



## Selective extraction of gold (III) from hydrochloric acid–chlorine gas leach solutions of copper anode slime by tri-butyl phosphate (TBP)



Nima SADEGHI, Eskandar Keshavarz ALAMDARI

Department of Mining and Metallurgical Engineering, Amirkabir University of Technology, Tehran, Iran

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**Abstract:** The oxidative leaching causes to dissolve various impurities such as Fe, Cu, Pd, Se in copper anode slime. Organic extractant tri-butyl phosphate (TBP) was used to purify leach solution. Several parameters, such as TBP, HCl and chloride inorganic salt concentrations were chosen in order to determine efficient state for impurities separation. Standard solvent extraction tests for extraction and separation of Au, Pd, Pt, Fe, Cu and Se were conducted with equal volume of aqueous and organic phases in batch experiments. The effect of hydrochloric acid, organic phase and metals initial concentration were examined at ambient temperature. It was found that 0.25 mol/L TBP in the presence of 2.5 mol/L hydrochloric acid can cause high extraction of gold. Meanwhile, in these conditions the extraction of other impurities is negligible. After extraction, pregnant organic phase was scrubbed by distilled water and some impurities were removed. Finally, gold was stripped by sodium thiosulfate solution. The stripping solution does not have any impurities. By adding  $\text{H}_2\text{SO}_4$  to stripping solution containing  $\text{Na}_2\text{S}_2\text{O}_5$ ,  $\text{SO}_2$  gas is released and  $\text{Au}^{3+}$  ions could be reduced.

**Key words:** gold; solvent extraction; separation; copper anode slime; TBP

### 1 Introduction

Recently, demands for gold and other precious metals have increased. New source identity and alteration recycling processes are the best strategies to satisfy these requests. Copper anode slime is one of the main sources for precious metals that has significant value of Au, Pt, Pb, Se, Ag, Th, etc [1].

Two main methods (e.g., pyrometallurgy and hydrometallurgy) were considered to extract precious metal from copper anode slime [2–7]. In recent years, hydrometallurgical process has been considered for precious metal recovery from copper anode slime that is solved at appropriate media along with a strong oxidizer [8–10]. Strong oxidizing agents lead to precious metals and impurities dissolution.

Solvent extraction is a suitable method for platinum group metals (PGMs) removal from low concentrated sources [11]. Our investigation [12] has shown that very low concentration of tri-butyl phosphate (TBP) could extract  $\text{HAuCl}_4$  from sensitized chloride solution. Extraction percentage of Au increased along with an increase in extractant and acid concentration. But TBP was also suggested for iron [13], selenium and tellurium [14], copper and other base metals [15],

palladium and platinum [16] extraction from chloride media. Hence, it seems that gold extraction may interface with other metal species extraction.

The aim of the present work was to develop a simple, efficient and environmentally friendly process for the separation and recovery of Au from chloride leach liquors of copper anode slime by commercial phosphorus based extractant. In the previous studies, only efficient extraction for target metal has been investigated and it has determined other impurities extraction, but in this study gold and impurities extraction was studied, individually. Then, by comparing different metals extraction by TBP, efficient condition for Au extraction and purification has been introduced. Practical parameters for extraction process include extractant, acid and chloride salt concentration on gold and impurities extraction. After impurities separation studies on extraction stage, scrubbing and stripping of organic phase were surveyed for higher purification. Finally, a flow sheet for Au separation from impurities (Fe, Cu, Pd and Se) was proposed.

### 2 Experimental

$\text{PtCl}_6 \cdot 6\text{H}_2\text{O}$ ,  $\text{PdCl}_6$ ,  $\text{SeO}_2$  and  $\text{FeCl}_3$  (Merck, Chemical Company GmBH, Germany) were used for

platinum, palladium, selenium and iron sources in aqueous solution, respectively. Selenium source was prepared by  $\text{SeO}_2$  dissolution in dilute hydrochloric acid solution. Analytical grade of tri-*n*-butyl phosphate (FLUKA, Switzerland) as the extractant and commercial grade kerosene (Isfahan Refinery Co.) as the diluent were used for preparing stock organic solutions. All other chemicals were A.R. grade. The copper anode slime was purchased from National Iranian Copper Industries Company (NICICO).

The copper anode slime was leached by chlorination processes in the presence of hydrochloric acid and chlorine gas. The elemental composition of leach liquors is shown in Table 1. As seen in Table 1, there is gold along with other impurities, such as copper, iron, palladium, platinum in leach liquors. Hence, the homogeneous solutions of metal chlorides, e.g., gold (500 mg/L), iron (1000 mg/L), palladium (170 mg/L) and selenium (680 mg/L) with 0.05–7 mol/L HCl were prepared. Metallic salts were dissolved in distilled water and then certain amount of this solution was diluted by hydrochloric acid and distilled water.

**Table 1** Concentration of metals and their variation in Sarcheshmeh anodic slime leach liquor (mg/L)

Au	Fe	Se	Cu	Ag	Pd
300–550	860–1250	800–1650	700–860	10–60	30–120

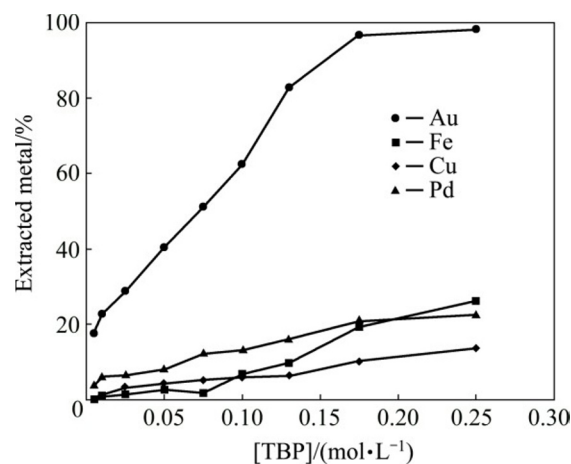
Batch experiments were conducted in a flask containing equal volume (20 mL) of aqueous, mixture of hydrochloric acid and definite initial concentration of Pd, Pt, Fe, Cu and Se, and organic phases (0.05–0.25 mol/L TBP) at ambient temperature. The mixture was mechanically agitated (400 r/min) for 30 min. The mixtures were then separated by a decanting funnel for 15 min to allow complete separation. The metal content of the aqueous phase was determined by atomic absorption spectroscopy (AAS, Varian, A240) and induction coupling plasma optical emission spectroscopy (ICP-OES, Varian, 715-ES), and then the organic phase was estimated by mass balance calculations. In some cases, the loaded organic (LO) phases were scrubbed or stripped by water and other appreciated solution, and the strip solution was analyzed for metal contents by ICP-OES/AAS. Acid content of the samples was determined by NaOH solution in the presence of phenolphthalein as the indicator. Stripping and scrubbing experimental activity was done as a simulation in experimental activity.

### 3 Results and discussion

#### 3.1 Effect of TBP concentration on co-extraction of gold with impurities

The concentration of organic extractant is one of the

most important parameters on extraction of main metal and impurities. Therefore, the effect of TBP concentration on the extraction of gold from the obtained leach liquor of copper anodic slime at optimum concentration of hydrochloric acid with different concentrations (0.01–0.25 mol/L) of TBP was investigated. According to our previous work [12], to study the effect of extractant concentration on extraction of Au, the concentration of HCl in the feed solution was determined to be 3 mol/L. Experiment was performed individually for gold, iron, copper and palladium. Figure 1 shows the extraction behavior of Au and other metals as a function of TBP concentration. As seen in this figure, gold was efficiently extracted in 0.175 mol/L TBP, but at this concentration, Fe, Pd and Cu also co-extracted 21%, 23% and 11%, respectively. It seems that gold extraction from other impurities can be done in a relatively selective manner and by using TBP solvent diluted kerosene. So, separation of gold from other metals with TBP at concentration greater than 0.25 mol/L could be favorable.



**Fig. 1** Influence of TBP concentration on Au(III), Fe(II), Cu(II) and Pd(II) extraction from leach liquor (Au 500 mg/L, Fe 860 mg/L, Cu 610 mg/L, Pd 71 mg/L, HCl 3 mol/L, 25 °C)

In Table 2, the effect of TBP concentration at 3 mol/L HCl and ambient temperature on the distribution and separation factors of gold from other impurities is shown. By increasing the concentration of TBP, the distribution factor of all metals increases. However, the distribution factor of all metals, except gold, in all of TBP concentration is less than 1. In the case of gold, the distribution factor in the TBP concentrations greater than 0.075 mol/L is more than 1. Therefore, it is expected that for optimizing the extraction of gold, the TBP concentration should be greater than 0.075 mol/L. On the other hand, as can be seen in Table 2, the separation factor of gold from iron, copper and palladium changes by increasing the TBP concentration; in fact, it first decreases and then increases steadily. According to the

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