



Copper leaching from waste electric cables by biohydrometallurgy



Fanny Lambert^{a,*}, Stoyan Gaydardzhiev^a, Grégoire Léonard^b, Gregory Lewis^c, Pierre-François Bareel^c, David Bastin^a

^a Laboratory of Mineral Processing and Recycling, University of Liege, Chemin des chevreuils B52, Liege, Belgium

^b Laboratory of Chemical Engineering, University of Liege, Allee de la Chimie B6a, Liege, Belgium

^c Comet Traitements SA, Rivage du Boubier, Châtelet, Belgium

ARTICLE INFO

Article history:

Received 17 July 2014

Revised 17 December 2014

Accepted 18 December 2014

Available online 13 January 2015

Keywords:

Recycling

Cables

Leaching

Bioleaching

Acidithiobacillus ferrooxidans

ABSTRACT

This study examines the leaching of copper from waste electric cables by chemical leaching and leaching catalysed by *Acidithiobacillus ferrooxidans* in terms of leaching kinetics and reagents consumption. Operational parameters such as the nature of the oxidant (Fe^{3+} , O_2), the initial ferric iron concentration (0–10 g/L) and the temperature (21–50 °C) were identified to have an important influence on the degree of copper solubilisation. At optimal process conditions, copper extraction above 90% was achieved in both leaching systems, with a leaching duration of 1 day. The bacterial leaching system slightly outperformed the chemical one but the positive effect of regeneration of Fe^{3+} was limited. It appears that the Fe^{2+} bio-oxidation is not sufficiently optimised. Best results in terms of copper solubilisation kinetics were obtained for the abiotic test at 50 °C and for the biotic test at 35 °C. Moreover, the study showed that in same operating conditions, a lower acid consumption was recorded for the biotic test than for the abiotic test.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Electric cables are components widely used in sectors like transport, construction, communication and consumer goods. They are constituents of items such as automobiles and electrical and electronic equipment.

During the recycling of WEEE and ELV, electric cables are isolated by hand picking or other physical separations. The obtained cables concentrate is traditionally sorted through physical separation methods such as shredding, screening, as well as gravity and electrostatic separations. These physical separations lead to important copper losses, around 32% in weight of the processed electric cables. The residues coming from these processes are usually dumped even though they are a non-negligible secondary source of metals. This study focuses on the residue coming from the recycling of electric cables of ELV and WEEE. It contains copper and aluminium but also a mixture of plastics (PVC, PER, EFTE, PET, PU).

End-of-life vehicles (ELV) and waste electrical and electronic equipment (WEEE) are facing more stringent legislative pressures concerning the recycling rate: different targets must be reached by 2015 and by 2018 in Europe (Directive 2000/53/CE and Directive 2012/19/UE). To achieve these targets, some not-yet treated

waste flows must be considered as residues coming from recycling of electric cables. New technologies have to be sought. In this context, hydrometallurgy could be suggested as an alternative way to recover the copper from low-grade residues.

Bioleaching technology was only investigated recently to process polymetallic wastes such as printed circuit boards (PCB) (Wang et al., 2009; Yang et al., 2009; Liang et al., 2010; Xiang et al., 2010), electronic scraps (Brandl et al., 2001; Ilyas et al., 2007) shredder residues (Lewis et al., 2011). For this purpose, chemolithotrophic bacteria from the specie *Acidithiobacillus ferrooxidans* were mostly studied as a mean to regenerate ferric from ferrous iron. High metal recoveries were reported for bioleaching of Cu from electronic scrap (Brandl et al., 2001) and PCB (Wang et al., 2009; Yang et al., 2009). In previous projects we have investigated the feasibility of bacterially assisted leaching to bring zero-valent copper in solution from similar material. Favourable metal solubilisation rates were achieved (Lewis et al., 2011; Gaydardzhiev, 2010).

The existing studies examine the feasibility of biohydrometallurgy although they do not systematically distinguish the part coming from the chemistry and the real benefit of bacteria presence. This paper focuses on the comparison of the chemical leaching and the indirect bacterial leaching in terms of leaching time and copper extraction. The objective is to evaluate the technical efficiency of both hydrometallurgical routes. Therefore at this

* Corresponding author.

E-mail address: Fanny.Lambert@ulg.ac.be (F. Lambert).

initial stage, selected process parameters such as ferric iron concentration, total iron concentration and temperature were studied.

2. Materials and methods

2.1. Material

The sample is composed of electric cables coming from end-of-life vehicles. Electric cables were crushed by a knife mill and were processed by a two-step gravity separation (upstream air classifier and vibrating pneumatic table). This separation leads to the recovery of a high grade copper concentrate but a part of the copper is lost in a low density fraction. This fraction is the sample subject of the current investigation.

For quantitative determination of metals, cables were initially ignited at 850 °C for 30 min to remove organic fractions (loss on ignition). Further on, the remaining ashes were digested subsequently in nitric acid and aqua regia. The obtained aliquots were analysed by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). Plastics were analysed by infrared.

The sample consists mainly of various plastic fragments and copper wires. Chemical analysis indicates that the sample contains 4.9% copper and 0.6% aluminium. The plastics are mainly PVC and PER, but also EFTE, PET and PU. The size of particles is below 5 mm. Copper and aluminium wires are well liberated from the plastics.

2.2. Microorganisms and culture conditions

The mixed bacterial culture comes from the University of Mining and Geology of Sofia (Bulgaria). The culture initially contained *A. ferrooxidans*, *Leptospirillum ferrooxidans* and *Acidithiobacillus thiooxidans* but *A. ferrooxidans* is the prevalent microbial specie. To avoid the inhibition of the bacterial activity in presence of metallic cations (mainly Cu^{2+} and Al^{3+}), the bacterial consortium was adapted to copper and aluminium concentrations higher than the concentrations of the pregnant leach solution. The nutrient medium used to maintain bacterial growth was the Lundgren-Silverman 9 K liquor which has the following composition: $(\text{NH}_4)_2\text{SO}_4$ 3.0 g/L, KCl 0.1 g/L, K_2HPO_4 0.5 g/L, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ 0.5 g/L, $\text{Ca}(\text{NO}_3)_2$ 0.01 g/L, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ 44.2 g/L (Rossi, 1990). Bacteria were cultured in a fermenter fed in semi-continuous by the nutrient medium with 16 g/L Cu^{2+} and 1 g/L Al^{3+} . The quantitative determination of microorganisms during experiments was carried out by a serial end-point dilution technique, commonly referred to as “Most Probable Number” method (Karavaiko et al., 1988).

2.3. Leaching procedure

Fourteen tests were considered to cover the influence of the selected operating parameters. The operational conditions are presented in Table 1. The tests are classified in abiotic and biotic tests; thymol was added as bactericide for all abiotic tests to avoid a bacterial growth. Temperature (21, 35, 50 °C), ferric iron concentration (0, 1, 2, 6 and 7 g/L) and total iron concentration (0–10 g/L) were investigated. The initial ferric iron concentration of the biotic tests is determined by the ratio between the inoculum coming from the fermenter (6–7 g/L Fe^{3+}) and the Lundgren-Silverman 9 K medium: 10–90% for the tests 7, 8, 9, 10, 12, 14 (resulting in 0.5–2 g/L initial Fe^{3+}) and 100–0% for the test 11 (resulting in 7 g/L initial Fe^{3+}). Some abiotic (tests 3, 4 and 13) were prepared as the first biotic tests, i.e. by mixing 10% inoculum and 90% 9 k medium (resulting

in 0.5–2 g/L initial Fe^{3+}), and thymol was added as bactericidal agent. On the contrary, the abiotic tests 1, 5 and 6 were prepared with ferric iron sulphate $\text{Fe}_2(\text{SO}_4)_3 \cdot 7\text{H}_2\text{O}$ (6–7 g/L initial Fe^{3+}) as ferric iron source. One blank was carried out with 0 g/L Fe^{3+} (test 2). The initial measured redox potential is directly related to the initial ratio $[\text{Fe}^{3+}]/[\text{Fe}^{2+}]$ as described by the Nernst equation. The tests 4, 10, 13 and 14 were carried out with an air injection in the reactor with a flow rate fixed at 3 mL/min, in order to improve the Fe^{2+} bio-oxidation and the copper dissolution. Other tests were carried out without air injection but aeration takes place through mechanical agitation. Averages of dissolved oxygen concentrations during the experiments are directly associated with the air injection. The last two experiments (tests 13 and 14) were performed with a synthetic sample to simplify and better understand the chemical system. These tests were made up with the same metallic content as for other tests (4.9% and 0.6% of analytical copper and aluminium respectively) but without plastics. In fact, plastics have an impact on the chemical system (acid consumption) and could also have an impact on the bacterial activity. Plastics were replaced by SiO_2 to keep the same solid content as in other tests. The tests 13 and 14 represent a simplified chemical system with pure copper and aluminium and without potential contaminants like plastics and minors chemical elements.

Representative samples were obtained by a riffle separator. In all configurations, a pulp density of 9% was used, so tests were carried out with a mass sample of 45–55 g and a volume of solution of 450–550 mL. Leaching experiments were carried out inside a 0.5-liter double jacket reactor, mechanically stirred at 700 rpm. The reactor was linked to a thermostatic bath in order to keep the temperature constant. Redox (vs. SHE) and pH measurements were continuously recorded using a control unit. Because of the alkaline nature of the material, sulphuric acid injection was necessary to keep the pH constant. The automatic acid addition was implemented through a micropump connected with the control unit. The pH was fixed at 1.9 to ensure optimal conditions of bacterial growth and minimise iron precipitation. The leach solution was placed in the reactor and was put at temperature and at pH = 1.9 before the addition of the solid. Samples of pregnant leach solutions were taken on a daily basis to carry out analysis of Cu, Fe^{2+} , total Fe and sulphuric acid consumption. Water evaporation was offset by distilled water addition. At the end of each experiment (from 1 to 7 days), the pulp was filtered to separate the pregnant leach solution from the solid leach residue. Both were analysed.

2.4. Analytical methods

Metals in the pregnant leach solution were analysed by atomic absorption and ICP-OES. The solid residue after leaching were dried, burnt at 850 °C for 30 min, grinded in an agate mortar and digested in nitric acid before being chemically analysed by atomic absorption and ICP-OES. Ferrous iron concentration was determined by $\text{K}_2\text{Cr}_2\text{O}_7$ titration and ferric iron was calculated as a difference between total and ferrous iron.

3. Results and discussion

3.1. Electrochemical mechanisms of the studied system

The chemical system studied is composed by the non-exhaustive following chemical species: Cu^0 – Cu^{2+} , Fe^{2+} – Fe^{3+} , Al^0 – Al^{3+} , O_2 , H^+ , SO_4^{2-} . The differences between the standard reduction potentials of demi-reaction (ΔE^0) predict the reactions that can take place from a thermodynamic perspective:

Download English Version:

<https://daneshyari.com/en/article/233090>

Download Persian Version:

<https://daneshyari.com/article/233090>

[Daneshyari.com](https://daneshyari.com)