

Book Chapter

Separation of Copper from Electric Cable Waste Based on Mineral Processing Methods: A Case Study

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Abstract

Recycling must always be a priority in waste management. Recycled copper does not lose any of its properties. Recycling of electrical cable waste requires a separation between metal and insulating material and for that to happen separation technologies have to be applied. The objective of this work was to essay the separation by jigging, shaking table and froth flotation of the copper and plastic fractions of the electrical cable waste, previously ground and with size below 2 mm. The effect of particle size was also analysed.

Jigging and shaking table have proved to be effective in the separation of copper from plastics. It was obtained a copper concentrate with a copper grade of about 97% by both methods with a copper recovery of about 97%. Jigging separation had similar separation efficiency in the seven size fractions, but in shaking table the separation efficiency slightly improved with the increase of the particles size.

Plastics are naturally hydrophobic and copper presented some hydrophobic behavior. The addition of low depressant concentration allowed copper depression. Froth flotation presented smaller separation efficiency than jigging and shaking table. Separation by froth flotation presented the worst results for the coarser and finer particles.

Keywords

Cable Waste; Copper; Jigging; Shaking Table; Froth Flotation; Particle Size

Introduction

Proper waste management is one of the major environmental concerns of public institutions. Waste management systems cover all actions that seek to recover and recycle materials present in the discarded wastes as a resource, in order to reduce health and environment problems, and to conserve natural resources and reduce the cost of production of many products. Products such as metals, plastics, glass and paper can be recycled.

It is not difficult to recycle clean and homogeneous waste, but problems arise when waste is constituted by different materials. One of those composite products is the waste of electrical cables. Electrical cables are composed by a conductor, mostly a copper wire, with a plastic insulation cover. Copper is the most valuable component of the cable that can be recycled. However, the recycling of the cable insulator materials, with lower value, can also be performed. The recovery of copper from electrical cable waste is important not only from the point of view of decreasing the amount of waste but also resource recycling. It is noted that electrical cables application is increasing with the growing use of computers, Internet, cable television, and the increase in electrical power service worldwide.

Copper is a metal naturally present in the earth's crust, and has been a vital metal in the development of civilization. Copper is a malleable and ductile metallic element that acts as an excellent conductor of heat and electricity, has low chemical reactivity, and is corrosion resistant and antimicrobial. Copper has the second highest electrical conductivity of any metal, only after silver, having its main uses in equipment (31%), building construction (28%), infrastructure (16%), transport (13%) and industry (12%) [1].

Copper comes from two sources: extraction and processing (refining) of raw material source, called primary production; and recycling of end-of-life products, called secondary production. ICSG [1] estimates that in 2018, at the refinery level, secondary copper refined production reached 17% of total copper refined production. In the last decades, the world mining production of copper has grown by 3% *per annum* to 20.6 million tonnes in 2018 and its largest producer was Chile (5.8 million tonnes) followed by Peru (2.5 million tonnes). Refinery Production in 2018 increased to 24.1 million tonnes, including 4.0 million tonnes of secondary refined production. The total global demand for copper in 2018 was approximately 25 million tonnes and China was its largest consumer with near 12.5 million tonnes [1].

Copper is one of the most recycled metals. All products made from copper can be recycled and recycled copper loses none of its chemical or physical properties. Recycling copper extends the use of resources, reducing energy consumption, and decreasing waste disposal, therefore conserving the environment. It is estimated that in 2015 about 29% of the copper used came from recycled copper and around 40% of the demand for copper within Europe was supplied from recycled copper [1].

To take full advantage of the benefits of electrical cables, their products require a proper recovery and management when they reach the end of their service life. Metal and plastic recycling of electrical cables require a previous separation of metals from plastics. In recent years, several separation technologies developed in mineral processing engineering, based on the differences in physical and chemical properties, have been applied to separate metals and nonmetals from electric and electronic waste. Several studies have been reviewed the progress and the potential of the available techniques for recovery metals and nonmetals from electric and electronic waste [2-8]. These technologies include the application of physical separation, such as gravity methods, which are based on the different density of materials [9-12]; magnetic separation [13-15]; electrostatic separation by the corona method [13,16,17]; electrical conductivity (Eddy currents) [18-20] and froth flotation [11,21-23].

Also, chemical (thermal) techniques, such as pyrolysis, gasification, depolymerization using supercritical fluids, and hydrogenolytic degradation, are used to separate organic and metallic materials [24-26]. Electrochemical methods, metallurgical, pyrometallurgical and hydrometallurgical processes employed to recover metals from other materials are also studied [27-34]. Furthermore, biometallurgical processing for recovering metals have been analysed [35-40].

Some of these studies intended to improve the separation of electrical and electronic waste through the use of physical/mechanical means. Two of these processes are gravity separation (especially jigging and shaking table) where the separation is based upon the density difference of materials, and froth flotation where the separation is based upon the hydrophobicity difference of materials.

In jigging, a mixture of solid-water is placed at the bottom of a perforated vessel (jig), through which vertical currents of water are forced, expanding (ascending currents) or compacting (descending currents) the pulsating bed. This promotes a particles stratification based on the density difference between the constituent particles of the mixture. The densest particles are in the base of that stratum, being kept inside the jigging cell, while the particles of lower density are in the superficial layers, overflowed.

In shaking table, the particles separation occurs by the action of backwards and forwards motion (stroke) of the table and by wash water applied along the length of the table. Vertical stratification takes place behind the riffles, with the finest and heaviest particles being at the bottom, whereas the coarsest and lightest particles being at the top. Heavy particles are concentrated behind the riffles and moving along the top of the table, while light particles move down the incline of the table with the majority of the water to discharge at the bottom as tailings.

Froth flotation is the separation method most used in mining industry. It is based on the selective adhesion of hydrophobic

particles to the air and of the hydrophilic particles to the water in a solid/water pulp. The separation takes place in a container (cell or column), where the water and the particles are put together, and where air is continuously injected to produce air bubbles. Small quantities of chemicals reagents are added to control the hydrophobicity/wettability of the particles. Hydrophobic particles adhere, after collision with the air bubbles, and moves upwards to the top of the cell where they are collected as the floated product, while hydrophilic particles settle in the pulp and become the non-floated product or sink.

This study aims to compare the separation of copper and plastics from the electrical cable waste through the use of jiggling, shaking table and froth flotation. The effect of particle size on separation efficiency was also investigated.

Materials and methods

Materials

Granules of electrical cables waste, from multiple copper wires with plastic insulators previously crushed, were used in this experiment. The degree of liberation is 100%, i.e., all copper and plastic particles are completely liberated. The single copper wire had a diameter of 0.15 mm. The density of the copper wires, measured by an Ultra Pycnometer (AccuPyc 1330), was 8.84 g/cm³ and the density of plastic was 1.34 g/cm³. The particles were sieved into seven size fractions: -0.25 mm, +0.25-0.35 mm, +0.35-0.5 mm, +0.5-0.7, +0.7-1.0 mm, +1.0-1.4 and +1.4-2 mm (Table 1). The mean size of the mixed particles (d_{50} from cumulative frequency plot) was 0.59 mm. The mean size of copper particles was 0.33 mm and the mean size of plastic particles was 1.03 mm. Most of the copper particles have sizes below 0.5 mm (88.7% by weight) against plastic particles that have sizes greater than 0.5 mm (about 84.5% by weight).

Table 1: Size and assay distribution of copper and plastic of granulates electrical cable waste.

Size (mm)	Weight (%)	Grade (%)		Distribution (%)	
		Cu	Plastic	Cu	Plastic
<0.25	13.96	79.58	20.42	27.24	4.81
		80.63	19.37	27.82	4.60
0.25-0.35	14.07	79.06	20.94	33.62	6.13
0.35-0.50	17.34	25.11	74.89	7.08	14.54
0.50-0.7	11.49	10.26	89.74	3.04	18.28
0.7-1.0	12.07	3.27	96.73	1.05	21.31
1.0-1.4	13.05	0.35	99.65	0.15	30.33
1.4-2	18.02				
Total	100.00	40.78	59.22	100.00	100.00

Jigging

Tests were carried out in a Denver laboratory jig, with a rectangular section of 10x15 cm and a bottom of steel wire screen. The frequency of the diaphragm movement was 250 cycles/minute, and in each test it was used 1.5 kg of material. The total time for separation was about 15 minutes. For investigating the effect of the water flow rate in the separation of copper/plastic mixture by jigging, three tests were conducted (with a water flow rate of 2, 3 and 4 L/min). Since plastic has lower density than copper, plastic is overflowed and copper is kept inside the jigging cell. The product that overflows in the jigging operation will be designated by floated; and the one that remains inside will be designated by sink. After the experiments, the sink was removed from the jig.

Shaking Table

Tests were carried out in a laboratory Wilfley table, with a rectangular shape of 1.25 m length and 0.55 m width. It is partially riffled alongside the table motion, and riffles are 4 mm high on the feed side, decreasing toward the concentrate edge, and the gap between riffles is 15 mm. There are two water supply points: feed water (near the feed box) and wash water. Particles build up behind each riffle and stratification occurs with heavier particles sinking to the bottom. The shaking action of the table carries the heavy particles along the back of each riffle to the concentrate discharge, which will be designated as

sink. The light particles are carried with the majority of the water over each riffle and move down the table to the tailings zone, which will be designated as floated. Multiple products can be produced in the wet shaking table by adding splitters. In this work, three products were generated (“light”, “heavy” and “middling”) by adjusting two splitters. However, after a first pass through the table, the middling product returned once again to the table in order to separate the copper from the plastics. It is expected that the light product will be enriched in plastic and the heavy product enriched in copper.

The separation on shaking table is controlled by many operating parameters (inclination, wash water flow rate, feed water flow rate, frequency and amplitude of table movement, feed pulp density). In this work, inclination and wash water flow were analysed (Table 2). In each test 2.5 kg of material were used. The frequency (300cycles/minute), amplitude of table movement (8 mm), feed water flow rate (2 L/min.) and position of the splitters were kept constant during all experiments.

Table 2: Range of the parameters selected for the shaking table study.

Parameters	Range		
Inclination (°)	4	5.5	7
Wash water flow rate (L/min)	3	4.5	6

Froth Flotation

The froth flotation assays took place in a Denver cell with a capacity of 3 dm³ at a low rotational speed of 600 rpm. Each test used 50 g of electric cable waste that was conditioned with sodium sulfide (407410 Sigma-Aldrich) and meso-2,3-Dimercaptosuccinic acid (D7881 Sigma-Aldrich), as depressants agents of copper, for about 5 minutes and later with methyl isobutyl carbinol (MIBC) (109916 Sigma Aldrich), as frothing reagent, for about 2 minutes before the flotation. Then the air valve was opened and the floated product was collected for about 6 minutes. The pH in the flotation cell was not controlled but it was measured periodically along the experiment. The pH remained approximately constant, in the range of 7.0-7.2. Tap water was used in the flotation tests.

After the experiments of jigging, shaking table and froth flotation, the floated and sink products were dried, screened and weighed. The separation was controlled using the recovery and grade of copper and plastic in the sink and in the floated products, after manual sorting and weighing the copper and plastic with a laboratory scale (precision ± 0.01 g). All the experiments were replicate three times under similar operating conditions. The effectiveness of the plastic separation was quantified as $\eta = R_{\text{CU}} - R_{\text{PL}}$ (where η is the separation efficiency, R_{CU} is the recovery of copper in the sink and R_{PL} is the recovery of plastic in the sink) [40].

Results and Discussion

Jigging

The recovery and grade of copper in the sink (concentrate), and the recovery and grade of plastic in the floated (tailing), as well as the separation efficiency were influenced by the water flow rate (Table 3).

Table 3: Experimental matrix and results of jigging separation (average of 3 replicates).

Water flow rate (L/min)	Sink		Floated		Separation Efficiency (%)
	Copper recovery (%)	Copper Grade (%)	Plastic recovery (%)	Plastic Grade (%)	
2	98.37	91.57	93.76	98.82	92.13
3	97.81	96.66	97.67	98.48	95.48
4	94.64	97.78	98.52	96.39	93.16

The recovery of copper and plastic in the sink decreased with increasing water flow rate. The highest recovery of copper in the sink (98.37%) was obtained for lowest water flow rate (2 L/min). On the contrary, the highest recovery of plastic in the floated (98.52%) was obtained for greatest water flow rate (4 L/min). By increasing the water flow rate from 2 to 3 L/min the recovery of copper in the sink was almost constant, but the grade of copper increased, because the recovery of plastic in the sink decreased. However, by increasing the water flow rate from 3 to 4 L/min the recovery of copper in the sink decreased, and the recovery of plastic in the floated was almost constant.

The highest separation efficiency (95.48%) was obtained with an intermediate water flow rate of 3 L/min, with a copper recovery in the sink of 97.81% and a copper grade of 96.66%. Sarvar et al., [23] obtained similar results in wet jigging separation of metals from computer printed circuit boards of the 0.59-1.68 mm size fraction, with a metal recovery in the sink of 97.5% and a metal grade of 92.5%. Also, He et al., [12] separated the same material but with an active pulsing air classifier, achieving a maximum separation efficiency of 92.4% and a metal recovery of 96.2%.

Shaking Table

To evaluate the effect of inclination and wash water flow rate in the separation of copper/plastic mixture by wet shaking table, 9 tests sets were performed (Table 4). The grade and recovery of copper in the sink (concentrate zone), the grade and recovery of plastic in the floated (tailing zone), and the separation efficiency were strongly influenced by the table inclination and wash water flow rate.

Table 4: Experimental matrix and results of shaking table separation (average of 3 replicates).

Experimental conditions		Sink		Floated		Separation Efficiency (%)
Inclination (°)	Wash water flow rate (L/min.)	Copper recovery (%)	Copper Grade (%)	Plastic recovery (%)	Plastic Grade (%)	
4	3	99.73	68.79	68.84	99.73	68.57
4	4.5	97.66	81.00	84.23	98.12	81.89
4	6	84.75	87.44	91.62	89.72	76.37
5.5	3	98.46	83.45	86.55	98.79	85.01
5.5	4.5	96.61	97.35	98.19	97.68	94.80
5.5	6	72.78	99.11	99.55	84.15	72.33
7	3	75.19	90.46	94.54	84.69	69.73
7	4.5	62.15	99.43	99.75	79.79	62.90
7	6	35.65	100.00	100.00	69.29	35.65

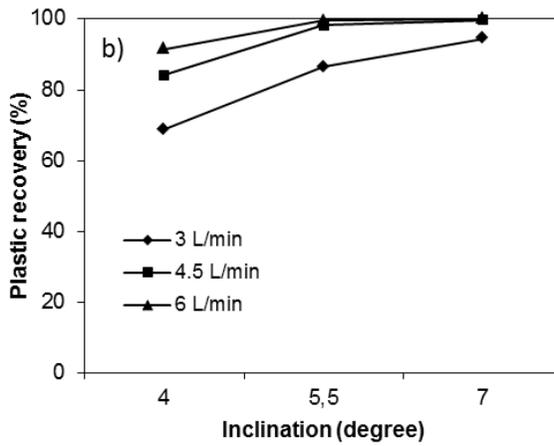
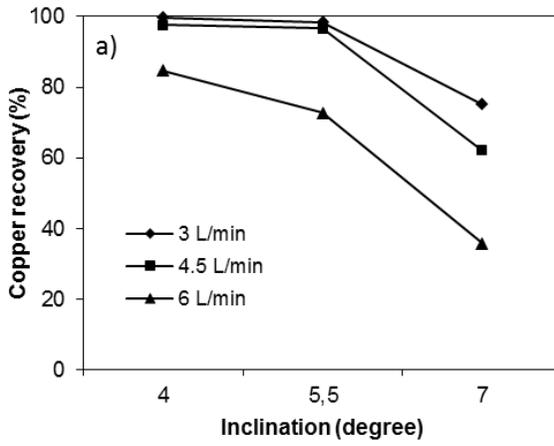
The highest recovery of copper in the sink (99.73%) was obtained with the lowest table inclination and the lowest wash water flow rate. On the contrary, the lowest recovery of copper in the sink (35.65%) was obtained for greatest table inclination and greatest wash water flow rate. The highest recovery of

plastic in the floated (100%) was obtained with a maximum of table inclination and wash water flow rate. The lowest recovery of plastic in the floated (68.84%) was obtained for the lowest table inclination and lowest wash water flow rate. As the table inclination or the wash water flow rate increased, the transport of copper to the floated product increased, which in turn decreased the recovery of copper in the sink product. Moreover, as the table inclination or the wash water flow rate increased, the transport of plastic to the floated product increased which in turn improved the grade of copper in the sink product.

The best separation efficiency (94.8%) was obtained for intermediate levels of table inclination of 5.5° and wash water flow rate of 4.5 L/min, with a copper grade of 97.35% in the sink and a copper recovery of 96.61%, and with a plastic grade of 97.68% in the floated and a plastic recovery of 98.19% (Table 4). These results were better than the ones obtained by Koyanaka et al., [9] in the separation of copper/plastic mixture using an inclined vibrating plate, getting a separation efficiency of 73%, a copper grade of 97% and a copper recovery of about 80%.

The effect of table inclination depends on the value of wash water flow rate and vice versa (Figure 1). When wash water flow rate was at the highest level (6 L/min), a change in table inclination level had a greater effect in copper recovery than the one observed when wash water flow was at its lowest level (3 L/min) (Figure 1a). For plastic recovery the opposite was observed, with a higher effect of table inclination when wash water flow rate was at a lower level (Figure 1b).

When table inclination was at the highest level (7°), a change in wash water flow rate had a greater effect in copper recovery than the one observed when table inclination was set at its lowest level (4°) (Figure 1c). For plastic recovery, the opposite was observed, with a higher effect of wash water flow rate when table inclination was set at a lower level (Figure 1d).



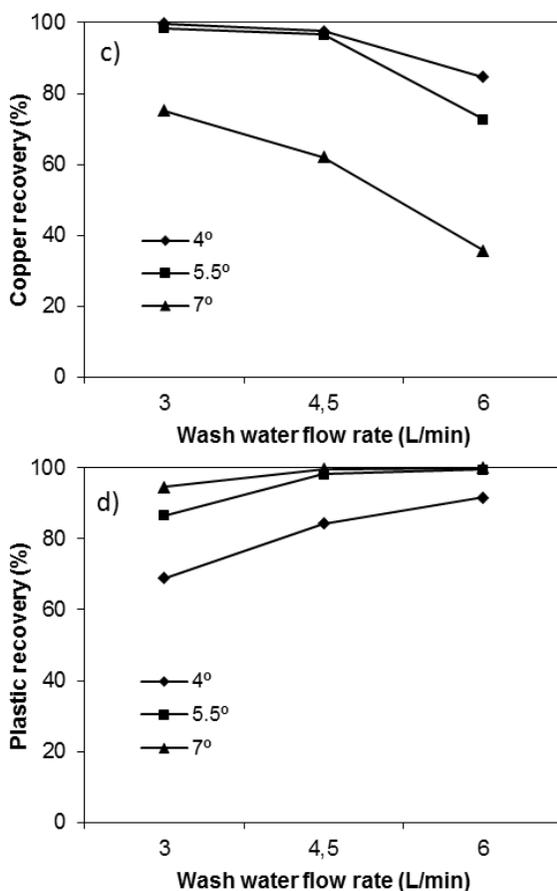


Figure 1: Effect of interaction between table inclination and wash water flow rate on copper recovery (a,c) and on plastic recovery (b,d).

Froth Flotation

Firstly, flotation separation tests were carried out with only a frother reagent (MIBC). Figure 2 shows the recovery and grade of copper in the sink (concentrate) and plastics recovery and grade in the floated (tailing) versus MIBC concentration. Although the flotation recovery of plastic was clearly greater than copper recovery, the flotation recovery of copper was significant, and so the selectivity of flotation separation was worse. Plastics are naturally hydrophobic because the flotation

recovery is higher. Plastic and copper showed a similar variation of the floatability with MIBC concentration. This means that the effect of the froth type, for different MIBC concentrations, influenced in a similar way the flotation of the plastic and copper. Plastic and copper had higher floatability for intermediate concentrations of the MIBC (90 mg/L). The lowest recovery of plastic and copper was obtained for the lowest and highest concentration of MIBC (15 and 180 mg/L). This was a consequence of the formation of weak froth in the presence of low concentrations of MIBC (15 mg/L), and a consequence of the formation of more and very stable froth, which conditioned the rise of the particles in the froth, for high concentrations of MIBC (180 mg/L).

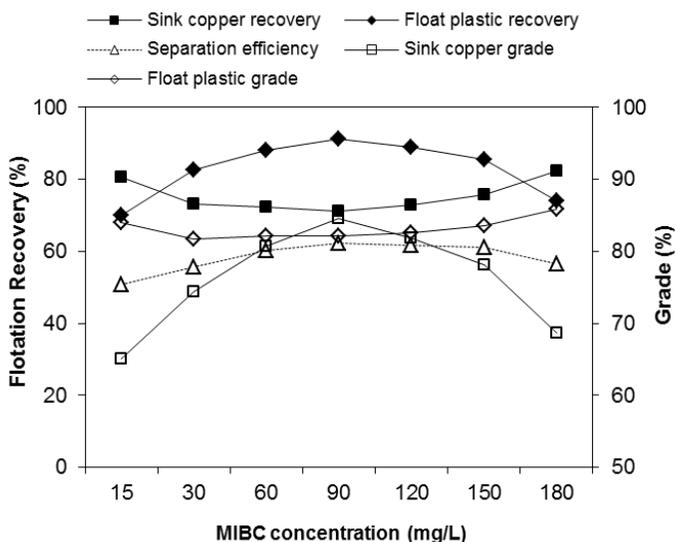


Figure 2: Recovery and grade of copper in the sink and of plastic in the floated, and separation efficiency versus MIBC concentration.

The best results were obtained for an intermediate concentration of MIBC (90 mg/L) with a copper grade of 84.6% in the sink and a copper recovery of 71.16, and with a plastic grade of 82.10% in the floated and a plastic recovery of 91.11% (Figure 2). These results were better than those obtained by Ogunniyi and Vermaak [21], in a study for beneficiation of printed circuit

board by froth flotation, where the maximum copper recovery in the sink was 66%. Also, Sarvar et al., [23], in froth flotation separation of metals from computer printed circuit boards of size fraction lower than 0.59 mm, obtained worse results, with a metal recovery in the sink of 85.7%, a metal grade of 75%, and a separation efficiency of 45.25%. However, these results were not as good as those obtained by Gallegos-Acevedo et al., [22], in a study for beneficiation of printed circuit board by froth flotation, where the maximum separation efficiency was 85.32%, the metal recovery in the sink was 92.62% and the fiberglass recovery in the floated was 92.70%.

Since copper presented some hydrophobic behavior, because part of it was floated, it was necessary to test some copper depressants in order to promote its wettability and consequent depression. After the use of some potential copper depressants such as N-(1-Naphthyl)ethylenediamine dihydrochloride (N9125 Sigma-Aldrich), starch (S4251 Sigma-Aldrich), sodium metabisulfite (255556 Sigma-Aldrich), sodium sulfide (407410 Sigma-Aldrich) and meso-2,3-Dimercaptosuccinic acid (D7881 Sigma-Aldrich), it was found that these last two reagents led to the best results, having depressed almost all copper.

Figure 3 shows the recovery and grade of copper in the sink, recovery and grade of plastic in the floated and separation efficiency versus concentration of these two copper depressor agents (sodium sulfide and meso-2,3-Dimercaptosuccinic acid), with a MIBC concentration of 90 mg/L. The two depressor agents showed similar effect on the floatability of copper. Flotation recovery of copper decreased with the increase of the two depressants concentration. These depressor agents had low effect on the plastic flotation, with only a significant decrease in the plastic flotation observed to a high concentration of sodium sulphide. Recovery of copper in the sink is about 98% for concentration of 10mg/L of the two depressor agents.

The best separations were obtained with 10^{-1} mg/L concentration of the two depressor agents, with the highest separation efficiencies (near 85%). For this depressor concentration and for the two depressor agents, it was obtained a sink with a grade of

87% in copper and a copper recovery of about 95%, and a floated with a grade of 96% in plastic and a plastic recovery of about 90% (Figure 3).

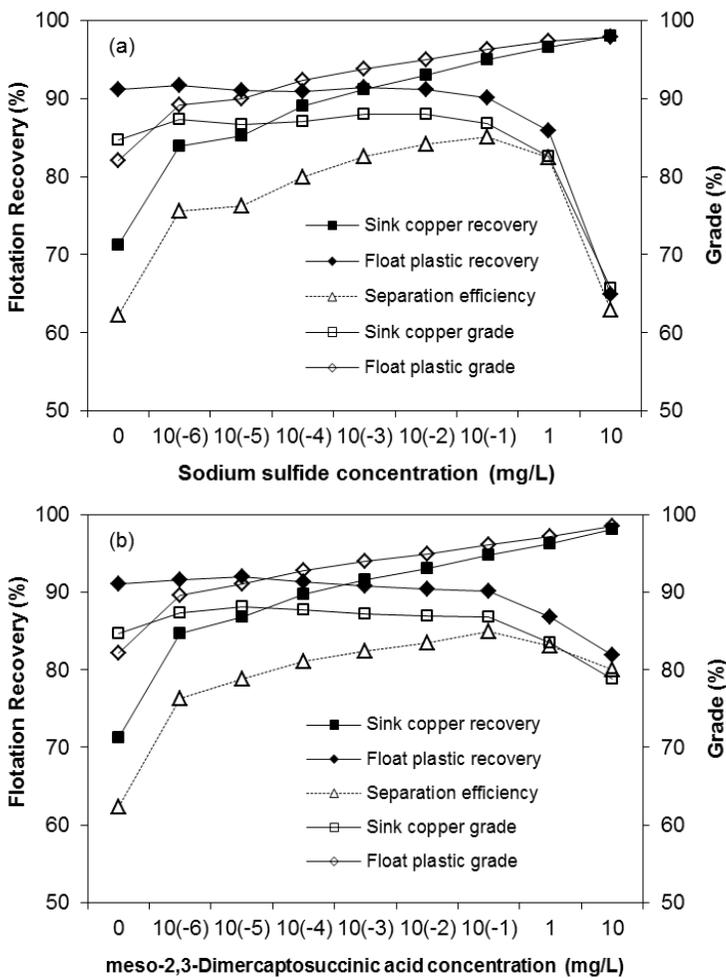


Figure 3: Recovery and grade of plastic in the floated, recovery and grade of copper in the sink, and separation efficiency versus sodium sulfide (a) and meso-2,3-Dimercaptosuccinic acid (b) concentration.

Considering the flotation test that led to the best results, that is, in the presence of sodium sulfite at concentration of 10^{-1} mg/L, and comparing the three separation methods, it was verified that

froth flotation presented smaller separation efficiency than jigging and shaking table. Jigging and shaking table separations led to similar results, with a separation efficiency of about 95%. Recovery of copper in the froth flotation was slightly smaller than recovery of copper in the jigging and shaking table. Also, the recovery of plastic in the froth flotation was smaller than the recovery of plastic in the jigging and shaking table. The copper grade of the sink in jigging and shaking table was about 97% with a copper recovery of about 97%, and the copper grade of the sink in froth flotation was 86.9% with a copper recovery of 95.1%.

Effect of Particle Size in the Three Methods of Separation

The size of the particles is an important factor in the separation by froth flotation and by gravity. Hence, the influence of the particle size in the separation of copper/plastic mixture by the three methods was analysed. The results of jigging, shaking table and froth flotation tests that led to better separations, for seven size fractions, are presented in Table 5.

Table 5: Results of separation by jigging, shaking table and flotation of the copper/plastic mixture, for seven size fractions.

	Size fraction (mm)	Sink		Floated		Separation efficiency (SE) (%)
		Copper Recovery (%)	Copper Grade (%)	Plastic Recovery (%)	Plastic Grade (%)	
Jigging	<0.25	96.24	99.84	99.39	87.14	95.63
	+0.25-0.35	98.06	99.72	98.85	92.45	96.91
	+0.35-0.5	98.67	99.62	98.57	95.15	97.24
	+0.5-0.7	98.50	93.88	97.85	99.49	96.35
	+0.7-1.0	98.39	82.72	97.65	99.81	96.04
	+1.0-1.4	98.33	57.97	97.59	99.94	95.92
	+1.4-2.0	98.63	10.41	97.02	100.0	95.65
Shaking table	<0.25	93.96	98.26	93.51	79.89	87.47
	+0.25-0.35	97.26	98.64	94.43	89.22	91.69
	+0.35-0.5	97.84	98.68	95.06	92.10	92.90
	+0.5-0.7	97.66	90.52	96.57	99.19	94.23
	+0.7-1.0	97.81	90.61	98.84	99.75	96.65
	+1.0-1.4	98.12	85.08	99.42	99.94	97.54
	+1.4-2.0	98.67	50.37	99.66	100.0	98.33
Froth flotation	<0.25	90.40	100.0	100.0	72.77	90.40
	+0.25-0.35	95.62	99.59	98.36	84.36	93.98
	+0.35-0.5	97.02	99.27	97.31	89.63	94.33
	+0.5-0.7	98.03	89.68	96.22	99.31	93.24
	+0.7-1.0	99.44	69.16	94.93	99.93	94.37
	+1.0-1.4	100.0	29.86	92.06	100.0	92.06
	+1.4-2.0	100.0	1.62	78.63	100.0	78.63

In jigging, the recovery of copper in the sink was the lowest for the finer fraction and the recovery of plastic in the floated slightly increased with increasing particles size (Table 5). While in the jigging separation of ores the finer particles of the heaviest mineral were in the lower strata of the jigging bed, in the case of copper the opposite was observed. During the bed expansion, the finest particles of copper and plastic were more easily elevated in the jigging bed than the coarser ones, making them more prone to overflow. Jigging separation of copper/plastic mixture had similar separation efficiency in the seven size fractions (Table 5). For all size fractions, the separation efficiency values changed less than 2%, with separation efficiencies of about 96%. For the three finer fractions, the sink was a product almost pure in copper, and for the four coarser fractions, the floated was a product almost pure in plastic.

In shaking table, plastic recovery in the floated increased with increasing particles size (Table 5). In the shaking table separation of ores, the finer particles were in the lower strata of the table bed. During the stratification operated in the shaking table, the coarser particles of plastic occupied the upper strata and were therefore more easily carried by the wash water into the floated. However, recovery of copper in the sink was lowest for the finer fraction, i.e., the recovery of copper in the floated was highest for the finer fraction. The separation efficiency slightly improved with the increase of the particles size. For the four coarser fractions, the floated was a product almost pure in plastic.

In this flotation tests, the copper and plastic recovery in the sink increased with increasing particles size. Other authors also verified that small plastic particles are easier to float than larger ones [41-44]. Moreover, Sarvar et al., [23] verified that metal recovery in the floated decreased with increasing particles size.

Separation by froth flotation presented the worst results for the coarser and finer particles, because the flotation of copper was significant for the finer fraction and the depression of plastic in the sink was significant for the coarser fraction. Lower sink copper recovery in the finer fractions was due to the fine size

particles, which are more easily entrained. Lower plastic recovery of the coarser fractions in the froth flotation tests was a consequence of the greater weight and size of the coarse particles that hampers their flotation. The intermediate size fractions presented similar separation efficiency of around 94%. For the three finer fractions, the sink presented a product almost pure in copper, because the recovery of plastic in the floated was higher. For the coarser fraction, the sink presented low grade in copper, because the recovery of plastic in the sink was significant (21.37%) and the copper content in that size fraction of the feed was low (0.35%).

The results showed that the shaking table and jigging separation were more favorable than the froth flotation in separating the copper/plastic mixture, since they led to higher separation efficiencies. This behavior was more evident for the coarse fractions. For the intermediate size fractions, the flotation presented separation efficiency similar to the shaking table but slightly lower than the jigging. In the three separation methods, for the three fine fractions, the sink was a product almost pure in copper, and for the four coarse fractions, the floated was a product almost pure in plastic.

Conclusions

In this study, electric cable waste with size below 2 mm, was subjected to separation by jigging, shaking table and froth flotation. It was possible to successfully separate copper from plastic by jigging and shaking table, with a separation efficiency of about 95%. In both methods, it was possible to obtain a sink product with a copper grade of 97% and a copper recovery of 97%, and a floated product with a plastic grade of about 98% and a plastic recovery of 98%. In jigging separation, the influence of particle size was minimal, but in shaking table the separation efficiency was slightly improved by the increase of the particles size, and the maximum separation efficiency was 98.33% in the coarser fraction.

Results showed that plastic was naturally floatable and copper presented some natural floatability. The best flotation separation

were obtained in the presence of sodium sulphide and meso-2,3-Dimercaptosuccinic acid, which decreased copper floatability. Although froth flotation led to worse separations than the two gravity methods, it also led to adequate separations, with an efficiency of 85%. Separation by froth flotation presented the worst results for the finer and coarser particles, with a separation efficiency of 79% for finer fraction and 90% for coarser fraction. This was a consequence of the lower recovery of the finer copper particles in the sink, since they were more easily entrained and a consequence of the lower floatability of the coarser plastic particles in the floated, because they were more difficult to float.

The results obtained showed that jigging and shaking table are potential methods for separating copper/plastics mixtures. Furthermore, the control of particles size is important in the separation of this mixture by shaking table and froth flotation. In the three separation methods, for the three fine fractions, the sink was a product almost pure in copper, and for the four coarse fractions, the floated was a product almost pure in plastic.

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