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PHYSICAL METHODS FOR PROCESSING ELECTRONIC AND ELECTRICAL EQUIPMENT WASTE (WEEE) FOR NONFERROUS METALS RECOVERY

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Obiectivul principal al prezentei lucrări a fost recuperarea metalelor prețioase, în special aurul, din DEEE-uri (microprocesoare). Prima etapă a fluxului de recuperare a metalelor prețioase a constat în sortarea şi măcinarea microprocesoarelor înglobate în materiale plastice şi ceramice. Măcinarea microprocesoarelor s-a efectuat în două tipuri de mori respectiv cele înglobate în plastic într-o moară cu cuțite tăietoare SM2000 tip Retsch şi a celor înglobate în ceramică în moara cu discuri oscilante tip Retsch 10. Separarea volumică şi magnetică a concentratelor a reprezentat o a doua etapă a fluxului. În urma acestor operații au rezultat şase probe de dimensiuni şi proprietati magnetice diferite. Tehnologia de separare propusă a permis determinarea distribuției de Au şi Ag în toate fracțiile rezultate, utilizând spectroscopia de fluorescență de rayeX.

This paper aims to recover precious metals, especially gold, from the WEEE (microprocessors). The first stage of the flow sheet of precious metals recovery consisted of sorting and grinding microprocessorsembedded in plastics and ceramics materials. Grinding was performed in twotzpes of mills, microprocessors that were embedded in plastic were ground in a Retsch SM2000 knife mill and those embedded in ceramic in a Retsch 10 rotating disc mill. Volumetric and magnetic separation of the concentrates represents the second phase of theproposed flow sheet. Following these operations six samples resulted, of different sizes and magnetic properties. The distribution of Au and Ag in all fractions resulted from the proposed separation technology has been ascertained by X-ray fluorescence spectroscopy.

Keywords: waste electrical and electronic equipment, microprocessors, grinding, magnetic separation, precious metals

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1. Introduction

The treatment of electronic and electric waste is a current topic as their role in modern life is increasing [1, 2]. The best option in waste treatment is recycling. There have been a large number of studies on the recycling of materials by mechanical [3, 4], thermal [5] and chemical [6] processes, but most of them dealt with the recovery of one or two specified materials of all WEEE compositions.

In this paper, the preliminary stages of recovering precious metals from electrical and electronic equipment (used microprocessors) waste are presented. The use of precious metals (PM) in this field is of primary importance given PMs unique properties, which confer to each of them a specific and irreplaceable role [7].

During the last decades, substantial quantities of gold have been used by the electronic industry in view of its excellent electric conductivity and resistance to corrosion. This ensures high reliability in WEEE, which over a period of time get obsolete and redundant. The process of recovery makes sense only if the cost of recovery is much lower than the value of the precious metal.

Many studies have been carried out with regard to the recycling of electronic and electric waste with a view to recover resources and at the same time preventing environmental contamination [8, 9]. The first stage of the experimental study consisted of separating and milling microprocessors embedded in plastic and ceramic materials. After this stage the concentrates were subjected to magnetic separation to obtain the magnetic and non-magnetic fractions. The elements and their concentrations in the mass of each sample were studied by X-ray fluorescence analysis. This study is intended to continue for obtaining useful data for the next steps for the recovery of precious metals used in microprocessors.

2. Experimental procedures

2.1. Experimental materials and devices

Waste microprocessors disassembled from obsolete computers were used for the experiments. Two types of microprocessors were used for the experiment: microprocessors embedded in plastic materials and microprocessors embedded in ceramic materials. Therefore, for the milling operation two types of mills were used, namely a Retsch SM2000 cutting knife mill for microprocessors embedded in plastic and a Retsch 10 disk mill for those embedded in ceramics.

Methods

A schematic flowsheet diagram of the preliminary stages for precious metal recovery is shown in Fig. 1.a and Fig.1.b.

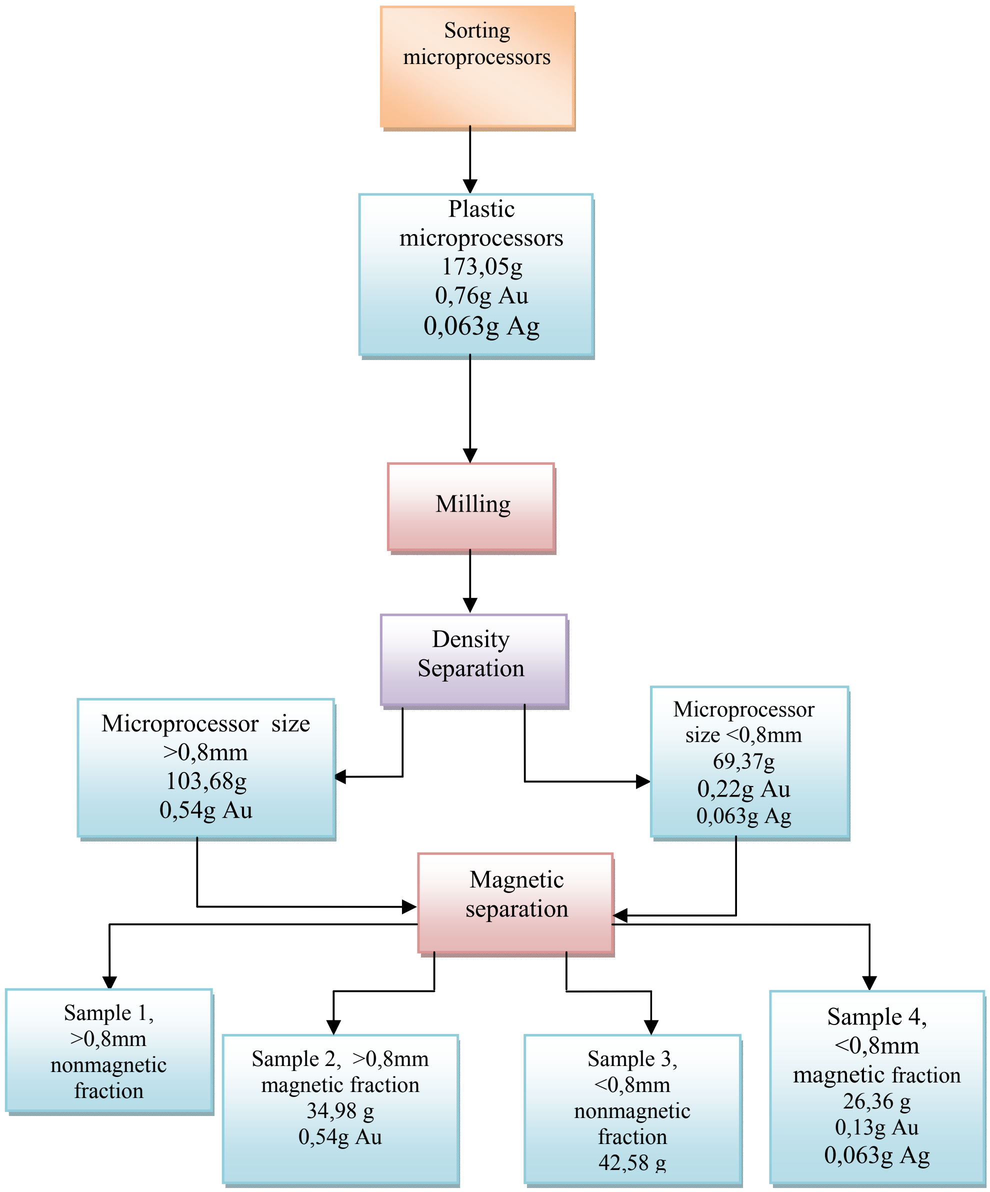

Fig.1.a.Flow and balance recovery of precious metals from microprocessors embedded in plastic

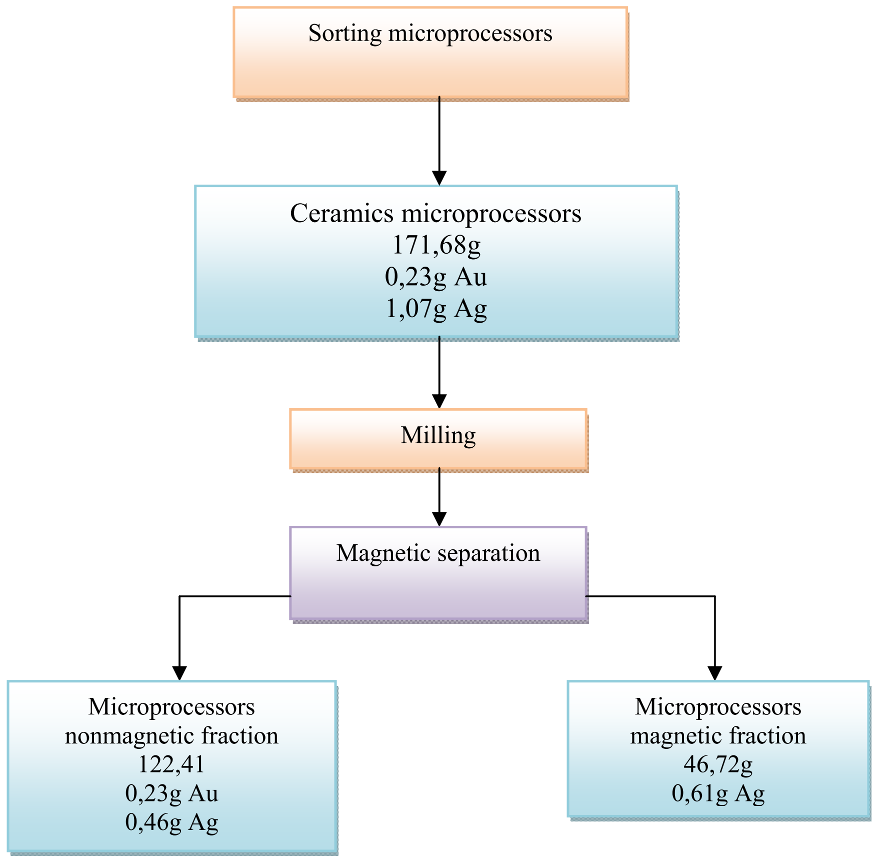

Fig.1.b. Flow sheet and balance recovery of precious metals from microprocessors embedded in ceramics

The technological steps of these flow sheets are: sorting chips, milling, magnetic separation of displacement and separation. The microprocessors were sorted, resulting in a quantity of 173.05 g of microprocessors embedded in plastic material and a quantity of 171.68 g of microprocessors embedded in ceramic material, and then milled.

2.2. Milling microprocessors

To separate metallic parts, the microprocessors were milled in two mills: *RETSCH* SM 2000 heavy-duty cutting mill (Fig.2.a) and *RETSCH* RS100 Vibratory Disc Mill (Fig.2.b). Plastic microprocessors were milled in a heavy-duty cutting mill resulting in a concentrate with different sizes of particles, ranging from 0.25-20 mm. The ceramics were milled in a vibratory disc mill for

10 minutes, resulting in a powder concentrate with a particle size up to 9 microns. The concentrates resulted by milling of plastic microprocessors were then volumetrically separated using a sieve with a mesh size of 0.8 mm.

Fig. 2.a. *RETSCH SM 2000* heavy-duty cutting mill

Fig.2.b. *RETSCH* RS100Vibratory Disc Mill

2.3. Magnetic separation

The magnetic separation of the milled concentrate was performed to separate the magnetic and non-magnetic fractions. The magnetic separation carried out by means of a Carpco l MIH (13)111-5 high-intensity induced-roll magnetic laboratory separator (Fig. 3). The Meter Magnet separator places all particles in contact with the highest magnetic field at the zones of steepest magnetic gradient and utilizes magnetic force and gravity to capture weakly magnetic particles. A turning, induced magnetic roll is used to transport material through the active area providing an opposing centrifugal force for separation of magnetic and nonmagnetic materials.

This technique is capable of efficiently removing weakly magnetic material occurring as contaminants in nonmagnetic products. On each fraction an analysis was performed to assess the effectiveness of magnetic separation of metallic elements.

Fig. 3. Carpco MIH (13)111-5 high-intensity induced-roll magnetic laboratory separato

2.4 Chemical analysis

Samples of 8g of each fraction were analyzed to determine the elements and their distribution in concentrates obtained after milling and separation. These samples were analyzed by X-ray fluorescence using an X-ray fluorescence XEPOS spectrometer.

3. Results and Discussion

3.1. Milling of microprocessors

Microprocessors have been reduced with a hammer to a smaller size and then milled in the two mills. Shearing occurs during microprocessor milling in heavy-duty cutting mill, a process that is performed between widia plates and rapid steel knives. At the startup of the mill the distance between the high rapid steel knives will be taken into account so that to be small enough to easily produce shear milling process. At the bottom of the milling chamber there is a bolter that is interchangeable so that the size of grinding can be adjusted. Plastic microprocessors whose initial size was reduced using a hammer in order to be introduced in the milling chamber are ground until they reach the size smaller than the mesh sieve at the bottom of the milling chamber. Once this is done the milling particles leave the milling chamber and reach the flask from where they are discharged intermittently. The aspect of microprocessor embedded in plastic after milling is shown in Fig.4.

Fig. 4. Aspect of plastic microprocessors milled in the cutting knifes mill

Microprocessors embedded in ceramics have also been reduced in size with a hammer and then milled in an oscillating disk mill. This mill has a capacity of 50g and the time needed for milling is 10 minutes, to reduce the size of the material from 40 mm to 9 microns. After milling the microprocessors embedded in ceramic, a powder form concentrate resulted (Fig. 5).

Fig. 5.Aspect of ceramic microprocessors milled in the oscillating disk mill

After milling, the plastic microprocessors were separated volumetrically using sieves with a mesh size of 0.8 mm to observe the distribution of metals at different particle sizes. From these physical processes three samples resulted, with different dimensions and aspects.

3.2. Magnetic separation

Magnetic separation was carried out to distinguish the magnetic and non-magnetic fractions from milled microprocessors. Table 1 presents the distribution of elements in all six fractions.

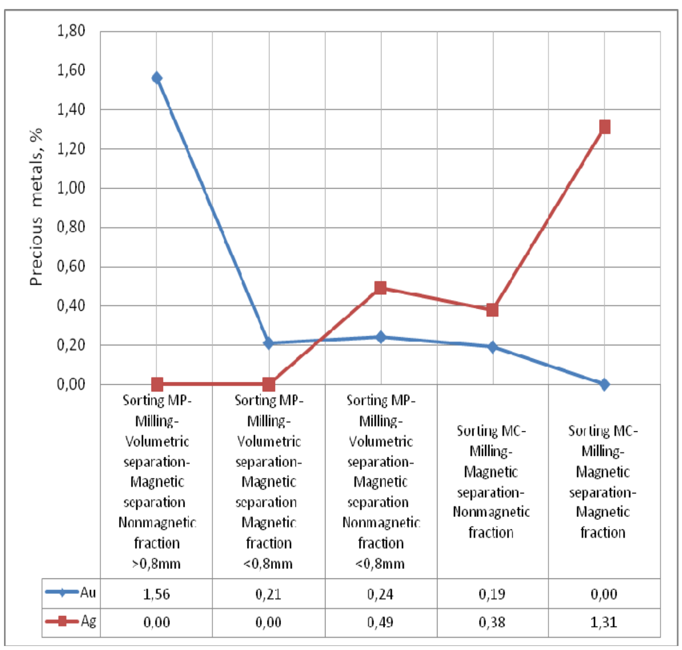

Fig. 6. Distribution of precious metals after complete separation technology

It is noted that copper is the most abundant metallic element in the plastic microprocessors while aluminum is the metal with the highest content in ceramic microprocessors. Iron and nickel, which are the typical ferromagnetic metallic elements, were largely separated into the magnetic fraction by the magnetic separation. It can be seen that the nickel and iron were left in the non-magnetic fraction, probably due to their presence in paramagnetic or diamagnetic particles as alloying elements. The paramagnetic or diamagnetic elements, such as aluminum, tin, copper, and lead, were mostly distributed in the non-magnetic fraction. Note that beside these metals others elements appear, but in low concentrations. Fig. 6 shows the distribution of precious metals in each sample after complete separation technology.

Tablel 1

Distribution of elements in mass sample

s Sample / Element,%	A Microprocessor plastic				B Microprocessor ceramic	
	1 Nonmag. fraction >0,8	2 Magnetic fraction >0,8	3 Nonmag. fraction<0,8	4 Fr. mag. <0,8	5 Nonmag. fraction	6 Magnetic fraction
Mg	0.00	0.34	0.23	0.50	0.36	0.21
Al	0.00	0.96	3.10	3.38	37.10	25.50
Na	0.00	0.00	0.00	0.18	0.00	0.00
Si	17,8	5.25	17.40	17.40	6.29	5.13
S	0.46	0.11	0.35	0.47	0.21	0.22
Cl	0.00	0.00	0.47	0.49	0.13	0.00
K	0.00	0.00	0.11	0.13	0.00	0.00
Ca	6.38	2.37	9.45	8.85	0.67	0.78
Ti	0.17	0.91	0.36	0.48	0.31	0.37
Fe	0.25	5.87	0.40	3.21	0.34	0.85
Ni	0.12	10.90	0.12	1.86	0.15	0.66
Cu	25.50	23.40	16.40	15.6	0.14	0.30
Zn	0.16	0.00	0.31	0.27	0.00	0.00
Br	13.80	5.07	11.30	10.30	0.00	0.00
Ba	2.62	3.52	2.42	2.39	0.46	0.58
Pb	0.30	2.89	1.33	2.04	0.26	0.37
Mn	0.00	0.00	0.00	0.00	0.00	0.00
Sr	0.16	0.00	0.00	0.12	0.00	0.00
Cr	0.00	3.90	0.00	0.00	1.59	1.85
Sn	0.51	0.23	0.00	2.82	0.00	0.00
Sb	0.00	1.56	0.00	0.20	0.00	0.00
Au	0.00	0.00	0.21	0.49	0.19	0.00
Ag	0.00	0.00	0.00	0.24	0.38	1.31
Co	0.00	1.07	0.00	0.00	0.17	0.34
W	0.00	0.00	0.00	0.00	9.24	13.2

Figs. 7-12 show the resulting X-ray fluorescence analysis diagrams for the six fractions obtained from physical proccesing of waste microprocessors.

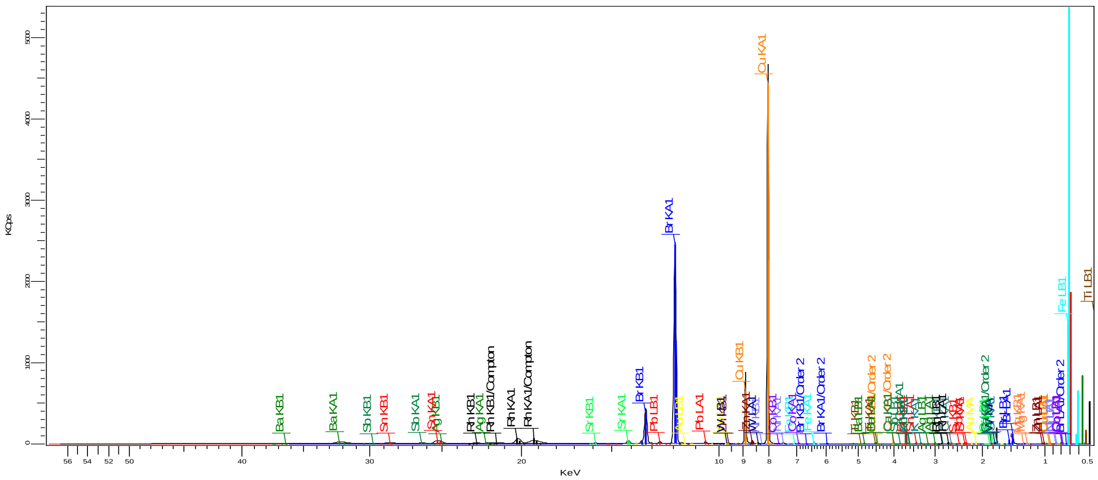

Fig.7. Diagram of XRF analysis for sample 1, microprocessors plastic waste milled, size> 0.8 mm, after magnetic separation, nonmagnetic fraction

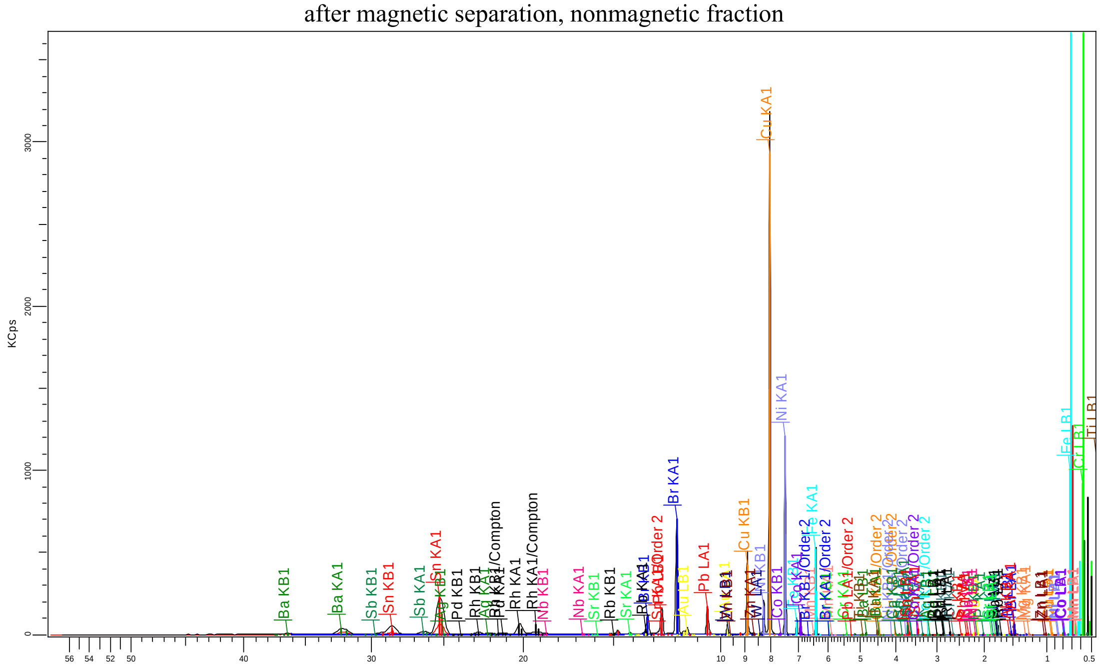

Fig.8. Diagram of XRF analysis for sample 2, microprocessors plastic waste milled, size> 0.8 mm, after magnetic separation, magnetic fraction

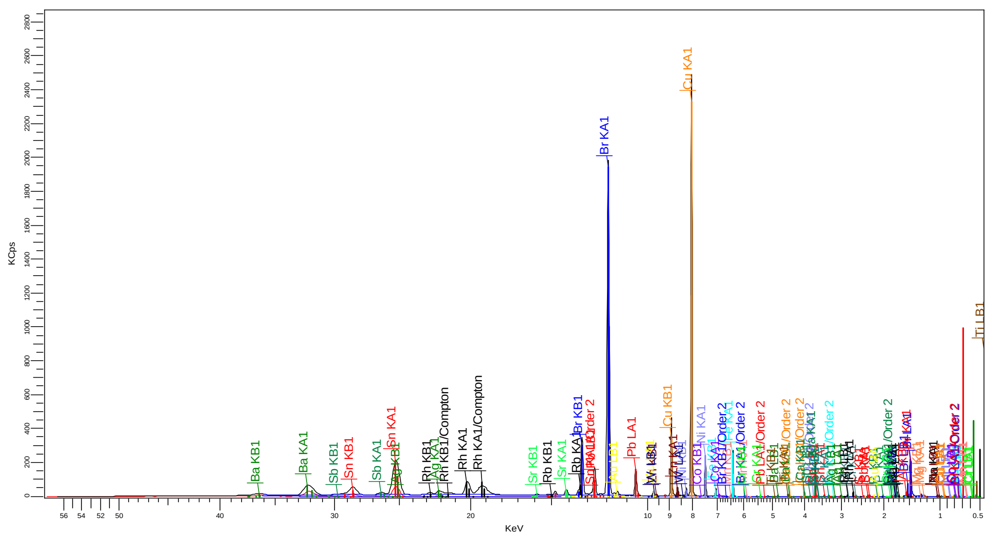

Fig.9. Diagram of XRF analysis for sample3, microprocessors plastic waste milled, size< 0.8 mm, after magnetic separation, nonmagnetic fraction

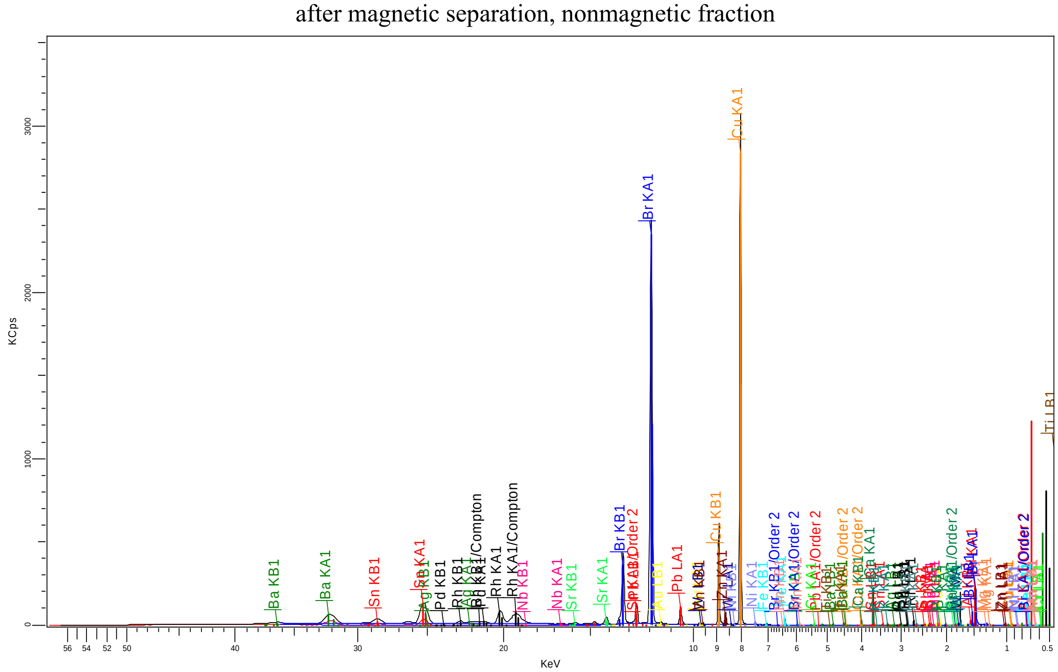

Fig.10. Diagram of XRF analysis for sample4, microprocessors plastic waste milled, size< 0.8 mm, after magnetic separation, magnetic fraction

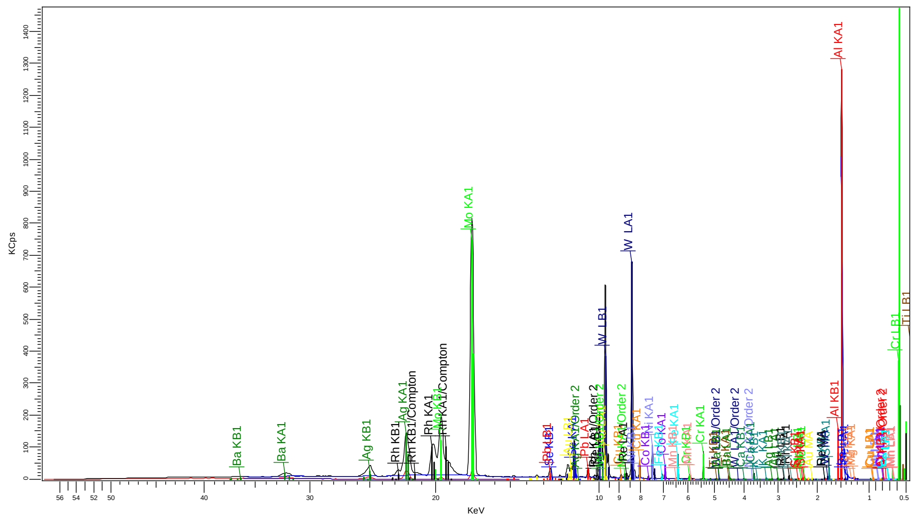

Fig.11. Diagram of XRF analysis for sample5, waste ceramic microprocessors milled, after magnetic separation, nonmagnetic fraction

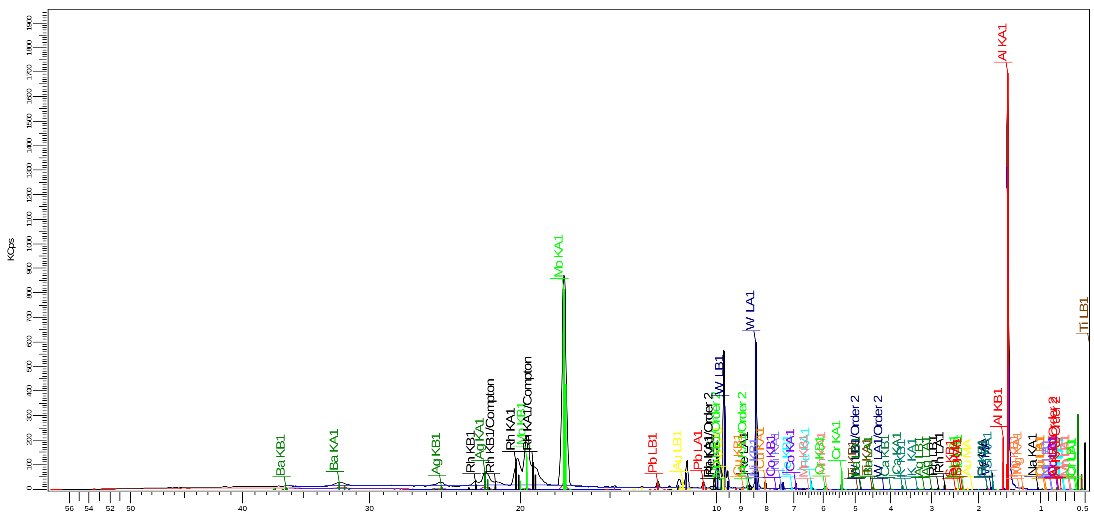

Fig.12. Diagram of XRF analysis for sample6, waste ceramic microprocessors milled, after magnetic separation, magnetic fraction

The precious metal distribution for each sample at the end of preparation technology is the following: It can be seen that gold is not present in the first sample because, after magnetic separation, it was distributed mostly in the magnetic fractions, namely sample 2, in samples with a size greater than 0.8 mm, while in those with sizes smaller than 0.8 mm, this precious metal was proportionately distributed in the samples with nonmagnetic (3) and magnetic (4) particles. In sample 4 (magnetic fraction of milled plastic microprocessor with a particle size smaller than 0.8 mm) in addition to gold silver appears with a concentration of 0.24%. It results that gold is well separated from larger particles while silver is separated from a smaller size.

Fractions resulting from magnetic separation of ceramic microprocessors exhibited the following precious metals distribution: Gold remained in the magnetic fraction in a concentration of 0.19%, while silver was distributed in both samples, with concentrations of 0, 38% in the non-magnetic fraction and 1.31% in the magnetic fraction. It resulted that microprocessors embedded in ceramic materials used in large quantities silver as the precious metal.

The separation of this content will be investigated in further works. In addition, the separation processes will be optimized to maximize the degree of recovery for the metallic components. This metals can be used as raw materials in metallurgical industries and also, hydrometallurgical processes will be used for recovery of precious metals, which consist in the individually recovery of metals from physically processed concentrates.

4. Conclusions

Samples were subjected to mechanical milling and separation processes consisting of milling, gravity separation and magnetic separation. The following conclusions can be drawn from the present study. Following the milling process, which was performed in two types of mills, due to different embedding materials for microprocessors, two types of concentrates resulted, one from microprocessors embedded in plastic, with particles of different sizes, and the other from microprocessors embedded in ceramic materials, in powder form.

The concentrates from plastic microprocessors were volumetrically separated resulting two fractions, one with a size greater than 0.8 mm and the other of size smaller than 0.8 mm.

All three magnetic concentrates were then separated and analyzed by x-ray fluorescence analysis. From the results of these tests it can be said that gold was separated best in the magnetic fraction of plastic microprocessors concentrates with size dimensions larger than 0.8 mm and had a much higher concentration than those with smaller size. In addition to gold, silver also appears in a small concentration in the magnetic fraction of these concentrates.

After magnetic separation, it was noticed that in the concentrates from microprocessors embedded in ceramics gold was left in the non-magnetic fraction, while silver was distributed in both fractions, but with a higher concentration in the magnetic fraction. Future works will focus on optimizing the processes for separating and recovering precious metals by hydrometallurgical processing methods, that will pursue the recovery of individual metals from polymetallic concentrates resulting from physical processing.

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