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Characterization and treatment of artisanal gold mine tailings

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Abstract

The solid waste generated by artisanal gold mining, with high mercury and gold contents, can be found in several areas in the South America. The present study focused on the tailings of an artisanal gold mine area located in the Brazilian northeastern. Samples of the mine tailings were taken and used to perform a physical and chemical characterization study using X-ray diffraction, scanning electron microscopy, neutron activation, X-ray fluorescence, induced coupled plasma-mass spectrometry, among others analytical methods. The results indicate that the material is composed mainly by quartz and goethite, the characteristic size of the particles (d_{50}) is about 150 μm, and the density is close of that of quartz. The main constituents are silicon, iron, and aluminum. The tailings gold content is of about 1.8 mg/kg and the mercury content is of about 10 mg/kg. A remarkable feature of this solid waste is that the gold and mercury are both concentrated in both the fine and the coarse particles, but not in particles of intermediary size. Leaching studies indicated that the tailings are stable in weak organic acids, but soluble in alkaline and aired cyanide solutions, in which 89% of gold and 100% of mercury are extracted in 24 h. Electroleaching experiments, performed using sodium chloride as electrolyte, indicated that mercury and gold are extracted simultaneously and the recovery of both metals can be as high as 70% in 4 h. In addition, chromium, nickel, and lead are found in relatively large amounts in the solution, which indicate an effectively action of the electroleaching method to clean up solid wastes contaminated with metals.

Keywords: Characterization; Solid waste; Cleanup process; Mercury removal; Gold mine; Electroleaching

1. Introduction

Several cases of environment degradation due to artisanal gold mine operations in tropical region have been reported [1–3]. After the 1980s, the practice of subsistence gold mining proliferated in several regions in Brazil, including the goldfields located in the Brazilian northeastern, where mercury contamination was also identified. For instance, in a survey performed at the Itapicuru River hydrographic basin, located in the semi-arid region of Bahia State and the main drink water source for millions of inhabitants, important values of heavy metals were present in sediments [4,5]. The high mercury contents (22–123 μg/kg) close to several artisanal gold mine spots in the region are clearly due to anthropogenic activity.

The solid waste of a site from an artisanal gold mine region located in the Serra de Santa Cruz (Bahia, Brazil), at 10°45′13″S, 40°23′04″W, was chosen as a case to perform a characterization and treatment study, because of the vulnerability of the drink water sources in this semi-arid region and taking into account the apparent extension of the degradation by the mining activity in this area.

The studied site is located in the Jacobina basin, which is part of the São Francisco province of Bahia, with a North–South-trending mountain range that is 200 km long by 15–25 km wide containing gold-bearing conglomeratic units and was formed between 2086 and 1883 Ma [6]. Gold is industrially mined in the Jacobina basin from gold-pyrite-bearing conglomerates and artisanaly mined from both quartz veins and gold-pyrite-bearing conglomerates [6]. There are also in the Jacobina basin disseminated gold-bearing mineralization, such as discordant in quartz veins, at the contact basic-ultrabasic rocks, and subconcordant at different statigaphic levels in quartzite and conglomerate [6]. The Serra de Santa Cruz site is close to the Mina Nova site, where the mineralization is contained in a system of Au–As subvertical veins and extension fissures modified by deformation, and the veins are composed of quartz with free gold, pyrite, rare

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arsenopyrite, tourmaline, chlorite, and white mica surrounded by a halo of disseminated pyrite within the quartzite [6]. The major elements of the quartz vains lode in this region are SiO_2 99.09%, Al_2O_3 0.22%, Fe_2O_3 0.77%, loss on ignation (LOI) 0.26%, and it contains gold between 13 mg/t and 1 g/t, chromium up to 5194 g/t, nickel up to 37 g/t, cobalt up to 22 g/t, uranium up to 16.2 g/t, copper between 19 and 167 g/t, zinc between 11 and 27 g/t, arsenic between 40 and 45 g/t, boron up to 4724 g/t and lead about 11 g/t, yttrium about 1.4 g/t, lanthanum about 2.8 g/t, thorium about 1 g/t and zirconium about 17 g/t [6].

In this study, the gold mine tailings are described, including their mineralogy, grain size, density, and chemical composition, after an electrochemical clean up technique is applied. The methodology presented in the present study can be used to characterize other gold mine tailings, and the study of the nature of solid wastes found in artisanal gold mines is relevant because it can aid the development of specific clean up or immobilization techniques.

2. Experimental techniques

2.1. Tailings sampling

Sampling campaigns were performed at the gold mine tailings of the Serra da Santa Cruz to provide information about the site, the extraction and processing method and the extension of the degradation. The tailings, which are disposed in heaps, were sampled in several points and the solid material dried, homogenized, re-sampled and used for granulometric, mineralogical and other characterization studies. The first sampling campaign took place in 1995, and samples were used to preliminary gold and mercury analysis and to evaluate the efficiency of the amalgamation process to gold concentration; this sample is referred here as sample A, and the results are summarized in Section 3.1. The second sampling campaign, was performed in 2002, and provided samples from a region of the heap related to the material ground in the first stage of the operation (named here as sample B) and another related to the material recently ground (named here as sample C). These three samples (especially sample B) were further used in a more detailed characterization study that included chemical and physical analysis and are presented in this work; samples B and C were also used in the clean up studies using electroleaching.

2.2. Physical characterization

The X-ray diffraction analysis, used to identify the main mineralogical composition of the solid waste, was performed on a Philips PW1710 diffratometer with Cu Kα radiation at the Department of Mining and Materials Engineering of McGill University (Canada). The diffractogram interpretation was made with the assistance of the X'Pert Quantify search match software by PANalytical. The scanning electron microscope JEOL 840-A equipped with a X-ray dispersion energy spectrometry system (EDS) from the Department of Mining and Materials Engineering of McGill University (Canada) was used to evaluate the composition and the texture of the particles of the tailings. The samples were directly mounted in glass lames with an epoxy resin and carefully polished.

The tailings size distribution was evaluated using the conventional screening test with a ro-tap and a set of screens from 20 to 400 mesh Tyler and the density was measured using the classical pycnometer method.

2.3. Inorganic assays

Several analytical methods were used to evaluate the tailing elements content in order to produce representative results. These methods included neutron activation analysis (INAA), induced coupled plasma (ICP), induced coupled plasma and mass spectroscopy (ICP-MS), fire-assay (FA), infrared (IR), atomic absorption spectroscopy with cold vapor generation (FIMS), and atomic absorption spectroscopy (AAS). The neutron activation analyses were performed at the Department of Physical Engineering of the Polytechnic School (University of Montreal, Canada), and the other analyses were performed at the Activation Laboratories Ltd. (Canada). One remarks that the accuracy of the INAA is about 5%, and the detection limit of FA is about 0.03 mg/kg and FIMS and FA-AAS is about 5 μg/kg.

2.4. Solubilization experiments

The toxicity characteristic leaching procedure (TCLP) developed by U.S. EPA [7,8] was used in this study for a preliminary evaluation of the hazard potential of the tailings. The TCLP experiments use buffered acetic acid with pH 5, to simulate the action of organic acids, after, the solution metals content were analyzed.

The current industrial process to gold extraction from ores uses cyanide solutions. Gold cyanidation is an electrochemical process that occurs according to the parallel reactions [9–11]:

$$2Au + O_2 + 4CN^- + 2H_2O \rightarrow 2[Au(CN)_2]^- + 2OH^- + H_2O_2 \quad (1)$$

$$2Au + 4CN^- + H_2O_2 \rightarrow 2[Au(CN)_2]^- + 2OH^- \quad (2)$$

Silver cyanidation follows reactions analogous to that given by Eqs. (1) and (2). Copper can form several complexes with cyanide, which depends of the cyanide concentration and the pH. In this study, the bulk leach extractable gold (BLEG) test was used to evaluate the recoverability of mercury and precious metals from the tailing, without additional grinding, by cyanidation. This test corresponds to a 24 h roller bottle alkaline cyanidation followed by filtration and analyses of the metals in solution by induced coupled plasma and mass spectrometry (ICP-MS).

In the present study, both TCLP and BLEG leach experiments and solution analysis were performed at the Activation Laboratories Ltd. (Ontario, Canada).

2.5. Electroleaching experiments

The electroleaching process has several analogies with the electrodyalitic remediation [12]; however, the main objective of