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Optimizing the thiosulfate leaching of gold from printed circuit boards of discarded mobile phone

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ABSTRACT

An environmentally benign process involving thiosulfate leaching was developed in order to recover gold from the printed circuit boards (PCBs) of discarded mobile phone. The effect of concentration of the reagents such as thiosulfate, copper(II) and ammonia on the leaching of gold was investigated in the temperature range 20–50 °C. Parameters were optimized through modeling of the leaching process using response surface methodology (RSM) based on central composite design (CCD). The optimum conditions for leaching of gold from PCBs were identified to be 72.71 mM thiosulfate, 10.0 mM copper(II) and 0.266 M ammonia. The initial rate of gold leaching was found to be 2.395×10^{-5} mol·m^{-2}·s^{-1} under the optimum conditions. As regards the kinetics of gold leaching, the pseudo-second order kinetic model with chemical control was found to be applicable in the low concentration range (40–60 mM thiosulfate, 5–7 mM copper(II) and 0.22–0.247 M ammonia), compared to that of pseudo-first order kinetic model at mid concentration range of the reactants viz., 60–70 mM thiosulfate, 7–9 mM copper(II) and 0.247–0.263 M ammonia. The apparent activation energy of the reaction in the temperature range 20–50 °C was found to be 78.6 kJ·mol^{-1}. The samples were characterized before and after leaching using scanning electron microscopy (SEM) which corroborated the chemical controlled leaching mechanism.

1. Introduction

Nowadays, electronic industry is the world's largest and fastest growing manufacturing industry. The rapid advent of changing technology makes early obsolescence of the gadgets and equipments thereby generating discarded electronics, which are now the fastest growing waste stream in the world (Tuncuk et al., 2012). Every year, 20 to 50 million tons of electrical and electronic equipment waste (e-waste) is generated world-wide, which could bring serious risks to human health and the environment (Herat, 2009; Tuncuk et al., 2012; Wath et al., 2011). Due to the high chemical stability and excellent conducting properties, gold metal has a wide application in the manufacture of electronic appliances, serving as the contact material in the printed circuit boards (PCBs). For instance, composition of precious metals (weight) in personal computer (PC) board scraps includes 930 ppm Ag, 31 ppm Au and 110 ppm Pd (Naseri and Rashchi, 2012). Thus, e-waste has attracted the attention of not only the government but also the public at large because of the presence of hazardous material and also the precious metal contents (Herat, 2009; Naseri and Rashchi, 2012; Zhang et al., 2012; Kumar et al., 2013; Manju et al., 2013; Syed, 2012; Yazici et al., 2010). The detailed literature survey by Tuncuk et al. (2012) as well as by Cui and Zhang (2008) on value distributions for different PCB samples showed that the major economic driver for recycling of PCBs is the gold metal. Therefore, recovery of gold from e-waste is necessary in order to supplement the depleting natural resources and also to promote the recycling for recovery of other valuable base metals (Kumar et al., 2013; Syed, 2012; Cui and Zhang, 2008; Havlik, 2010).

The gold leaching using thiosulfate solutions has been extensively studied as an alternative method for the traditional cyanidation technology (Aylmore and Muir, 2001; Breuer and Jeffrey, 2000, 2003; Chu et al., 2003; Jeffrey et al., 2003; Naseri and Rashchi, 2012). It is known that in the presence of ammonia and copper ions, gold can be readily brought into thiosulfate solution by the formation of a gold(I) thiosulfate complex (Aylmore and Muir, 2001; Breuer and Jeffrey, 2000; Chu et al., 2003; Jeffrey et al., 2003), as shown in Eq. (1). The thiosulfate leaching system is accompanied by the homogeneous reduction of copper(II) ions by thiosulfate (Aylmore and Muir, 2001; Breuer and Jeffrey, 2000, 2003; Chu et al., 2003; Jeffrey et al., 2003) according to the simplified overall reaction, Eq. (2). It is important to note

Abbreviations: 3D, three-dimensional; AAS, atomic absorption Spectrometer; ANOVA, analyses of variance; CCD, central composite design; Ea, Activation energy; EDS, energy dispersive spectroscopy; MLR, multiple linear regression; PC, personal computer; PCBs, printed circuit boards; RSM, response surface methodology; SEM, scanning electron microscopy.

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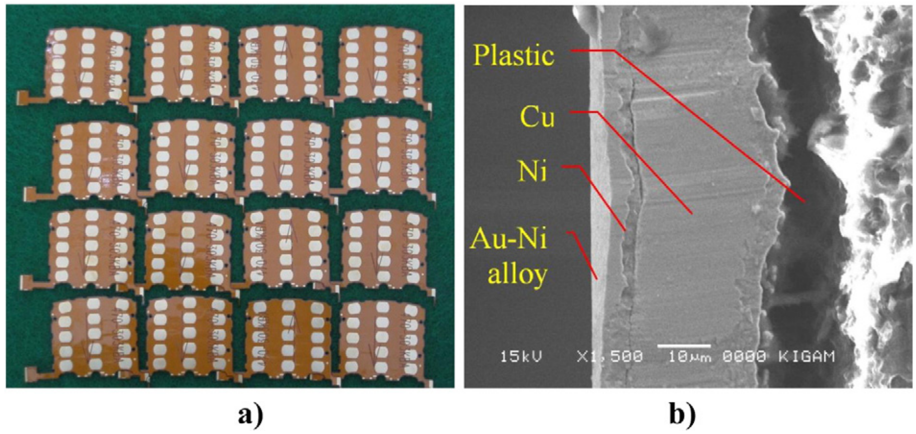

Fig. 1. Mobile phone PCBs scrap used in the study: (a) the original scrap and (b) typical SEM image of the section.

that this reaction not only reduces cupric ion concentration but also consumes thiosulfate, both of which are essential for gold leaching.

$$Au + Cu(NH_3)_4{}^{2+} + 5S_2O_3{}^{2-} \rightarrow Au(S_2O_3)_2{}^{3-} + Cu(S_2O_3)_3{}^{5-} + 4NH_3 \quad (1)$$

$$2Cu(NH_3)_4{}^{2+} + 8S_2O_3{}^{2-} \rightarrow 2Cu(S_2O_3)_3{}^{5-} + S_4O_6{}^{2-} + 8NH_3 \quad (2)$$

The leaching of gold from the PCBs using ammonia–copper(II)–thiosulfate solution has been investigated in our laboratory (Ha et al., 2010, 2011) as well as by other researchers (Feng and Van Deventer, 2010; Tripathi et al., 2012). These studies mainly focused on the influence of factors and mechanism of gold leaching to obtain valuable conclusions. As described in our previous paper (Ha et al., 2010), gold in the PCBs was leached as gold(I) thiosulfate complex using ammonia–copper(II)–thiosulfate solution in open-reactor. Gold extraction was found to be enhanced with solutions containing 15–20 mM Cu(II), 0.1–0.14 M thiosulfate, and 0.2–0.3 M ammonia. One of the causes of increase in the consumption of thiosulfate and/or copper(II) is the presence of oxygen in solution (Chu et al., 2003; Muir and Aylmore, 2004). The literature data reported by Senanayake (2004) for the leaching of gold are in the range 1–25 mM Cu(II), 0.1–0.8 M thiosulfate and 0.25–1.7 M ammonia. It was concluded that at lower concentrations of reagents, the leaching followed first order reactions with respect to copper(II) and thiosulfate, which at higher concentrations however, became zero order with respect to these reagents.

Almost all studies followed the conventional method. This method of optimization involves changing one independent variable at a time, while the other variables remain fixed. Unfortunately, they either rely on the classical one parameter at a time approach that ignores the combined interaction between physicochemical parameters or are theoretical in nature, while the electrochemical catalytic mechanism to leach gold in ammoniacal thiosulfate solutions was complicated and not very clear (Breuer and Jeffrey, 2000). The optimization strategy using the response surface methodology (RSM), a combination of statistical and mathematical techniques, has the advantage of modeling and analyzing the problems in which a response of interest is influenced by several variables (Montgomery, 2001). The RSM offers several advantages

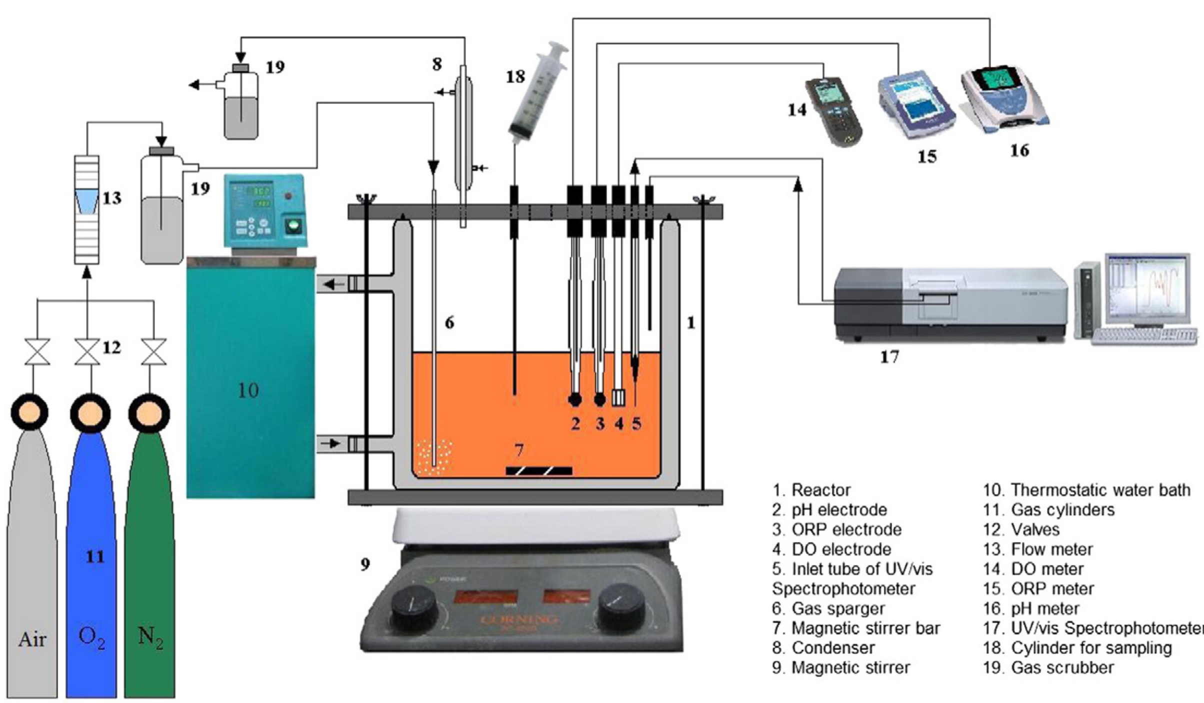

Fig. 2. A schematic diagram of reactor system for gold leaching.