It is therefore necessary to consider possible application areas of all the constituents contained in the processed waste material [5].

Circuit boards (PCBs) waste is characterized by significant heterogeneity and relatively high complexity, albeit with the levels of complexity being somewhat greater for populated scrap boards. As has been seen in respect of material composition, the levels of inorganics in particular are diverse with relatively low levels of precious metals being present as deposited coatings of various thickness in conjunction with copper, solders, various alloy composition, non-ferrous and ferrous metals. Hydrometallurgical approaches depend on selective and non-selective dissolution to achieve a complete solubilization of all the contained metallic fractions within PCBs waste [2, 3, 4].

The aim of this work was to find the possible hydrometallurgical processing for printed circuit boards and to win the maximum of metal types contained in PCBs. Sample crushing was applied to determine its effect on the recovery of gold, silver as well as of the accompanying metals.

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## Experimental

### Materials

The circuit boards (PCBs) waste were selected as an input material for testing the leaching of gold, silver and accompanying metals. The chemical composition of the applied waste is given in Tab. 1.

Tab. 1. Chemical composition of the printed circuit boards (PCBs) waste under study.

Waste	Components [%]									
	Au	Ag	Cu	Pb	Zn	Fe	Sn	Ni	Al	Pd
PCBs (Slovakia)	0.014	0.08	47.5	1.4	1.1	10.36	3.3	0.85	2.7	0.003

### Mechanical treatment and crushing of the PCBs waste

The PCBs were mechanically pretreated by eliminating the semiconductors, condensers, and resistances. Under industrial conditions, these parts are collected separately by specialised companies that use them for obtaining of heavy and noble metals. Residue of the PCBs are then crushed in special crushers. Subsequently the plastic parts are separated from the metallic ones. The metals are recycled and the plastic materials are dumped.

Hammer mill Omniplex 40/20 Ha (Alpine, Germany) crusher was used for treatment of the circuit boards (PCBs) waste. After crushing, the -800  $\mu\text{m}$  input material has been sieved and leached in a glass reactor using leaching solutions for extraction of the observed metals as shown in the Tab. 1.

### Leaching of Au, Ag and accompanying metals from the PCBs waste

Four types of leaching media have been applied:

- PCBs waste was used to test the effect of sulphuric acid with hydrogen peroxide leaching of zinc, copper, iron, aluminium and nickel.
- Gold and silver recoveries from PCBs waste were tested through the medium of ammonium thiosulphate in the presence of cupric sulphate and ammonia.
- Lead and tin recoveries were tested through leaching by sodium chloride.
- For palladium leaching aqua regia was used.
- The leaching was investigated under conditions given in Tab. 2.

Tab. 2. Parameters for leaching of circuit boards (PCBs).

Parameters	Leaching reagents			
	$\text{H}_2\text{SO}_4 + \text{H}_2\text{O}_2$	$(\text{NH}_4)_2\text{S}_2\text{O}_3 + \text{CuSO}_4 \cdot 5\text{H}_2\text{O} + \text{NH}_3$	NaCl	$\text{HCl}:\text{HNO}_3$ (3 : 1)
Volume of glass reactor [ml]	500	500	500	500
Volume of leaching solution [ml]	450	450	450	450
Concentration of leaching reagents [M]	2 + 0.2	0.5 + 0.2 + 1	2	0.5
pH	6	9	6	2
Weight of sample [g]	45	40	34	33
Time of leaching [min]	480	2880	120	120
Stirring rates [ $\text{s}^{-1}$ ]	8.33	8.33	8.33	8.33
Temperature [ $^{\circ}\text{C}$ ]	80	40	25	25

## Results and discussion

### Leaching of the crushed circuit boards (PCBs)

The application of crushing proved to be an effective method of the PCBs waste pretreatment before the extraction of gold, silver and accompanying metals into the leach liquors. For leaching Au, Ag and accompanying metals from PCBs wastes the numbers of leaching media were used (Tab. 2). Their selection was done in a way that allowed selective leaching of the metals of interest. In order to make the chemical reactions intensive, the presence of effective oxidation reagents was necessary. Their selection was done in a way that allows selective leaching of the metals.

The dependence of zinc, copper, iron, aluminum, nickel, gold, silver, lead, tin and palladium recovery on the leaching time for the PCBs waste is shown in Figs. 1-3.

Leaching of PCBs waste with sulphuric acid and hydrogen peroxide gave 76 % Zn, 85 % Cu, 82 % Fe, 77 % Al and 70 % Ni recovery into the leachate after 480 min (Fig. 1).

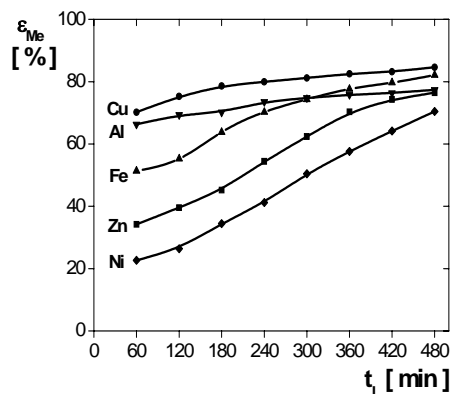


Fig. 1. Recovery of Zn, Cu, Fe, Al and Ni,  $\epsilon_{Me}$  vs. leaching time,  $t_L$  for circuit boards (PCBs) waste pretreated by Omniplex-hammer mill, 40/20 Ha (Alpine, Germany). Leaching reagent:  $H_2SO_4 + H_2O_2$ .

The leaching of “as-received” sample of the PCBs waste with the ammonium thiosulphate afforded only 16 % gold and 12 % silver into leach after 48 hours of leaching. The results for the same but the pretreated waste by milling have accelerated the process of thiosulfate leaching. Pretreatment enables to achieve for the ammonium thiosulphate leaching with ammonium 98 % gold and 93 % silver extraction after 48 hours of leaching (Fig. 2).

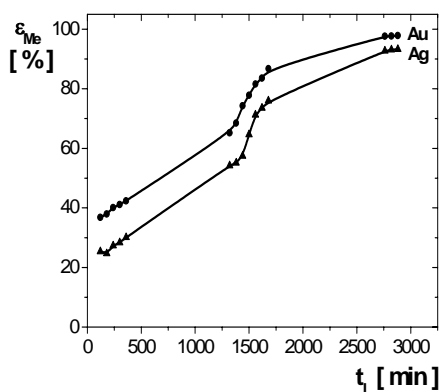


Fig. 2. Recovery of Au and Ag,  $\epsilon_{Me}$  vs. leaching time,  $t_L$  for circuit boards (PCBs) waste pretreated by Omniplex-hammer mill, 40/20 Ha (Alpine, Germany). Leaching reagent:  $(NH_4)_2S_2O_3 + CuSO_4 \cdot 5H_2O + NH_3$ .

However, when sodium chloride solution was applied, it was possible to achieve 88 % recovery of Pb and 83 % recovery of Sn even after 120 min (Fig. 3). In the case of palladium 90 % recovery was achieved after leaching in aqua regia solution after 120 min.

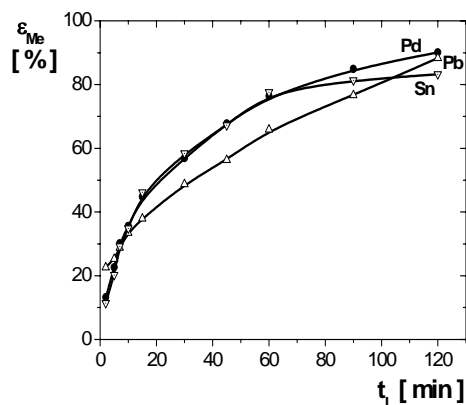


Fig. 3. Recovery of Pb, Sn and Pd,  $\epsilon_{Me}$  vs. leaching time,  $t_L$  for circuit boards (PCBs) waste pretreated by Omniplex-hammer mill, 40/20 Ha (Alpine, Germany). Leaching reagent: NaCl and HCl +  $HNO_3$  (aqua regia).

### Conclusion

For the achievement of a technologically acceptable recoveries, pretreatment was necessary. Comminution by Omniplex-hammer mill 40/20 Ha (Alpine, Germany) was used for the purpose of our work. The pretreatment was necessary in order to achieve a suitable input sample for leaching and it was positively reflected in the Au, Ag, Pd, Cu, Pb, Zn, Fe, Sn, Ni and Al leaching recoveries.

During the experiments it was possible to get excellent recoveries of all the metals that were of interest. In case of Au, Ag and Pd the recoveries were 98 %, 93 % and 90 %. Thus the aim of the experiments was achieved.

The application of leaching reagents that facilitated appropriate kinetics and selective leaching of the investigated metals was found to be a very suitable method.

Hydrometallurgical approaches offer the opportunity to eliminate the loss of the metal yield from recycling processes and have a potentially more significant environmental impact in implementation.

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