Separation and Recovery of Precious Metals from Leach Liquors of Spent Electronic Wastes by Solvent Extraction

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Abstract: Solvent extraction was employed to recover precious metals (Au (III), Pd (II) and Pt (IV)) from the leach solution of spent electronic wastes containing Cu (II), Cr (III) and Fe (III). First, pure Fe (III) and Au (III) were recovered by simultaneous extraction with Cyanex 923 followed by selective stripping with HCl and Na2S2O3. Second, Pt (IV), Pd (II) and Cu (II) were extracted by Alamine 336 from the raffinate. After the removal of Cu (II) by stripping with weak HCl, Pd (II) and Pt (IV) were separately stripped by controlling the concentration of thiourea in the mixture with HCl. A process flow sheet for the separation of precious metals was proposed.

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Keywords: gold, platinum, palladium, separation, solvent extraction

1. INTRODUCTION

Precious metals (PMs) such as gold (Au), platinum (Pt) and palladium (Pd) are widely used in many industrial areas, including jewelry, corrosion-resistant materials, and chemical catalysts, due to their specific properties [1,2]. However, increasing demand and the limited natural availability of these precious metals have stimulated efforts to develop effective separation processes to recover PMs from various secondary resources, such as waste printed circuit boards[3], anode slimes[4] and spent automobile catalysts [5,6]. However, in high concentration HCl in either the presence of an oxidizing agent or aqua regia, the secondary resources typically leach, leading to the complete dissolution of the precious metals, together with some impurities like Fe (III), Cu (II), Cr (III), Ni (II) and Zn (II)[6-8]. In order to recover the precious metals with high purity from the leach solution, solvent extraction[1,6,9-15], ion exchange[16-18] and precipitation[3,19,20] methods have subsequently been employed.

Many studies have reported on the extraction and separation of Pt (IV) and Pd (II) using solvent extraction [5,6,21-28]. However, only a few works have reported on the separation of Au (I/III), Pt (IV) and Pd (II) from the leach liquors of secondary resources. To separate Au (I/III), Pt (IV) and Pd (II) from different solutions, a number of extractants, such as methyl iso-butylketone (MIBK)[29], tri-isobutyl phosphine sulfide (Cyanex 471X), a mixture of tetra trialkyl phosphine oxides (Cyanex 923)[11,12], and tri-capryl methylammonium chloride (Aliquat 336)[1] have been extensively. Although MIBK can selectively extract Au (III) from a chloride solution containing Fe (III), Ru (III), Os (III), Pt (IV), Pd (II) and Rh (III), the selectivity for Au (III) is not high and it is difficult to remove the impurities co-extracted into the MIBK by simple scrubbing [29]. Aliquat 336, Cyanex 923 and Cyanex 471X can selectively extract Au (III) over Pt (IV), Pd (II) and other metals from sulfuric acid/hydrochloric acid solutions [1,11,12]. The main disadvantage of Cyanex 923, Cyanex 471 and Aliquat 336 is that the co-extraction of Pt (IV) and Pd (II) together with Au (III) is significant. According to most of the reported studies on the separation of Au (III), Pt (IV) and Pd (II) from different solutions, solvent extraction has some limitations, including low extraction rates and poor separation.

The objective of the present work was to develop a solvent
Table 1. Compositions of real and diluted leaching solution

<table>
<thead>
<tr>
<th>Elements</th>
<th>Au</th>
<th>Pd</th>
<th>Pt</th>
<th>Fe</th>
<th>Cu</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual leaching solution, mg/L</td>
<td>346</td>
<td>646</td>
<td>45.7</td>
<td>122</td>
<td>545</td>
<td>33</td>
</tr>
<tr>
<td>Diluted actual leaching solution, mg/L</td>
<td>63</td>
<td>128.5</td>
<td>9.2</td>
<td>26.5</td>
<td>122.4</td>
<td>6.9</td>
</tr>
</tbody>
</table>

extracion process for separating and recovering Au (III), Pd (II) and Pt (IV) from the real leach solution of spent electronic wastes. The leach liquor of spent electronic wastes used in this work contained Au (III), Pt (IV) and Pd (II) together with some base metals, such as Fe (III), Cu (II) and Cr (III). In the acidic chloride solution, Au (III), Pt (IV), Pd (II) and Fe (III) exist as anionic species [30-33]. It is known that amines and neutral extractants can extract Au (III), Pt (IV), Pd (II) and Fe (III) from a hydrochloric acid solution [28,34]. Therefore, tri-octyl/decyl amine (Alamine 336) and neutral extractants (MIBK, TBP and Cyanex 923) were used for the separation of Au (III), Pt (IV), Pd (III) from the leach solution which contained Fe (III), Cu (II) and Cr (III). Complete separation of Au (III), Pd (II) and Pt (IV) from these leach solutions was achieved by extraction with Cyanex 923 and Alamine 336. For each extraction step, an optimum stripping condition was determined. On the basis of the results, a new process flow sheet for the separation of Au (III), Pt (IV), Pd (II) from leach solution by solvent extraction is proposed.

2. EXPERIMENTAL

Commercial extractants, such as tributyl phosphate (TBP, Yakuri Pure Chemical Co.), MIBK (Daejung Chemicals & metals Co. LTD) and Alamine 336 (BASF Co.) and Cyanex 923 (Cytec) were used without further purification. Kerosene (Samchun Pure Chem. Co.) was used as a diluent. First, most of the metals present in the spent electronic wastes were dissolved in aqua regia. The acidity of the aqua regia was controlled by adding neutralizing agents to recover Au. After the recovery of Au, the solution pH was around 0.7, the solution composition is shown in Table 1. Since there was insufficient quantity of real leach solution to conduct solvent extraction experiments, the pH 0.7 leach solution was diluted with HCl solution of the same acidity, and then employed in the solvent extraction experiments (see Table 1).

Solvent extraction and stripping experiments were performed by mixing equal volumes (10 mL) of aqueous and organic phases for 30 min using a wrist action shaker (Burrel, model 75). After equilibrium, the two phases were separated using a separating funnel. All the experiments were performed at room temperature (25 ± 1 ºC). Metal ion concentrations in the aqueous phase before and after extraction were determined by inductively coupled plasma-optical emission spectroscopy (ICP-OES; Spectro Arcos). The concentration of metals in the loaded organic phase was calculated by mass balance. The distribution coefficient (D) was calculated as the concentration of metal present in the organic phase to that present in the aqueous phase at equilibrium. The percentage of extraction and stripping is defined as Eqs. (1) and (2).

\[
\text{Extraction percentage} = \frac{\text{equilibrium mass of metal in the organic phase}}{\text{initial mass of metal in the aqueous before extraction}} \times 100
\]

(1)

\[
\text{Stripping percentage} = \frac{\text{equilibrium mass of metal in the aqueous after stripping}}{\text{initial mass of metal in the organic before stripping}} \times 100
\]

(2)

3. RESULTS AND DISCUSSION

3.1. Selective extraction and separation of Au and Fe

3.1.1. Effect of neutral extractants

In order to selectively extract Au (III), three kinds of neutral extractants (TBP, MIBK and Cyanex 923) were employed. The concentration of TBP/MIBK/Cyanex 923 was varied from 0.01 to 0.2 M at the unity volume ratio of the two phases. Figs. 1-3 show the variation in the extraction percentage of Au (III), Pd (II), Pt (IV), Cu (II), Cr (III) and Fe (III) with extractant concentration. As seen in Figs. 1-3, the extraction efficiency of these metals with TBP and MIBK was much lower than that obtained with Cyanex 923. The extraction percentage of Au (III) was around 10% at any TBP/MIBK concentration range, while that of Fe (III), Pd (II), Pt(IV) and Cu(II) was negligible (see Figs. 1 and 2). In
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**Fig. 1.** Effect of MIBK concentration on extraction of Au, Pd, Pt, Cu, Fe and Cr. Leach liquor, mg/L: Au-63, Pd-129, Pt-9.2, Fe-26.5, Cu-122.4, Cr-6.9; [MIBK] = 0.01-0.2 M; O/A = 1.

**Fig. 2.** Effect of TBP concentration on extraction of Au, Pd, Pt, Cu, Fe and Cr. Leach liquor, mg/L: Au-63, Pd-129, Pt-9.2, Fe-26.5, Cu-122.4, Cr-6.9; [TBP] = 0.01-0.2 M; O/A = 1.

In contrast, Cyanex 923 selectively extracted both Au (III) and Fe (III) better than the others (see Fig. 3). The extraction percentage of Au (III) and Fe (III) increased from 18 and 5%, to 99.5 and 91.7%, respectively, as the Cyanex 923 concentration was increased from 0.01 to 0.2 M. The co-extraction of Pd (II), Pt (IV) and Cu (II) was zero at any Cyanex 923 concentration range. In an acidic chloride solution of pH 0.7, Au (III), Pd (II) and Pt (IV) exist as anionic species, AuCl$_4$$^-$, PdCl$_4^{2-}$ and PtCl$_6^{2-}$ [30,33-36]. It has been reported that the formation of anionic species of CuCl$_2$$^-$ and FeCl$_3$$^-$ strongly depends on the concentration of chloride ions [32,33,37]. Although the anionic species of Cu (II) and Fe (III) like CuCl$_2$$^-$ and FeCl$_3$$^-$ can exist in the leach liquor employed in this work, some cationic and electrically neutral species, such as Cu$^{2+}$, FeCl$^{2+}$, FeCl$_2^+$, and FeCl$_3$ can also exist [31-33,36]. Since MIBK, TBP and Cyanex 923 extract neutral species, the solvent extraction of Au (III) and Fe (III) by the above-mentioned neutral extractants can be represented as Eq. (3) [10,31,32,37]. In acidic leach liquors of pH 0.5, most of the Cr (III) exists as Cr$^{3+}$ [38] and thus the extraction of Cr (III) by MIBK, TBP and Cyanex 923 was negligible.

\[ \text{M}^{n-} (\text{aq}) + n\text{H}^+ (\text{aq}) + m\text{L}_{\text{org}} = \text{H}_n\text{MmL}_{\text{org}} \]  

(3)

where M$^{n-}$ and L represent anionic species and the neutral extractant, respectively. The subscript aq and org represent the aqueous and organic phases, respectively.

The extraction efficiency of Au (III), Fe (III), Pt (IV), Pd (II) and Cu (II) by these neutral extractants in the present study was in the order of MIBK ≈ TBP << Cyanex 923 for the same extractant concentration, which agrees well with the values reported in the literature [39,40]. The extraction order of these metals by MIBK, TBP and Cyanex 923 might be related to the extraction efficiency of hydrogen ions during the extraction process. Since the interaction between hydrogen ions and Cyanex 923 is much stronger than that with TBP/MIBK[41], Au (III) and Fe (III) were readily extracted by Cyanex 923 in our experimental conditions. The tendency of metal-chloro complexes of precious metals to be extracted by solvation mechanism is [MCl$_4$$^-$] > [MCl$_6$$^{2-}$] > [MCl$_4$$^{2-}$] [1,28]. Au (III) and Fe (III), which exist as AuCl$_4$$^-$ and FeCl$_4$$^{2-}$, have lower charge densities than Pd (II), Pt (IV) and Cu (II), which exist as PdCl$_4$$^{2-}$, PtCl$_6$$^{2-}$ and CuCl$_4$$^{2-}$, respectively. It has been reported that a complex with a lower charge density attracts less water molecules, thus forming a smaller hydration shell[1,28], which has a positive effect on the formation of electrically neutral species in the solvation reaction. Therefore, the extraction percentage of Au (III) and Fe (III) was much higher than that of Pt (IV), Pd (II) and Cu (II) in the present work. According to the obtained results, 0.1 M Cyanex 923 was considered to be the optimum concentration to selectively extract both Au (III) and Fe (III) from the leach solution in the presence of Pt (IV), Pd (II), Cu (II) and Cr (III).
Fig. 3. Effect of Cyanex 923 concentration on extraction of Au, Pd, Pt, Cu, Fe and Cr. Leach liquor, mg/L: Au-63, Pd-129, Pt-9.2, Fe-26.5, Cu-122.4, Cr-6.9; [Cyanex 923] = 0.01-0.2 M; O/A = 1.

Fig. 4. Stripping isotherm of Fe from 0.1 M Cyanex 923 using 0.5 M HCl. Loaded 0.1 M Cyanex 923:24 mg/L Fe; A/O = 1:3-5:5.

Table 2. Effect of HCl concentration on stripping of Au and Fe from loaded Cyanex 923.

<table>
<thead>
<tr>
<th>[HCl], M</th>
<th>Stripping percentage, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Au</td>
</tr>
<tr>
<td>0.01</td>
<td>0.33</td>
</tr>
<tr>
<td>0.1</td>
<td>0.35</td>
</tr>
<tr>
<td>0.2</td>
<td>0.31</td>
</tr>
<tr>
<td>0.5</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Loaded organic: 60 mg/L Au, 24 mg/L Fe; [HCl] = 0.01-1 M; [Cyanex 923] =0.1 M

3.1.2. Separation of Au (III) and Fe (III) from the loaded Cyanex 923 by stripping

HCl solutions with varying concentration from 0.01 to 0.5 M were employed as a stripping solution, and the obtained results are shown in table 2. The stripping percentage of Fe (III) increased from 3.6 to 53% with increasing HCl concentration from 0.01 to 0.5 M, while the stripping percentage of Au (III) was nearly zero. When Eq. (3) is responsible for the extraction of Fe (III) by Cyanex 923, the stripping reaction can be represented as

\[
\text{HFeCl}_4\text{L(org)} = \text{L(org)} + \text{FeCl}_4^{-}\text{(aq)} + \text{H}^+\text{(aq)} \quad (4)
\]

In this case, the stripping percentage of Fe (III) should decrease with the increase in HCl concentration in the stripping solution. In contrast, our data showed the reverse behavior. When FeCl₃ is extracted by Cyanex 923 instead of HFeCl₄, the stripping reaction by HCl solution can be represented as

\[
\text{FeCl}_3\text{L(org)} + \text{Cl}^-\text{(aq)} = \text{L(org)} + \text{FeCl}_4^-\text{(aq)} \quad (5)
\]

Eq. (5) indicates that the stripping percentage of Fe (III) from the Cyanex 923 will increase as HCl concentration increases, which is in good agreement with our data. Therefore, in our extraction conditions it can be said that Fe (III) is extracted into Cyanex 923 as FeCl₃.

Table 2 shows that Fe (III) in the loaded Cyanex 923 can be removed by stripping with 0.5 M HCl solution, leaving Au (III) in the stripped Cyanex 923. In order to construct a McCabe-Thiele diagram for the stripping of Fe (III) from the loaded Cyanex 923 using 0.5 M HCl, the A/O ratio was varied from 1:3 to 5:1. The loaded Cyanex 923 was prepared by contacting the aqueous solution with 0.1 M Cyanex 923 at an O/A ratio of unity. The loaded Cyanex 923 contained 60 mg/L Au (III) and 24 mg/L Fe (III). The McCabe-Thiele diagram (Fig. 4) shows that four stages at an A/O of 2:1 can strip most of the Fe (III) from the loaded Cyanex 923.

According to the batch simulation experiments with four stages of counter-current stripping, the Fe (III) was completely stripped from the loaded Cyanex 923 and the concentration of Au (III) in the stripping solution was negligible. After the stripping of Fe (III) from the loaded Cyanex 923, the stripped organic phase containing 60 mg/L Au (III) was used for further stripping experiments with Au (III) from the stripped Cyanex 923.

It has been reported that either NaSCN or Na₂S₂O₃ are effective for stripping Au (III) from a loaded organic [42,43].
Therefore, NaSCN and Na$_2$S$_2$O$_3$ solutions were used in the present stripping experiments. The concentrations of these stripping reagents were varied from 0.01 to 0.2 M to strip Au (III) from the stripped Cyanex 923. Fig. 5 shows how the stripping percentage of Au (III) varies with the concentration of the stripping reagents. The stripping percentage of Au (III) was lower than 20% at any NaSCN concentration range, while it increased from 5% to 99% as the Na$_2$S$_2$O$_3$ concentration was increased from 0.01 to 0.2 M. It has been reported that Au(III) has a strong tendency to form complexes with SCN$^-$ and S$_2$O$_3^{2-}$ [44-46]. Although the complex formation constant of Au (III) with SCN$^-$ is larger than that of S$_2$O$_3^{2-}$ [44], the complex formation constants of Au (III) with these two ligands are so large that most of the Au (III) exists as either Au(SCN)$_4^{3-}$ or Au(S$_2$O$_3$)$_2^{3-}$. The reason why the Na$_2$S$_2$O$_3$ solution led to a higher stripping percentage of Au(III) from the loaded Cyanex 923 than the NaSCN solution may be due to the reduction of Au (III) to Au (I) in the presence of the Na$_2$S$_2$O$_3$ solution. Since the sulfur in S$_2$O$_3^{2-}$ can be oxidized to a higher oxidation state, Au (III) can be reduced to Au (I) in the stripping solution [45]. When this redox reaction occurs in the stripping solution, the stripping reaction of Au (III) from the loaded Cyanex 923 will be facilitated. The reaction occurring during the stripping with Na$_2$S$_2$O$_3$ solution can be represented as

$$\text{AuCl}_4^{-} + 4\text{S}_2\text{O}_3^{2-} = \text{Au(S}_2\text{O}_3)_2^{3-} + \text{S}_4\text{O}_6^{2-} + 4\text{Cl}^{-} \quad (6)$$

### 3.2. Separation of Pd (II), Pt (IV) and Cu (II)

#### 3.2.1. Effect of Alamine 336 concentration

In general, amines are effective for extracting both Pt (IV) and Pd (II) from concentrated HCl solution [28]. Therefore, Alamine 336 was used in the present work to extract Pt (IV) and Pd (II) from the Au (III) and Fe (III) free raffinate. The concentration of Alamine 336 was varied from 0.1 to 1 M. The composition of the Au (III) and Fe (III) free raffinate was as follows: Pd (II)-128.5 mg/L, Pt (IV)-9.2 mg/L, Cu (II)-122.4 mg/L, and Cr (III)-6.9 mg/L. Figure 6 shows the variation in extraction percentage of Pd (II), Pt (IV), and Cu (II) with Alamine 336 concentration. The extraction percentage of Pd (II), Pt (IV) and Cu (II) increased as Alamine 336 concentration increased from 0.1 to 1 M (see Fig. 6). The extraction order of these metals by Alamine 336 was Pt (IV) > Pd (II) > Cu (II). These results agree well with the reported results that the extraction percentage of precious metals by amines was in the order of [MCl$_4$]$^{-}$ > [MCl$_6$]$^{2-}$ > [MCl$_4$]$^{2-}$ [1,28]. Because the PtCl$_6^{2-}$ has the lowest charge density, the extraction percentage of PtCl$_6^{2-}$ by Alamine 336 was higher than that of PdCl$_4^{2-}$ and CuCl$_4^{2-}$. The extraction percentage of Cr (III) was zero at any Alamine 336 concentration. It can be concluded that 1 M Alamine 336 can extract most of the Pd (II), Pt (IV) and Cu (II), while leaving Cr (III) in the raffinate.

#### 3.2.2. Effect of O/A ratio

In order to investigate the effect of O/A ratio on the
Fig. 7. Effect of O/A ratio on extraction of Pd, Pt, Cu, Cr by Alamine 336. Raffinate, mg/L: Pd-128.5, Pt-9.2, Cu-122.4, Cr-6.9; [Alamine 336] = 1 M; O/A = 1:5-5:1.

Fig. 8. Effect of thiourea concentration on stripping of Pd and Pt from Alamine 336 by the mixture of 0.5 M HCl and thiourea. Loaded 1 M Alamine 336, mg/L: Pd-126, Pt-8.9; Stripping reagent = 0.5 M HCl+ 0.1-1.5 M thiourea; O/A = 1.

Table 3. Effect of HCl concentration on stripping of Cu from loaded Alamine 336.

<table>
<thead>
<tr>
<th>[HCl], M</th>
<th>Stripping percentage, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>Pt/Pd 99.9, Cu 99.9</td>
</tr>
<tr>
<td>0.05</td>
<td>Pt/Pd 97.8, Cu 97.8</td>
</tr>
<tr>
<td>0.1</td>
<td>No stripping, Cu 97.2</td>
</tr>
<tr>
<td>0.3</td>
<td>Cu 96.9</td>
</tr>
</tbody>
</table>

Loaded organic: 126 mg/L Pd, 8.9 mg/L Pt, 88.9 mg/L Cu; [HCl] = 0.01-0.3 M; [Alamine 336] = 1 M.

3.2.3. Separation of Pd (II), Pt (IV) and Cu (II) by stripping

According to the distribution of copper (II), cationic and neutral species of Cu (II), such as Cu^{2+}, CuCl^{+}, and CuCl_{2} exist in a moderate acid solution and these species cannot be extracted by amines [32,46]. Thus HCl solutions with 0.01-0.3 M were used for stripping experiments in this study. The loaded Alamine 336 was prepared by contacting the raffinate containing Pd (II)-128.5 mg/L, Pt (IV)-9.2 mg/L, Cu (II)-122.4 mg/L and Cr (III)-6.9 mg/L with 1 M Alamine 336 at an O/A ratio of unity. The loaded Alamine 336 contained Pd (II)-126 mg/L, Pt (IV)-8.9 mg/L and Cu (II)-88.9 mg/L. In the stripping experiments, the volume ratio of the two phases was controlled to unity. Table 3 shows the variation in stripping percentage of Pd (II), Pt (IV) and Cu (II) with HCl concentration. The stripping percentage of Cu (II) decreased from 100 to 96% with the increase in HCl concentration from 0.01 to 0.3 M, while no Pd (II) and Pt (IV) was stripped in this HCl concentration range. When HCl concentration was 0.01-0.3 M, anionic species of Pt (IV) and Pd (II), such as PtCl_{6}^{2-}, PtCl_{4}^{2-}, PdCl_{4}^{2-} and PdCl_{3}^{-} still exist in the solution[35], which can be extracted by amines, resulting in the low stripping of Pt (IV) and Pd (II) from the loaded Alamine 336. The obtained results indicate that Cu (II) can be removed from the loaded Alamine 336 by selective stripping over Pt (IV) and Pd (II) with 0.01 M HCl solution.

In the stripping of Pt (IV) and Pd (II) from amines, a mixture of thiourea and HCl is considered to be the optimum stripping reagent, due to its high stripping efficiency [5,21,23,27]. Previous studies have reported that the concentration of thiourea in the mixture with the HCl strongly affects the stripping and separation efficiency for Pd (II) and Pt (IV) from Aliquat 336 and Alamine 308 [27,28]. Therefore, in order to achieve the optimum condition for stripping and separating Pd (II) and Pt (IV) from the stripped
Fig. 9. Conceptual flowsheet for the separation and recovery of Au, Pd and Pt from real leaching solution by solvent extraction

Alamine 336 containing Pd (II)-126 mg/L and Pt (IV)-8.9 mg/L using a mixture of HCl and thiourea, the concentration of HCl was fixed at 0.5 M and that of thiourea in the mixture was varied from 0.1 to 1.5 M. Figure 8 shows the variation in stripping percentage of Pd (II) and Pt (IV) according to thiourea concentration. Most of the Pd (II) was stripped from the loaded Alamine 336 at any thiourea concentration range in the 0.5 M HCl solution. However, the stripping percentage of Pt (IV) increased from 20% to 85% when the thiourea concentration was increased from 0.1 to 1.5 M. The obtained results agree well with the results reported in the literature, which indicate that Pd (II) can be selectively stripped over Pt (IV) from loaded amines using a mixture of thiourea and HCl [21,23,27,28]. According to Fig. 8, the mixture of 0.1 M thiourea and 0.5 M HCl can be considered the optimum condition for selectively stripping Pd (II) over Pt (IV) from the loaded Alamine 336. The Pt (IV) remaining in the stripped Alamine 336 can be stripped by increasing the thiourea concentration in the 0.5 M HCl solution.

A proposed process for the selective extraction and separation of Au (III), Pt (IV) and Pd (II) from the real leach solution of spent electronic wastes which contained Fe (III), Cu (II) and Cr (III) by Cyanex 923 and Alamine 336 is presented in Fig. 9. Compared to the process for separating of Au (III), Pt (IV) and Pd (II) from sulfuric acid solution by Cyanex 923[11], the advantage of the current process lies in the fact that no Pt (IV) and Pd (II) were co-extracted by Cyanex 923, and thus the recovery step of Au from the loaded Cyanex 923 was very simple. Using this process, pure Au (III), Pt (IV) and Pd (II) solutions can be recovered from the leach solution of spent electronic wastes.

4. CONCLUSION

Solvent extraction experiments were performed to recover precious metals such as Au (III), Pd (II) and Pt (IV) from the real leach solution of spent electronic wastes which contained Fe (III), Cu (II) and Cr (III). First, an extraction of the pH 0.7 leach solution using Cyanex 923 led to the complete extraction of Au (III) and Fe (III), leaving the other metals in the raffinate. Only Fe (III) could be removed from the loaded Cyanex 923 by stripping with dilute HCl solution, leaving most of the Au (III) in the stripped Cyanex 923. Pure Au (III) was recovered by stripping of the stripped Cyanex 923 with Na2S2O3 solution. Second, extraction of the Au (III) and Fe (III) free raffinate with Alamine 336 resulted in the selective extraction of Pt (IV) and Pd (II) as well as Cu (II). Cu (II) from the loaded Alamine 336 was selectively stripped over Pd (II) and Pt (IV) by dilute HCl solution. After the separation of Cu (II) from the loaded Alamine 336, the Pd (II) and Pt (IV) were separately stripped by controlling thiourea concentration in a mixture with HCl solution. Based on the obtained results, a process flow sheet for the recovery of Au (III), Pd (II) and Pt (IV) with high purity from the leach liquors of spent electronic wastes was proposed.

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