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Electrodialytic remediation of copper mine tailings using bipolar electrodes

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ABSTRACT

In this work an electrodialytic remediation (EDR) cell for copper mine tailings with bipolar stainless steel plates was analyzed. The bipolar plates were inserted inside the tailings, dividing it into independent electrochemical cells or sections, in order to increase the copper removal efficiency from mine tailings. The bipolar plates design was tested on acidic copper mine tailings with a fixed: applied electric field, liquid content, initial pH, and remediation time. The laboratory results showed that inserting bipolar plates in EDR cells improves the remediation action, even though the applied electric field is reduced by the electrochemical reactions on the plates. Basically three aspects favor the process: reduction of the ionic migration pathways, increase of the electrode surface, and in-situ generation of protons (H^+) and hydroxyls (OH^-). Furthermore, the laboratory results with citric acid addition significantly improve the remediation actions, reaching copper removal of up to nine times better, compared to conventional EDR experiments without any plates or citric acid addition.

1. Introduction

In 2007 in Chile, copper mine production was 5.56 MMT (Million Metric Tons) of copper content [1], 36% of world production that year. Approximately 3.27 MMT of copper content was obtained by sulfide's ore flotation, generating mine tailings as a waste product. According to these figures, considering copper ore with an average-grade of 1% and copper concentrate with 30%, around 790 MMT of mine tailings pulp with 40% weight solids, were generated in 2007.

Mine tailings contain high concentrations of chemicals and elements that are of concern to the environment. Mine tailings are transported as pulp form to specially conditioned sites called tailing ponds.

Mine tailings, not only have a damaging effect on hydro resources by the natural leaching of chemicals, but also generate effects on flora and fauna, and have serious effect on air quality by the generation of fugitive emissions of fine particles.

Due to the magnitude of the mining activity in Chile, it becomes necessary to find solutions to mitigate the impact of mine tailings on the environment. One aspect of the solution to the problem is to give stability to the mine tailings by heavy metal's remediation processes. Between the processes applicable to this type of waste, electroremediation is a technique which has raised interest over the last 20 years. This type of remediation is based on the application of an electric field to a humid solid sample using two electrodes. Electro-kinetics remediation (EKR) has proven to be a good method to remove heavy metals in fine solid waste such as grounds, clays, ashes and mud [2–4]. On the other hand, electrodialytic remediation (EDR) [5,6] improves the process with the introduction of ionic interchange membranes, isolating the phenomena of remediation from electrode reactions.

The electro-remediation of mine tailings, as in the case of the treatment of other solid waste, requires enhancement method which had been already reported in literature, among others, additions of complexing agents [7], addition of bacteria [8], pH control [9], and use of ultrasound [10].

In order to further enhance EDR, in this work stainless steel plates are inserted inside mine tailings, as is shown in Fig. 1. When an electric field is generated between these plates, they behave in bipolar form [11]: one of its faces acts as an anode and the other as a cathode according to the position they have with respect to the electrode work (monopolar) of the EDR cell. In these bipolar electrodes the following electrode reactions will occur: oxidation and reduction of water, oxidation and reduction of the pair Fe^{2+}/Fe^{3+}, reduction Cu^{2+}/Cu°, and other electrodes reactions, depending on electrolyte availability. On the other hand, as a consequence of the electrochemical reactions of water, chemical reactions in the neighboring zones to the electrodes (bipolar plates), such as oxidation Fe^{2+}/Fe^{3+} and precipitation of $Cu(OH)_2$, could be produced.

By installing several stainless steel plates, the original EDR cell will be divided into independent sections according to the number of installed plates. The main objective is to increase the active surfaces of the electrodes of the original EDR cell, to reduce the migration pathway of the polluting agents, and to generate in-situ, protons (H^+), hydroxyls (OH^-), and oxidizing agents like the Fe^{3+}, that will increase the dynamics of the process.

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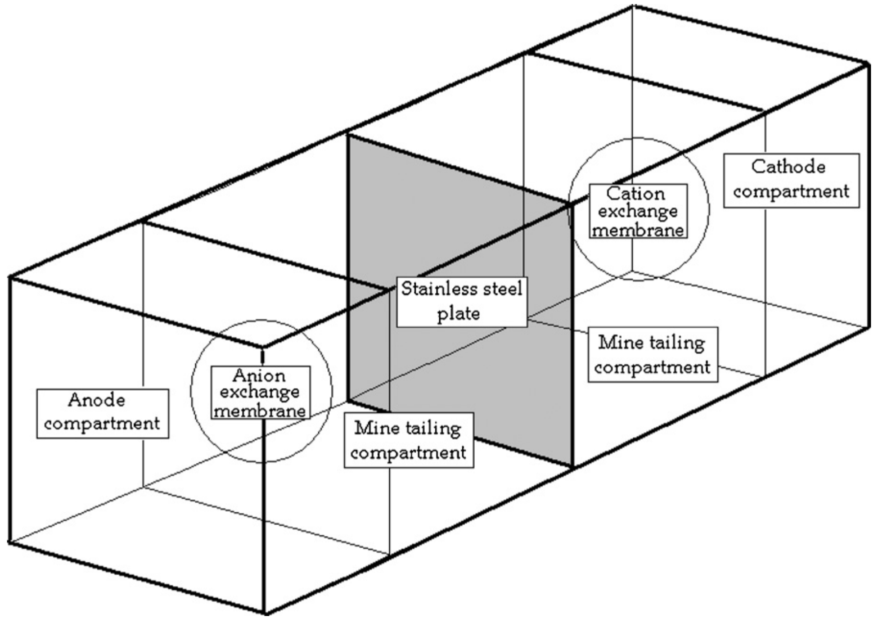

Fig. 1. Schematic description of the EDR cell with one bipolar plate.

Table 1
Summary characteristics of the mine tailings investigated.

Ore deposit type	Porphyry copper
Primary ore minerals	Pyrite, chalcopyrite, bornite, molybdenite, galena, tennantite, magnetite, hematite
Secondary ores minerals	Chalcocite, covellite
Gangue minerals	Quartz, albite feldspar, biotite, calcite, anhydrite, tourmaline-schorl, rutile, apatite, sericite-muscovite, chlorite, epidote, kaolinite, monmorillonite
Grain size distribution	50% (w/w) smaller than 200 μm
Cu content	1610 ± 22 mg/kg dry matter
pH	3–4

2. Experimental

2.1. Experimental tailings

The mine tailing used for remediation experiments was sampled from the Cauquenes impoundment at Codelco-El Teniente copper mine in the VI Region of Chile. Table 1 shows general characteristics of mine tailings used in this work.

2.2. Analytical methods

2.2.1. Copper concentration

The copper content of the tailings was determined by adding 20 mL 1:1 HNO_3 to 1.0 g of dry material and treating the sample in autoclave, according to the Danish Standard DS 259:2003 (30 min at 200 kPa (120 °C)). The liquid was separated from the solid particles by vacuum through a 0.45 μm filter and diluted to 100.0 mL. The metal content was determined by AAS in flame. At least three analysis of each sample were measured and an average was used in this work.

2.2.2. pH

pH was measured by mixing 5.0 g dry matter and 25.0 mL distilled water. After 1 h of contact time, pH was measured using a pH electrode.

2.3. Tailings pre-treatment

Before remediation experiments, the tailings were stove-dried for two days at 70 °C. Once dried, the material was pulverized in a mortar and sieved with meshes #4 and #20, until its

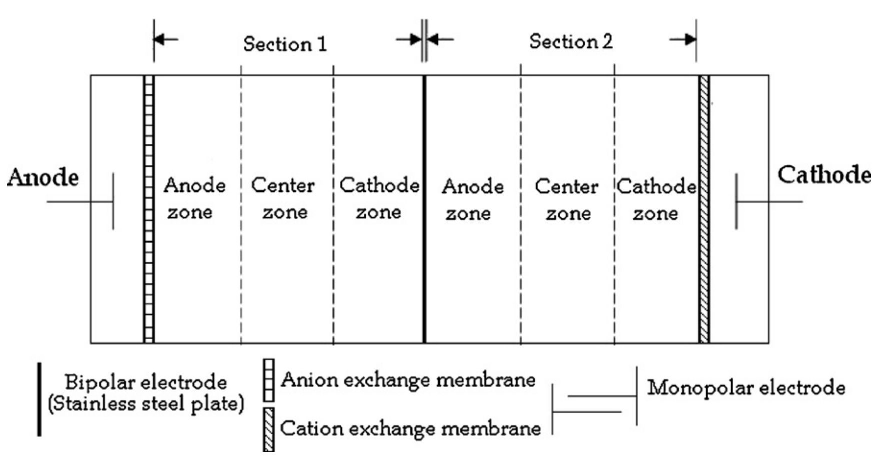

Fig. 2. EDR cell with one bipolar plate showing division in sections and zones.