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The Recovery of Non-ferrous Metals from Broken Light Bulbs using the Magnetic Liquid Based Separation

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The paper presents results of a study on the selective separation technology of ferrous and non-ferrous metals from broken light bulbs. The proposed method is to use magnetic fluids to obtain a magnetic fluid based- separation. [1] The study was conducted using three types of waste materials: regular light bulbs, auto light bulbs and neon tubes. In order to process the waste materials, a six stages technologic flow was developed: a) separation of light bulbs components; b) Physical and chemical analysis of raw materials; c) grain conditioning of the raw material; d) dry magnetic separation of ferrous components; e) magnetic fluid separation of non-magnetic material; f) recovery of the magnetic fluid adhered to the surface of the separated material grains. [2] This study shows that magnetic fluid separation is only profitable for regular and auto light bulbs and is not profitable in the case of neon tubes.

Keywords : separation technology, magnetic fluid

1. Introduction

By using a magnetic fluid we intended to create an unconventional separation technology that is both economic and non-polluting – the magnetic fluid based separation. The need for such a method is obvious as ore and non-ferrous concentrate resources continue to decrease and their price is growing. On the other hand, in 1 September 2009 a law of the European Council became valid. This law states that old regular light bulbs (filament ones) should be replaced with the new economic light bulbs (gas ones), lowering by 20% the emissions of greenhouse gases till the year 2020. In this situation the concern to find appropriate solutions for the recovery and reuse of metals contained in light bulbs is justified.

This paper demonstrates how the levitation technique can be used in recycling useful non-ferrous metals left in electro technical waste [3].

2. Experimental Conditions: Phases of the Technologic Flow

The technologic flow developed for the recovery of electro-technical waste consists of the following phases: [4] (Fig. 1).

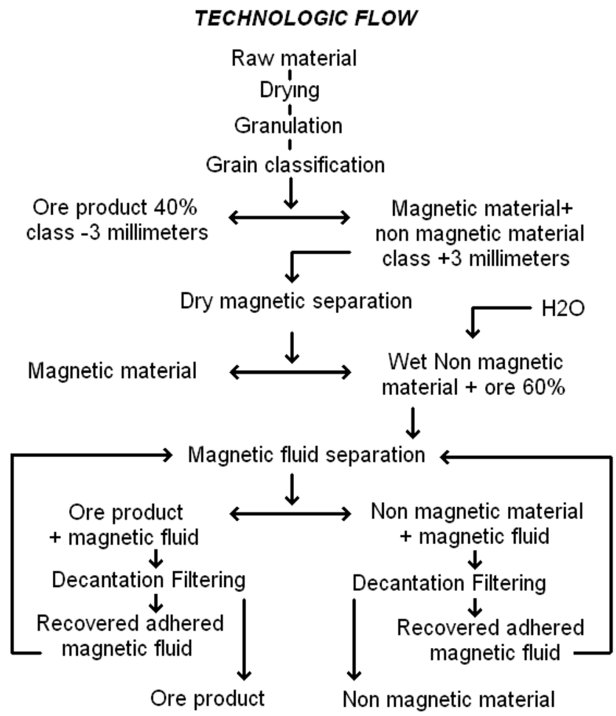

Fig. 1. The technologic flow developed for the recovery of electro-technical waste.

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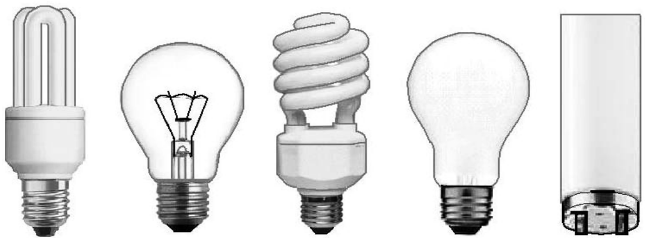


Fig. 2. Types of electro-technical waste, light bulbs + neon tubes.

a) Separation of light bulbs components;
b) Physical and chemical analysis of raw materials;
c) Grain conditioning of the raw material;
d) Dry magnetic separation of ferriferous components;
e) Magnetic fluid separation of non-magnetic material;
f) Recovery of the magnetic fluid adhered to the surface of the grains of separated material.

It can be observed that at grain ranking, using a sieve about 20-40% of the grinded ore product is removed in –3 mm class and what is left is a mixture of ore + magnetic material + non-magnetic material.

Using dry magnetic separation, the magnetic material is separated from the mixture and what is left is a new mixture of ore and non-magnetic material. Then, using magnetic fluid separation, the non-magnetic material is separated form the mixture and we are left with two things: ore and magnetic fluid as well as concentrated non-ferrous material and magnetic fluid. Through decantation the magnetic fluid can be recovered and reused in the technologic flow.

a) Separation of light bulbs components

This process consists of grinding the light bulbs (in medium size pieces) and separating the component elements such as cartridge case- filament- and glass. In this way we obtain metallic and non-metallic components as well as glass, textolit and ebonite.

b) Raw material analysis

For this experiment we used as raw material 10 pieces from each type of electro-technical waste mentioned below:
– Auto light bulbs with large, medium and small socket
– Regular light bulbs with steel and brass cartridge case
– Neon tubes with aluminum and brass socket

Beside the steel and brass cartridge cases, we are left with ferrous and non-ferrous metals (copper-nickel-zinc, lead-tin and copper-zinc alloys). We also have very small amounts of non-ferrous metals like tungsten and molybdenum.

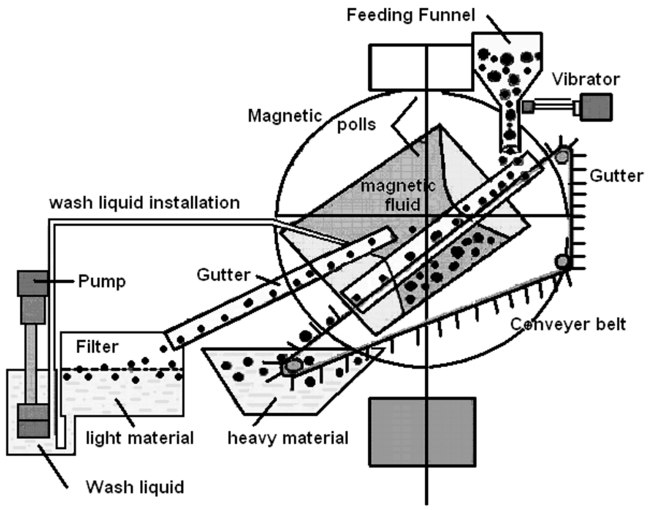
c) Conditioning of grain raw material involves the following operations: initial breaking of the waste light bulbs, grinding of the material obtained after the initial breaking and then ranking this obtained granular material. The raw material used for the experiment passed through several steps as follows: first it was broken into pieces and these pieces were put through a grinder. First, the distance between the grinder's disks was set to 5-8 mm and then, the distance was reduced to 1 mm. Grinding is done with the purpose of disposing the association between metallic and useless components, and to obtain a finer granulation. The degree of dissociation experimentally determined is 90%. In order to eliminate as much useless material as possible (about 40%), the grain ranking was done by using 5 mm and 3 mm sieves successively.

Chemical composition of raw materials was determined by spectral and chemical analysis of the basic constituent components of each type of electro-technical waste. For the socket, filament and filament holder, physical analysis is performed. To obtain a very accurate chemical composition of the raw material, a chemical analysis of the main components (filament holder and socket) was used.

d) Dry magnetic separation of the ferrous components consists of separating those components that have magnetic susceptibility from the +3 mm class grain mixture so that the non-magnetic material left can be magnetic-fluid processed.

The separation was done using a SEB-650 electro-magnetic separator with the purpose of retrieving magnetic components. Working parameters are: supply voltage of 220 V, the magnetic field of 1000-1500 Oersteds. The distance between the conveyer belt and separator was 30 to 80 mm. Magnetic materials were collected separately.

e) By magnetic-fluid separation of the +3 mm class non-magnetic material we aim to separate the non-magnetic components left in the mixture after the dry magnetic separation. The method of separation is based on the ability to control and change the apparent density of the magnetic fluid by applying external magnetic fields. The intensity and configuration of these external magnetic fields can be modified. This makes it possible to separate components found in a mixture based on the difference in their specific weight. The working parameters for the magnetic fluid processing of non magnetic raw material were: useful volume of separation cell (0.8-1) liter; the magnetization at saturation point of the magnetic fluid is (250-330) GS and the induced magnetization of the magnetic fluid is (125-150) GS; apparent density of the



Fig, 3. View of the SEB-650 electro-magnetic separator.

separation environment is (2300-2700) kg/m^3. A magnetic fluid separator was used, whose principle scheme is shown in the Fig. 3. The wet material is subject to separation inside a cell with a useful volume of 1 liter and using oil based magnetic fluid [6].

Metallic fractions (heavy) are collected at the bottom of the separation cell and ore fractions (light) levitate at the surface of the magnetic fluid and are collected at the top of the cell. The quantity of water adhering to the surface of material granules goes beyond 150 kg/tone.

f) Recovery of the mechanically driven magnetic fluid is done after a 30 minutes decantation period in the vessel where separated fractions are collected while the magnetic fluid is returned to the separation cells.

This is done because some magnetic fluid is carried out of the separation cells on the surface of the separated fractions.

The adherent magnetic fluid can be recovered by washing with proper solvents (like kerosene). In this way, the irrecoverable losses are about 0.25%.

If this method is to be economically efficient, it is mandatory to recover the magnetic fluid adherent to the surface of separated granules [7].

3. Results and Discussions

After a physical analysis of the raw material used in this study, weight extractions of materials have been determined and presented in Table 1.

Figs. 4-6 depict the weight extractions for each of the 3 types of raw materials. It can be seen that:

– Auto light bulbs contain a slightly higher amount of useful materials (socket + filament) compared with the quantity of ore (useless material) (Fig. 4)
– Regular light bulbs have a small amount of useful material and a large amount of useless material (Fig. 5).

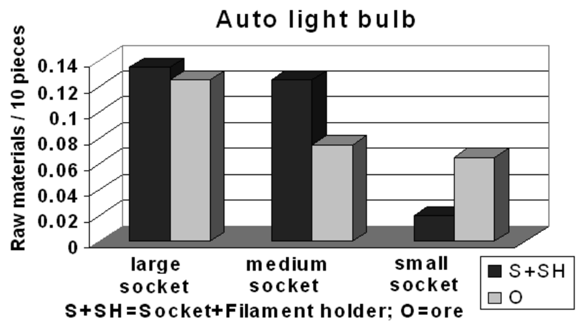


Fig. 4. Weight extractions from auto light bulbs.

Table 1. Measured weight extractions from raw materials.

Raw material	Weight G [kg/10pieces]	Socket + Filament holder **S+SH** [kg/10 pieces]		Ore, **O** [kg/10 pieces]	
		1. **Auto light bulbs**			
- With large socket	0.260	0.135	51.92%	0.125	48.08%
- With medium socket	0.200	0.125	62.5%	0.075	37.5%
- With small socket	0.085	0.020	23.53%	0.065	76.47%
		2. **Regular light bulbs**			
- With steel cartridge case	0.338	0.049	14.5%	0.289	85.5%
- With brass cartridge case	0.367	0.050	13.62%	0.317	86.38%
		3. **Neon tubes**			
- Big, with aluminum holder	3.920	0.060	1.53%	3.860	98.47%
- Medium, with aluminum holder	2.200	0.065	2.95%	2.135	97.05%
- Medium, with brass holder	3.390	0.067	1.976%	3.323	98.024%
- Small, with brass holder	1.910	0.065	3.40%	1.845	96.59%

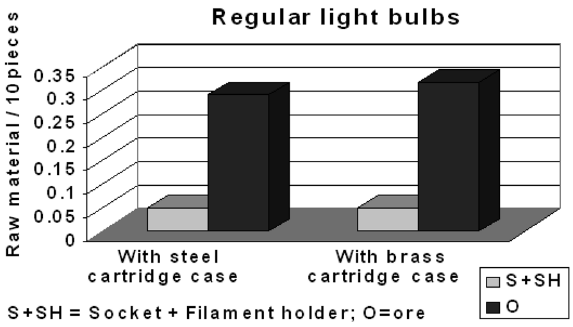


Fig. 5. Weight extractions from regular light bulbs.

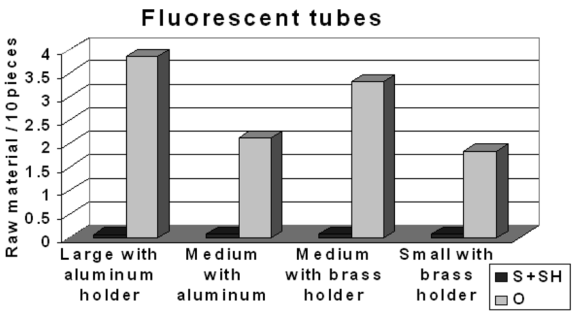


Fig. 6. Weight extractions from neon tubes.

– Neon tubes have such a small amount of useful material that it sometimes is not worth processing them (Fig. 6).

To obtain a very accurate chemical composition of the raw material, a chemical analysis of the main components (filament support and socket) was done. The experimental results obtained after determination of the chemical composition of the raw materials are presented in Table 2.

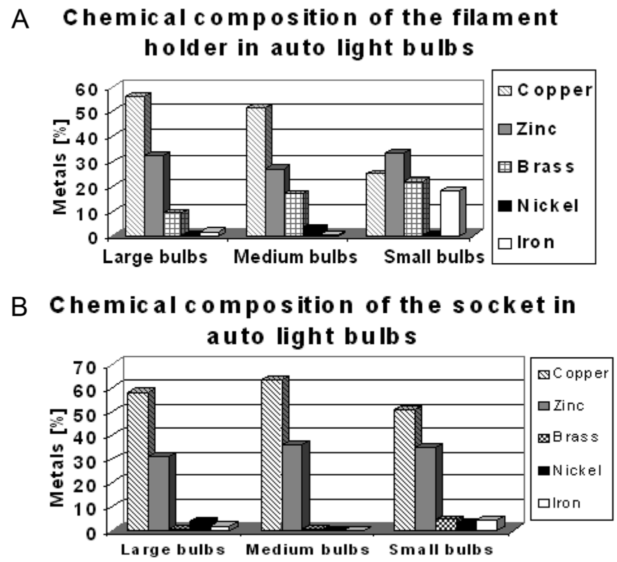


Fig. 7. The chemical composition of auto light bulbs.

In Fig. 7 one can observe that large auto light bulbs contain large amounts of Nickel (3.98%)-Copper (57.8%) and Zinc (32.09%) in the socket and filament holder. The medium-size auto light bulbs contain Copper (63.25%) in the socket and Zink (35.81%) in the filament holder. Small auto light bulbs contain large amounts of Brass (22.1%) and Iron (18.25%). Parts of this electro-technical waste are special brass types like Copper-zinc alloys, Nickel-copper-zinc alloys, electro-technical tin and tungsten. Beside these metallic components, there are also useless components.

Table 2. The chemical composition of raw materials.

Nr.	Types of raw material		Metals [%]				
			Copper	Zinc	Brass	Nickel	Iron
	Auto light bulbs						
1	Large	socket	57.80	31.15	0.36	3.98	2.11
		Filament holder	56.10	32.09	9.40	0.32	1.80
	Medium	socket	63.25	35.81	0.49	0.16	0.12
		Filament holder	51.42	26.90	17	3.31	0.49
	Small	socket	50.55	35.12	4.55	3.10	4.15
		Filament holder	24.98	33.40	22.10	0.60	18.25
	Regular light bulbs						
2	With brass socket	socket	58.50	32.19	0.28	0.003	1.35
		Filament holder	29.54	11.00	49.90	3.50	0.00
	With iron socket	socket	0.59	3.15	0.55	0.07	93.88
		Filament holder	29.12	7.08	32.06	6.65	0.84
	Neon tubes						
3	With neon socket		70.90	25.09	0.22	0.002	0.35
	With filament holder		64.02	20.80	0.55	10.88	1.12

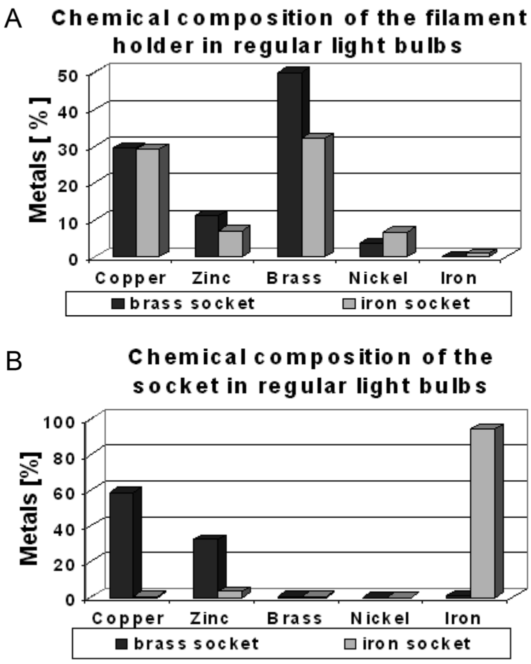


Fig. 8. The chemical composition of elements found in regular light bulbs.

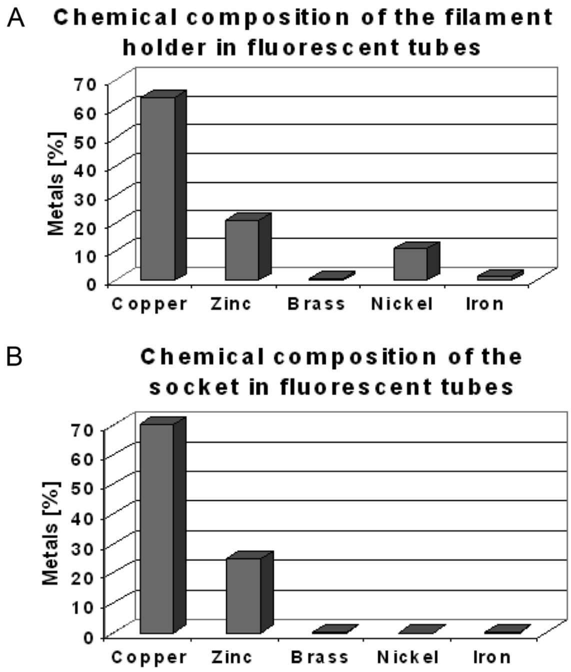


Fig. 9. The chemical composition of elements found in neon tubes.

In Fig. 8, the chemical composition of the elements found in regular light bulbs is presented. As it can be seen, the socket contains a large amount of Iron (93.19%) in the case of light bulbs that have iron sockets and large amounts of Copper (58.50%) and Zinc (32.19%) in the case of regular light bulbs that have brass sockets. The filament holder contains electro-technical tin (49.90%) – Copper (58.50%) and Nickel (32.19%) in the case of regular light bulbs with brass socket. Regular light bulbs with iron socket contain smaller amounts of electro-technical tin (32.06%) – Copper (29.12%) and Nickel (6.65%) in the filament holder.

Regular light bulbs with galvanized steel (or with iron socket) will be processed only till the point of magnetic product. Magnetic fluid separation is not profitable because of the very small quantity of non-magnetic material contained. As for the magnetic materials, because of the low weight extraction and their chemical composition, they will be further processed by metallurgical means. Neon tubes will not be processed using magnetic fluid separation because they contain a very small amount of metallic components compared with the amount of useless material left.

Fig. 9 presents the chemical composition of the elements found in neon tubes. As it can be seen, the socket contains Copper (70.90%) and Zinc (25.09%) while the filament holder contains Copper (64.02%) – Zinc (20.8%) and Nickel (10.88%), other metals are found in insignificant quantities.

The experimental results obtained at grain ranking, dry magnetic separation and magnetic fluid separation of raw material, are presented in Table 3.

Table 3. Sum up of material obtained through separation.

Raw material	+3 mm class	1. Mixture of auto light bulbs		2. Regular light bulbs		3. Neon tubes	
Grain ranking [kg]	Quantity	88.67	100%	234	100%	425	100%
	Useful material	39.90	45%	109	46.58%	17.0	4%
	Useless material	48.77	55%	127.96	53.42%	408	96%
Dry magnetic separation [kg]	Quantity	39.90	100%	109	100%	17.0	100%
	Magnetic Material	1.05	2.64%	22.33	20.5%	0.54	3.18%
	Nonmagnetic Material	38.85	97.36%	86.67	79.5%	16.46	96.82%
Magnetic fluid separation [kg]	Quantity	38.85	100%	86.67	100%	16.97	100%
	Nonmagnetic concentrate	25.29	65.1%	19	20.77%	0.51	3.00%
	Useless material	13.56	34.9%	68.67	79.23%	16.46	96.99%

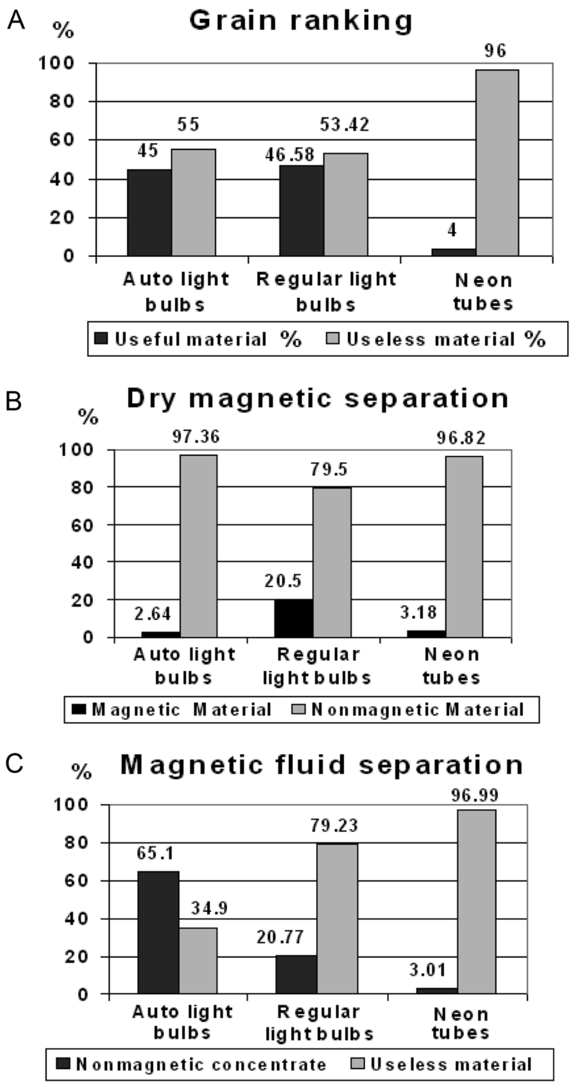


Fig. 10. Sum up of materials obtained through separation.

We considered three types of electro-technical waste: regular light bulbs, auto light bulbs and neon tubes. A technologic flow was developed to recycle and re-use useful components. Table number 3 shows that when this process is completed, at grain ranking, the largest amount of useful components came from regular light bulbs (46.58%) followed by auto light bulbs with (45%) and neon tubes with (4%). In the case of dry magnetic separation, important quantities of magnetic materials were recovered as follows: 20.5% from regular light bulbs – 2.64% from auto light bulbs and 3.18% from neon tubes. By using magnetic fluid separation, non-magnetic materials were recovered as follows: 65.1% from auto light bulbs – 20.77% from regular light bulbs and only 3 % from neon tubes.

In figure number 10, it can be observed that at grain ranking, the greatest quantity of useless separated material is obtained from neon tubes (96%). By using dry magnetic separation, for a mixture of regular light bulbs we obtained 79.5% useless material. By using magnetic fluid separation on neon tubes we obtain 96.99% useless material. The main idea is that magnetic fluid separation is only profitable for regular and auto light bulbs. In the case of neon tubes, the magnetic fluid separation is not profitable due to the large amount of useless materials contained.

Magnetic fluid separation is used to separate the non-

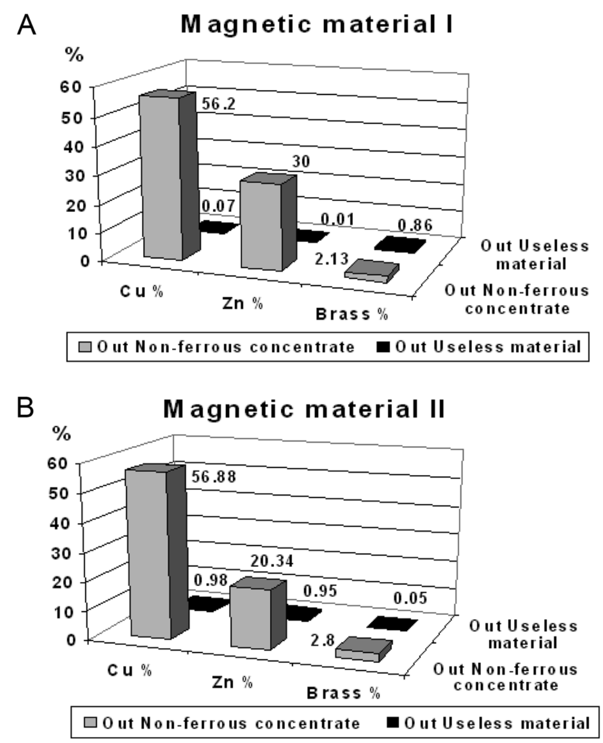


Fig. 11. Materials obtained through magnetic fluid separation.

Table 4. Products obtained through magnetic fluid separation method.

	Contained metals	Copper (%)	Zinc (%)	Brass (%)
IN	Magnetic Material I (auto light bulbs) = 776 kg	36.44	19.42	1.63
	Magnetic Material II (brass socket light bulbs) = 733 kg	10.5	15.55	0.52
OUT	Non-ferrous concentrate I = 500 kg	56.2	30	2.13
	Useless material I = 276 kg	0.07	0.01	0.86
	Non-ferrous concentrate II = 124 kg	56.88	20.34	2.8
	Useless material II = 609 kg	0.98	0.95	0.05

Table 5. Characterization of final products.

a) Non-ferrous metals from auto light bulbs	Chemical composition		
Annual quantity=40 tons / year / 3 million light bulbs	Cu=56%	Zn=30%	Pb+Sn=(2.5-11)%
b) Non-ferrous metals from regular light bulbs with brass sockets	Chemical composition		
Annual quantity=13.6 tons / year / 3 million light bulbs	Cu=(56-60)%	Zn=(20-26)%	Pb+Sn=(2.8-11)%
c) useless materials=1088 tons / year	Useless material left from regular and auto light bulbs		

magnetic components left in the mixture after the dry magnetic separation. The method of separation is based on the ability to control and change the apparent density of magnetic fluid by applying external magnetic fields. The intensity and configuration of these external magnetic fields can be modified. This makes it possible to separate components found in a mixture based on the difference in their specific weight [8].

In Table 4, you can see the quantity of metals obtained after the magnetic fluid separation of electro-technical waste.

Fig. 11 presents the chemical analysis of the materials obtained after the magnetic fluid separation. Note that it is possible to recover from the non-ferrous concentrate I (auto light bulbs) the following elements: Copper (~56.2 %) and Zinc (~30%). Note that it is also possible to recover from the non-ferrous concentrate II (brass socket light bulbs) the following elements: Copper (~56.88%) and Zinc (~20.34%). We observed that in the useless material left there are traces of non-ferrous metals whose recovery is not profitable.

3.1. Characterization of final products

The analysis of the magneto fluid processing capabilities of different waste types (different types of light bulbs and neon tubes) determined an estimation of the quantity of non-ferrous materials that can be produced. By knowing the national raw material resources (used light bulbs) and taking into consideration the costs of the magnetic fluid separation method, Table 5 shows the products that could be obtained.

4. Conclusions and Proposals

a) It has been observed that by moistening the raw material before the magnetic fluid separation reduces the quantity of adhered magnetic fluid with up to 55%.

b) To ensure the efficiency of this separation method it is mandatory to recover the magnetic fluid left on the separated fractions [9]. These have been washed with oil and the newly obtained magnetic fluid (very diluted) was used (after a purification process) as a solvent for diluting other magnetic fluids. In this way, the losses of magnetic fluid were reduced to a minimum of 0.1%.

c) In the phase of magnetic fluid separation we recover, from waste electro-technical materials, non-magnetic concentrate and useless material. This type of separation is only profitable in the case of regular and auto light bulbs and is not profitable in the case of neon tubes.

d) Regular light bulbs with galvanized steel and iron sockets will be processed till the point of magnetic product and further by metallurgical means. The magnetic fluid separation is not recommended in this case because of the small amounts of non-magnetic material.

e) The old – filament light bulbs contain large amounts of useful materials (magnetic + non-magnetic). Because they will be replaced with new – ergonomic light bulbs, it is important and efficient to recover and reuse the useful metals they contain.

f) Based on these experimental results it may be proposed to conduct a study on the opportunity of creating (in the first phase of) a pilot experimental industrial installation with a capacity of 200 tones per year. Used and rejected light bulbs across the country could be recycled and the useful metals they contain could be reused.

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