The importance of recovering precious metals from waste electrical and electronic equipment

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Abstract. The evolution of electronic equipment in recent decades is experiencing a remarkable development. Due to increasing of consumption and also a very fast replacement rate due mainly to obsolescence, the amount of resulting electrical and electronic waste (WEEE) is increasing.

The WEEE term includes all of electrical and electronic equipment starting from mobile phones, computers, video cameras to tv set, washing machines, refrigerators. In other words, all electrical and electronic equipment from a household, electronic equipment from automotive or industrial electronic components. Now in all worldwide it is estimated that WEEE represents about 5% of all municipal solid waste.

The recovery process can be taken into account only if the cost of recovery is much lower than the value of the precious metals recovered from this. Regarding to waste disposal restrictions and strict environmental regulations, are needed economically viable and environmentally friendly technologies.

The paper presents the results of laboratory experiments on the recovery of precious metals, especially gold, present in various electrical and electronic components. WEEE used in the experiments was used from mobile phones, computer motherboards, computerized microprocessors and various types of gold-plated contacts.

1. General consideration
Historically, the recovery of precious metals from electronic waste has been one of the ways to stimulate the electronics recycling industry.

WEEE, also contains hazardous materials for the environment and health, greenhouse gases or heavy metals harmful to health.

Among the hazardous substances contained in WEEE are:
- freon: CFC, HFC, HCFC can be found in refrigeration equipment;
- brominated flame retardants, which are found in both electronic boards and plastic cases;
- PCB capacitors - polychlorinated biphenyl compounds. Found in older appliances, manufactured until '90 years like washing machines, refrigeration equipment, dishwashers, microwave ovens, copying equipment, power supplies, etc;
- PVC - plastic material with chlorine content, used in some electronics and for insulating cables;
- mercury - is used in energy saving lamps and bulbs, in the backlit lamps of LCD screens but we also find it in batteries and old appliances, in switches and relays.
Analyzing the structure of electronic waste from personal computers, metal fractions represent more than 60% (including iron, copper, aluminum, gold and others) the rest being plastics, and only 2.70% of the waste becomes polluting residues [1].

As regards printed circuits waste, they contain in addition other materials and a number of precious metals, namely: 0.06% Ag, 0.023% Au and 0.01% Pt. This means that 60g of Ag, 23g of Au and 10g of Pt can be obtained from one ton of recycled printed circuits. Compared from one ton of gold ore is obtained between 2 and 4 grams of gold [1]. Electronic-waste WEEE is classified in several categories based on the European WEEE Directives 2002/96/EC and 2012/19/EU [2], [3] and this is presented in Table 1. So, this type of waste is a complex mixture of ferrous material, nonferrous material, plastic and ceramic materials.

Generally metals from WEEE can be grouped in precious and platinic metals Au, Ag, Pt, Rh, Ir; concern metals Cu, Al, Ni, Sn, Zn, Fe; hazardous metals Hg, Be, Pb, Cd, As; scarce metals Te, Ga, Se, Ta, Ge. The WEEE man, designed by Paul Bonomini, is a huge robotic figure made of scrap electrical and electronic equipment. It weighs 3.3 tonnes and stands seven meters tall – representing the average amount of e-products every single one of us throws away over a lifetime [4].

![WEEE Man at the Eden Project](image)

Figure 1. WEEE Man at the Eden Project [4]

One of the electronics parts take into account are printed circuit boards (pcb). This type of wastes are found in a lot of electronic and electrical devices (computers and laptops motherboards, computer video cards, mobile phones motherboard and others).

| Category of equipment                      | Abbreviation |
|-------------------------------------------|--------------|
| Large household appliances                 | Large HH     |
| Small household appliances                 | Small HH     |
| IT and telecommunications equipment        | ICT          |
| Consumer equipment                         | CE           |
| Lighting equipment                         | Lighting     |

Table 1. Waste from electrical and electronic equipment (WEEE)/electronic waste (e-waste) categories according to the European directive on WEEE [2], [3].
Material from construction of pcb plates are in next proportion 40% metals (tin, copper, silver, gold), 60% plastics and ceramics (fiberglass, cellulose paper or phenolic material; polymers and industrial plastics containing polyethylene, polypropylene, epoxy and polyesters) [5].

Printed circuit boards must be crushed in small pieces, smaller that 1-2 mm in various type of mills or using different types of technique. After crushing must be applied a separation using magnetic and electrostatic techniques.

Thus, other type of electronic waste with high content of gold are: different types of gold contacts from the dismantling of computer motherboards or industrial equipment, gold contacts of pcb plates, microprocessor sockets, microprocessors, mobile phone motherboards.

### Table 2. Metals content from printed circuit boards [1], [6]

| Metals       | Cu wt% | Fe wt% | Al wt% | Pb wt% | Sn wt% | Zn wt% | Ni wt% | Au ppm | Ag ppm |
|--------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| min          | 6.9    | 1.4    | 2      | 1.35   | 1      | 0.16   | 0.28   | 20     | 200    |
| max          | 22     | 20.5   | 14.2   | 6.3    | 4      | 2.2    | 2      | 1000   | 2000   |

The recovery process have sense only if the cost of recovery is much lower than the value of precious metals. In addition, waste disposal restrictions and strict environmental regulations require viable and environmentally friendly economic technologies.

### Table 3. List of substituted leaching agents of gold [7]

| Reagents                                | References                  |
|-----------------------------------------|-----------------------------|
| Ammoniacal thiosulfate                  | Vinh et al., 2010           |
| Aqua-regia                              | Young and Derek, 2009       |
| Chloride–hypochlorite                   | Feng and van Deventer, 2006|
| Thiourea                                | Adnan et al., 2001          |
| 1-Phenyl-2-thio-3-(2-hydroxyethyl) urea | Kwang et al., 2008          |
| Acid thiourea                           | Örgül and Atalay, 2002     |
| Aqueous ozone–chloride                  | Viñals et al., 2006         |
| Thiocyanate                             | White, 1905                 |
| Thiosulfate                             | Kuzugudenli and Kantar, 1999|
| Halides                                 | Viñals et al., 2006         |
| Bromine                                 | Parsad et al., 1991         |
| Thiourea–thiosulfate                    | Hongguang and David, 2002   |
| Ammonia, Ethylene thiourea, Iodine, Natural organic acids, Acid ferric chloride | McNulty, 2001 |
2. Laboratory experiments
For laboratory experiments was selected different types of waste from electrical and electronic equipment containing precious metals, especially gold in their composition.

Thus, were used different types of gold contacts from the dismantling of computer motherboards, gold contacts of pcb plates, microprocessor sockets, microprocessors, mobile phone motherboards.

The microprocessors was used in two variants, grind in a ball mill and unmilled. It was also tried to grind the sockets of microprocessors. These types of waste are shown in the following figures.

From all of the methods mentioned in the literature, will be used the method using nitric acid concentration 55% for the dissolution of metals (except gold), [7], [8]. The following figure shows the 7 types of waste studied.

![Figure 2. Electronic and electric waste used in experiments](image)

After, approximately 30 minutes of addition at the 55% nitric acid solution, the high content of gold waste containers are shown in the figure below. As I mentioned, reactions was violent, with the release of gases (nitrogen oxides), and the temperature was somewhere to 75-89 °C.

![Figure 3. Samples of 7 types of waste used in experiments](image)

1 – phones motherboards; 2 – microprocessor socket (partially grinded); 3 – gold contacts from a single computer base plate; 4 – different types of gold contacts; 5 – gold contacts from pcb plates; 6 – partially ground computer microprocessors; 7 – unmilled computer microprocessors.

From the photo we see different degrees of dissolution (copper) depending on the preparation of the waste and its type:
- containers 3 and 4 containing pins from various golden contacts, the process is completed being necessary only to filter the suspension from the glass container;
**Figure 4.** Gold waste containers, after 30 minutes of addition at the 55% nitric acid solution

- container 6 has shown a violent reaction, due in particular to the finely ground powder which has led to the "swelling" of the contents of the container;
- in containers 1, 5 but especially for container 7 reactions went less violent, especially due to the fact that the gold film protects copper, requiring a longer time for corrosion and dissolution.

**Figure 5.** Example of filtration operation

Next, we tried to use a method with a much lower impact on the environment, using CH$_3$COOH 20% (acetic acid) and H$_2$O$_2$ 9% (hydrogen peroxide) [7], [9]. Also, in this case was an attempt made to dissolve the copper film which is the substrate of the gold layer.

For experiments was used mobile phone sim cards and gold contacts from pcb boards. In Figure 6 is presented this experiments, and finally the gold recovered.

**Figure 6.** Separation and filtration operation, green method

This is green process, can be used in order to eliminate toxic products and dangerous effluent which must be treated with care, or stored controlled. The results of this method have been encouraging, but as a remark it should be mentioned that it is used for dissolving thin layers of copper.

Likewise, in literature is presented many environmentally friendly methods of extracting and recovering gold not only from electronic products, but also from ores. This methods will replace in the near future the classic method of extracting and recovering gold [7], [10].
3. Results and discussion

The results of the experiments, for first method presented in paper is presented in figure 7 and table 4.

Also, all resulting effluents must be collected in special containers. Must be checked for gold content and the metals dissolved in these solutions, and also must be recovered by electrolysis or cementation [11], [12].

After processing waste results some conclusions:
- waste 5 gold contacts of pcb plates, have a very good recovery yield, the gold particles being relatively large, without very many impurities
- waste 3,4 gold contacts, provide fine gold particles, especially due to the fact that the coating films have ever smaller layer thicknesses.
- waste 7 unmilled microprocessors, confirms that the gold content in microprocessors is one of the highest.
- waste 1 motherboards mobile phones, is observed an advanced impurification with silicon pills (from small microprocessors) but also with plastic

The initial quantities of waste used in experiments, the quantities of nitric acid and quantity of gold is presented in Table 4.

![Figure 7. The results of the experiments – recovered gold](image)

The purpose of this work is not to promote this method because have a low efficiencies, the acids used are expensive and presents danger in use. There are more environmentally friendly and high-yielding methods.

One of this green method is presented in second part of experimentation.

It is intended to draw attention once again, that these categories of waste also contain deficient and expensive materials such as copper, silver, gold.

Table 4. Results of experiments

|                      | Phones     | Microprocessor | Gold contacts from a single computer base plate | Different types of gold contacts | Gold contacts from PCB plates | Partially ground microprocessors | Unmilled computer microprocessors |
|----------------------|------------|----------------|-----------------------------------------------|---------------------------------|-------------------------------|----------------------------------|-----------------------------------|
| Weight, [g]          | 79.62      | 30.18          | 21.23                                         | 16.32                           | 32.16                         | 29.94                            | 30.07                             |
| Quantities of nitric acid, [ml] | 145        | 55             | 100                                           | 80                              | 125                           | 80                               | 85                                |
| Gold weight, [g]     | 7.2026 *   | - **           | 0.4610                                        | 0.61870                         | 0.4478                        | - **                             | 1.5123                            |

* is present a large amount of plastic, silicon microprocessor pills, other impurities

** remaining residue will dissolve in aqua regia
As noted in the previous figures, there are categories of WEEE such as the gold contacts of the PCB and microprocessors containing higher amounts of gold compared to the other wastes studied.

From a complete computer motherboard, video cards and other cards it is estimated that can be recovered at least 0.4 and 0.6 g gold, without taking into account other deficient metals such as copper and silver.

With the technological evolution of recent decades, there is a reduction in the thickness of coatings used in the construction of electrical contacts and other electronic devices.

Following these experiments resulting harmful waste that must be stored controlled and then neutralized. Basically, from resulting effluents, copper, silver and other metals can then be recovered by electrolysis.

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