SEM study of a lead-iron slag flotation process

Abstract

Companies producing lead-acid batteries are required by law to recycle their battery scrap. The recycling can be performed by a pyrometallurgical process resulting in slags containing mainly lead and iron. A study was carried out with the aim of recovering the lead contained in this slag. This work has economic and environmental implications. Slag characterization was performed by X-ray diffraction, X-ray fluorescence and scanning electron microscopy (SEM). A laboratory-scale mechanical cell was used for flotation tests. The results showed that Pb-Fe selectivity is possible using ethyl xanthate as collector. The coke floats together decreasing concentrate grade. However, this is no problem because coke participates in the metallurgical process for the production of lead. A concentrate containing 22.9% Pb was obtained from a slag with 2.2% Pb. The process removes more than 99.6% of the iron contained. However, the recovery was only 19.0%. Analyses from scanning electron microscopy detected the presence of lead inside the iron particles, limiting the possibility of lead recovery.

Keywords: SEM application, slag flotation, lead flotation, iron-lead separation, lead recovery.

1. Introduction

Most of the lead consumed in Brazil comes from the recycling of automotive, industrial and telecommunication batteries (Teixeira & Silva, 2015). Secondary lead is obtained from recycling of lead-acid battery scrap. The scrap is composed of five components: the active material (PbSO₄, PbO and PbO₂), metallic lead, sulfuric acid, plastic and separator (polypropylene and SiO₂). Figure 1 shows the approximate composition of a lead-acid battery scrap.

The recycling process consists of three steps: dismantling of the battery, separation of its components (active material, metallic lead, plastic, sulfuric acid and separators), and lead production in a rotary furnace. Metallic lead is fed to the furnace with other lead compounds (active material), iron scrap (Fe source), coke (C source) and soda ash (fluxing agent). It is then processed in batches for seven hours with temperatures up to 1000 °C (Nunes, 2015).

According to Queneau et al. (1989) the following overall reaction takes place in furnaces:

\[
2 \text{PbSO}_4(l) + \text{Na}_2\text{CO}_3(l) + \text{Fe}(s) + 9 \text{C}(s) \xrightarrow{\Delta} 2 \text{Pb}(l) + \text{FeS}.\text{Na}_2\text{S}_2(l) + 9 \text{CO}(g) + \text{CO}_2(g) \quad (1)
\]
First, occurs the conversion of lead sulfate to lead sulfide by the addition of carbon as indicated in Eq. (2):

\[ \text{PbSO}_4 + 2\text{C} \rightarrow \text{PbS} + 2\text{CO}_2 \]  

(2)

Then, the iron added as scrap reduces lead sulfide to metallic lead as shown in Eq. (3):

\[ \text{PbS} + \text{Fe} \rightarrow \text{Pb} + \text{FeS} \]  

(3)

Lead oxide compounds, from the active material, react with carbon to produce metallic lead according Eqs. (4) and (5) (Nunes, 2015):

\[ \text{PbO} + \text{C} \rightarrow \text{CO} + \text{Pb} \]  

(4)

\[ 2\text{PbO} + \text{C} \rightarrow 2\text{CO} + 2\text{Pb} \]  

(5)

Following chemical reactions in the furnace, two distinct phases are formed; one with higher density (metallic lead) and another with lower density (slag). Both metallic lead and slag are removed from the furnace at temperatures above their melting points (Figure 2a).

A pyrometallurgical process typically allows a 93% to 97% recovery of the lead contained in the scrap. The remaining lead is lost in the slag, a residue which constitutes about 20% to 25% of the total furnace-feeding load (Nunes, 2015). After the solidification process, slags are stored in enclosed areas for 40 days for the natural breakdown process (Figure 2b).

![Figure 2](image)

The metallurgical slag used in the study: (a) at the furnace output (liquid) and (b) on the natural breakdown process during its storage period.
2. Materials and methods

The slag sample used came from the metallurgical plant of the company Acumuladores Moura S/A. The furnace load consists of battery residues (including metallic lead) and the reagents added, namely iron (scrap), carbon (coke), and sodium carbonate.

The collectors used were sodium xanthates provided by SNF FLOMIN. The frothers methyl-isobutyl-carbinol (MIBC) and polyglycol were supplied by PIETSCHEMICALS and SNF FLOMIN, respectively. The sodium sulfide was produced by CROMATO PRODUTOS QUIMICOS. Sodium hydroxide (NaOH) or sulfuric acid (H₂SO₄) was used for the pH adjustments.

A jaw crusher and a cylindrical ball mill (U. S. AKRON STOWEWARE (90H110)) were used for sample grinding. Flotation experiments were performed at a lab-scale DENVER Sub-A flotation cell. The experiments followed the standard procedure with froth removal every 15 seconds. All flotation tests were carried out with 300g of sample. The particles size was fixed by sieving in the range 38-104 µm. The sample was initially washed in distilled water to eliminate part of the dissolved ions. After washing, the conductivity of the pulp, with 10% solids (by weight), had between 300 and 400 μs/cm. An INOLAB conductivity meter, model WTW, was used for monitoring the dissolved species in the pulp. The collector was added after pH adjustment and conditioned for 15 minutes, whereupon the frother was added and the air released to start flotation. The impeller speed of the flotation cell was maintained at 1200 rpm.

3. Results and discussion

3.1 Slag characterization

The results of the XRD analyzes showed phases containing mainly iron oxides and lead sulphide. It is noted in Figure 3 that there is homogeneity in chemical analyses were performed by atomic absorption spectrophotometry at the laboratory of the Acumuladores Moura.

In order to characterize the slag in regard to size distribution, chemical composition and crystallographic phases present in the slag were used: (1) a Vibratory Screening apparatus, using a Tyler series set of sieves; (2) an X-ray Fluorescence Spectrometer - PANalytical, model AXIOS ADVANCED; (3) An X-ray Diffractometer (XRD) - BRUKER D4; (4) a Scanning Electron Microscopy (SEM) - FEI-BRUKER, model Quanta 400; and (5) a Petrographic Microscope.

The samples for MEV were metalized with carbon and analyzed in modules of secondary electrons, backscattered electrons and EDS and (5) a petrographic microscope.

According to X-ray fluorescence analysis, the sample contains Fe₂O₃ (40.3%), SO₃ (26.4%), Na₂O (15.0%) and PbO (5.0%) as the main elements.

Images from scanning electron microscope (Figure 4) showed free (or isolated) lead particles with different sizes (-106 +75 mm; -150 +106 mm; -212 +150 mm; and +212 mm). Lead particles can be identified by their lighter coloration. The relative quantity of lead particles was similar in all size fractions, indicating that the material doesn’t have a preferential distribution by size. As a result no size range of the slag can be rejected before flotation.

![Figure 3](image-url)


The gallery image is a typical X-ray diffraction pattern of different slag fractions, showing the phases present: galena (G), quartz (Q), wickenburgit (W), calcite (C), and magnetite (M) as the main identified phases. The sample contains Fe₂O₃ (40.3%), SO₃ (26.4%), Na₂O (15.0%) and PbO (5.0%) as the major elements. Images from scanning electron microscope (Figure 4) show free (or isolated) lead particles with varying sizes (-106 +75 mm; -150 +106 mm; -212 +150 mm; and +212 mm). The relative quantity of lead particles was similar in all size fractions, indicating that the material doesn’t have a preferential distribution by size. As a result no size range of the slag can be rejected before flotation.
3.2 Flotation

Different collectors were tested for lead particles: fatty acids, amine, sodium dodecyl sulfate, sulfosuccinamate and xanthate. The xanthates presented the best potential for selectivity. No selectivity was observed in the tests with the other collectors.

A complication concerning to slag flotation is related to the ease release of ionic species from the particle surface to the liquid phase causing contamination in the process water. The presence of these ions in solution may cause collector precipitation (Rao & Finch, 1989) or undesirable depression/activation (Liu et al., 2013). Once in contact with the slag, the conductivity of the distilled water used in flotation tests increase from 5 μs/cm to 10,110 μs/cm. The removal of these ionic species is crucial for lead flotation. Selectivity was only achieved in pulps with conductivity up to 220 μs/cm. Table 1 shows the influence of collector concentration in slag flotation with ethyl xanthate at pH 9.5. From a slag sample with 2.2% Pb, it is possible to reach a grade of 22.9% Pb in the concentrate. The selectivity in the lead-iron separation can be observed in the Figure 5.

<table>
<thead>
<tr>
<th>COLLECTOR (g/t)</th>
<th>SAMPLE</th>
<th>RECOVERY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feed</td>
<td>Concentrate</td>
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</tr>
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</tr>
<tr>
<td>750</td>
<td>2.2</td>
<td>26.1</td>
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Table 1
Influence of ethyl xanthate concentration in slag flotation.
Chemical analysis revealed a carbon content of 47.5 % in the concentrate which explains the difficulty in reaching higher lead grade. However, the carbon does not constitute a problem, since it is a reagent (as coke) in the metallic lead production process. The flotation results indicate a very low recovery for lead. In order to enhance recovery, three possibilities were tested: (1) increase of the collector conditioning time, (2) use of sodium sulfide as activator, and (3) use of a xanthate with greater chain size. Results from attempts (1) and (2) were unsatisfactory. However, a recovery of 32.9 % was achieved using amyl xanthate (Figure 6) at the cost of a reduction of the grade to 15.5 % Pb. Despite the selectivity achieved with amyl xanthate, the lead recovery remained low.

Iron particles were sectioned to obtain internal images. The images showed that a lead portion rests inside the hydrophilic iron grains (Figure 7), which explains why it is not possible to get good recovery in lead flotation.

Figure 6
The influence of the xanthate chain length in slag flotation at pH 9.5 and 750 g.t⁻¹ of collector.

Scanning electron microscopy (SEM) was used to investigate the difficulty found with increasing recovery.

Figure 7
Image of the cross section showing the presence of lead (light) inside the hydrophilic iron grain (≈150 +106 μm).

4. Conclusion

Recovery of slag produced in the lead recycling process has economic and environmental implications. This work investigated the possibility of recovering the lead contained in the slag by flotation, the most efficient mineral processing technique. Slag flotation is difficult due to variations in particle surface characteristics as compared to more stable mineral surfaces.

The lead-iron selectivity was achieved using ethyl xanthate as collector. The concentrate contains 22.9 % Pb and only 6.0 % Fe. The process eliminates 99.6 % of the iron contained in the flotation feed. However, the metallurgical lead recovery was only 19.0 %. A maximum lead recovery of 32.9 % was achieved with amyl xanthate. The coke floats with lead decreasing the concentrate grade. However, this is not a problem because the carbon can be reused as a reagent in lead metallurgy. Analysis of the flotation concentrate through SEM showed that a greater recovery was not possible due to the presence of lead inside the iron particles.

Flotation separation is based on differences in surface properties not considering the inside of the particles. Although the process achieves a selective adsorption of the collector on lead particle surfaces (eliminating 99.6 % wt. of the iron), and visually it seemed a perfect separation, the recovery was always very low. The discovery of lead inside the iron particles elucidated the mystery of "good separation" with low recovery. The result of the study is important because this can occur with other slags and, as it does not occur in the flotation of ores, it is a little-known phenomenon.

Acknowledgments

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References


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