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Biosorption of gold from computer microprocessor leachate solutions using chitin

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ABSTRACT

The biosorption of gold from discarded computer microprocessor (DCM) leachate solutions was studied using chitin as a biosorbent. The DCM components were leached with thiourea solutions, and two procedures were tested for recovery of gold from the leachates: (1) biosorption and (2) precipitation followed by biosorption. For each procedure, the biosorption was evaluated considering kinetic, equilibrium, and thermodynamic aspects. The general order model was able to represent the kinetic behavior, and the equilibrium was well represented by the BET model. The maximum biosorption capacities were around 35 mg g^{-1} for both procedures. The biosorption of gold on chitin was a spontaneous, favorable, and exothermic process. It was found that precipitation followed by biosorption resulted in the best gold recovery, because other species were removed from the leachate solution in the precipitation step. This method enabled about 80% of the gold to be recovered, using 20 g L^{-1} of chitin at 298 K for 4 h.

1. Introduction

The electronics industry has become one of the world's fastest-growing industrial sectors. Consequently, large amounts of waste electrical and electronic equipment (WEEE) are generated, estimated at 20–50 million tons of WEEE annually worldwide (Wang and Xu, 2014; Wong et al., 2007). Over one billion computers and their microprocessors were discarded between 1997 and 2010, in Japan and the United States alone (Kiddee et al., 2013). The incorrect disposal of WEEE can cause serious pollution problems, because this material contains a variety of toxic substances that can contaminate the environment and threaten human health (Hong et al., 2015; Ni et al., 2013; Tomko and McDonald, 2013). At the same time, WEEE contains valuable metals such as, gold, silver, platinum, and cobalt, which can be recovered (Bertuol et al., 2015a; Jing-Ying et al., 2012; Kwak and Yun, 2010). The development of technologies to recover metals from WEEE can therefore help in obtaining valuable products, while at the same time solving an environmental problem (Park et al., 2012; Birloaga et al., 2014; Sun et al., 2015).

Discarded computer microprocessors (DCMs) contain gold, which can be recovered (Bertuol et al., 2015b). Generally, gold is first extracted from WEEE by leaching (Petter et al., 2014), after which the gold is recovered from the leachate solution (Syed, 2012; Zhang et al., 2012). However, in addition to gold, the leachate contains the leaching agent and other extracted metals, which can hinder gold recovery (Fan et al., 2014). Techniques that have been used to recover gold from solutions include solvent extraction, chemical precipitation, and ion exchange (Fan et al., 2014; Syed, 2012; Zhang et al., 2012). Biosorption, an emerging and eco-friendly technique, is a promising technology for the removal of heavy metals from aqueous solutions (Ali et al., 2012), and has been used for the recovery of gold (Abidin et al., 2013; Adhikari et al., 2013; Park et al., 2012). The major advantages of biosorption are its effectiveness in removing heavy metal ions, as well as the ability to use inexpensive biosorbents. Biosorption processes are particularly suitable for the treatment of dilute solutions of heavy metals (Ali, 2010, 2012, 2014). However, no previous studies have used chitin as a biosorbent for the recovery of gold.

Chitin is the second most abundant natural polysaccharide and is the major structural component in the exoskeleton of arthropods, as well as in the cell walls of yeasts and other fungi. The main commercial sources of chitin are crab and shrimp shells, which are abundantly available as waste products of the seafood industry (Jayakumar et al., 2010). Chitin contains hydroxyl and N-acetyl groups in its structure, which are able to bind with ions in aqueous media (Dotto et al., 2012, 2013, 2015a). To the best of our knowledge, there have been no previous studies concerning the biosorption of gold from leachate solutions using chitin as a biosorbent.

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The present work investigates the recovery of gold from DCM leachate solutions using biosorption with chitin. Firstly, chitin and DCMs were obtained and characterized. Gold was then extracted from the DCMs using thiourea. Subsequently, evaluation was made of two methods of recovering the gold from the leachate: (1) biosorption and (2) precipitation followed by biosorption. For each procedure, the biosorption step was studied in detail. The biosorption kinetics was investigated using the pseudo-first order, pseudo-second order, and general order models. The biosorption equilibrium was studied using the Freundlich and BET models. In terms of the thermodynamics, determination was made of changes in the Gibbs free energy (ΔG^0), enthalpy (ΔH^0), and entropy (ΔS^0). It is important to point out that this work contributes both to the disposal management of solid wastes (chitin and DCMs), as well as to the recovery of a valuable metal (gold).

2. Materials and methods

2.1. Preparation and characterization of chitin

Chitin was extracted from shrimp (*Penaeus brasiliensis*) waste, as described in our previous work (Dotto et al., 2012, 2013, 2015a). Briefly, shrimp waste was submitted to demineralization, deproteinization, deodorization, and drying steps. The chitin was then ground (using a Wiley No. 3 mill) and sieved to obtain particles in the size range from 105 to 125 μm.

Chitin was characterized in terms of parameters important for biosorption. The point of zero charge (pH_{ZPC}) was determined by the eleven points experiment (Hao et al., 2004). The functional groups on the surface and the degree of deacetylation were identified by Fourier transform infrared spectroscopy (Prestige21 FT-IR spectrometer, Shimadzu, Japan) (Silverstein et al., 2007). The specific surface area (S_A), pore volume (V_p), and average pore radius (P_R) were determined with a volumetric adsorption analyzer (Quantachrome, USA), employing the Bennett, Emmet, and Teller (BET) method (Ocampo-Pérez et al., 2012). The crystallinity index was determined by X-ray powder diffractometry (XRD) (Miniflex 300, Rigaku, Japan) (Al-Sagheer et al., 2009). The textural characteristics were examined by scanning electron microscopy (SEM) (JSM-6610LV, JEOL, Japan) (Goldstein et al., 1992).

2.2. Procurement and characterization of microprocessors

The DCMs were obtained from a collection point in Santa Maria (Rio Grande do Sul, Brazil). Only the DCM pins were used in the leaching operation, because they contained the majority of the gold. The pins were manually removed and characterized using photographic images (GT-S7582L, 5MP, Samsung), scanning electron microscopy (JSM-6610LV, JEOL, Japan), and energy dispersive X-ray spectroscopy (EDS) (JSM-5800, JEOL, Japan) (Goldstein et al., 1992).

2.3. Leaching of gold from the microprocessors

Gold was leached from the DCM pins using thiourea (Ubaldini et al., 1998). Firstly, 1.00 g of DCM pins was placed in a 100.0 mL volumetric flask. Afterwards, 20 mL of an aqueous thiourea solution (50.0 g L^{-1}) and 20 mL of an aqueous ferric sulfate solution (15.0 g L^{-1}) were added to the flask. H_2SO_4 was then added until the solution pH reached 1.00, and the volume was completed to 50 mL with deionized water. The solution was stirred at 100 rpm for 60 min at 25 ± 2 °C. At the end of the experiments, the leachate solutions (containing gold, reactants, and other extracted metals) were filtered (Whatman n° 40 filter paper) and stored in the dark for further use. The gold and iron concentrations were determined by flame atomic absorption spectrometry (FAAS) (240 FS AA, Agilent, USA). The experiments were performed in replicate (n = 10), with deionized water and analytical grade reagents.

2.4. Biosorption of gold from the leachate solutions

The biosorption of gold from the leachate solutions was studied using two methods: (1) biosorption before precipitation and (2) biosorption after precipitation. The experimental scheme for gold biosorption from the DCM leachates is shown in Fig. 1. The leachate before precipitation was labeled BP and the leachate after precipitation was labeled AP.

2.4.1. Precipitation

Precipitation was performed in order to remove the other substances present in the solution and consequently improve the biosorption performance. The precipitation was achieved by adding NaOH (5.00 mol L^{-1}) until pH 6.00 was reached. The volume of solution doubled after the precipitation process. Afterwards, the sludge was removed and the liquid phase (AP) was used in the biosorption experiments. The concentrations of gold and iron were determined by FAAS (240 FS AA, Agilent, USA).

2.4.2. Biosorption

For both solutions (BP and AP), the gold biosorption tests were performed in batch mode using a temperature-controlled agitator (MA 093, Marconi, Brazil) under the following fixed conditions: 150 rpm stirring rate and 20 mL solution volume. The effects of different contact times (0–120 min), biosorbent dosages (0.50–20.00 g L^{-1}), and temperatures (298–328 K) were investigated (these experimental conditions were selected for evaluation in preliminary tests). After the experiments, the solid phase was separated by filtration (Whatman n° 40 filter paper) and the gold concentration remaining in the liquid phase was measured by FAAS. The experiments were performed in triplicate (n = 3) and included blanks. The gold recovery percentage (R, %), biosorption capacity at time t (q_t, mg g^{-1}), and equilibrium biosorption capacity (q_e, mg g^{-1}) were determined using:

$$R = \frac{(C_0 - C_f)}{C_0} 100 \quad (1)$$

$$q_t = \frac{V(C_0 - C_t)}{m} \quad (2)$$

$$q_e = \frac{V(C_0 - C_e)}{m} \quad (3)$$

where C_0 is the initial gold concentration in the liquid phase (mg L^{-1}), C_e is the equilibrium gold concentration in the liquid

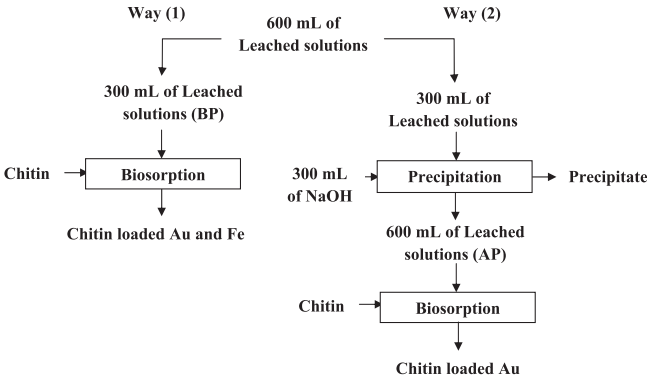

Fig. 1. Experimental scheme for biosorption of gold from the DCM leachates.