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Removal of Te and Se anions in alkaline media in presence of cyanide by quaternary ammonium salts

R. Solis-Rodriguez[1], S. Bello-Teodoro[1], A. Moreno-Báez[2], J.I. Galván-Tejada[2], J.G. Arceo-Olague[2], H. Luna-García[2] and O. Alonso-Gonzalez[1*]

1. Academic Unit of Engineering, Autonomous University of Zacatecas "Francisco García Salinas", Zacatecas, Mexico
2. Academic Unit of Electrical Engineering, Autonomous University of Zacatecas "Francisco García Salinas", Zacatecas, Mexico

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**Corresponding author: omero.alonso@uaz.edu.mx (O. Alonso-Gonzalez).*

Abstract

Precious metals are currently associated with selenium (naumannite, Ag_2Se) and tellurium (calaverite, $AuTe_2$; sylvanite, $(Au,Ag)_2Te_4$) to form species refractory to cyanidation. The aim of this preliminary work was to study the use of the solvent extraction technique to recover tellurium and selenium ions from a synthetic solution similar to the cyanidation effluents to recycle the free cyanide back to the process. For the extraction of the Se and Te anions, the use of quaternary amines as extractants was evaluated (tallow trimethyl ammonium chloride, Quartamin TPR; hexadecyl trimethyl ammonium chloride, Amine F; and trioctyl methyl ammonium chloride, Aliquat 336) employing nonylphenol as a modifier in the organic phase (iso-octane). The results obtained showed that the extraction was strongly affected by the pH and that it was possible to recover up to 83% of Se and 10% of Te with Quartamin TPR from two synthetic solutions containing 23 mg/L of Te and 20 mg/L of Se with a molar cyanide:metal ratio of 1:4 at pH 11, a ratio of aqueous/organic (A/O) = 1 (V/V) and an extractant concentration of 0.022 mol/L. A maximum distribution coefficient (D) of 4.97 was obtained at pH 11. The McCabe-Thiele diagram indicates that two theoretical extraction stages are necessary to obtain a good extraction of Se complexes using Quartamin TPR.

Keywords: *Solvent Extraction, Tellurium Extraction, Selenium Extraction.*

1. Introduction

In the extraction of precious metals, the cyanidation process has been in use for over a century; despite the environmental and toxicological problems, it has remained as the most widely used and economical process available. In the late 90s, there were great efforts to extract gold and silver from some ores classified as “refractory minerals”, which are difficult to dissolve by simple cyanidation. The most important gold tellurides are calaverite ($AuTe_2$), petzite (Ag_3AuTe_2), and sylvanite ($(Au, Ag)_2Te_4$) [1]. In the case of selenides, the most important minerals are naumanite (Ag_2Se) and aguilarite (Ag_4SeS) [2]. Examples of tellurides deposits include La Bambolla Mine (Sonora, Mexico), Cripple Greek (Colorado, USA), and Kalgoorlie (Western Australia) [3].

In order to improve the gold recovery from tellurides and selenides present in some deposits, these ores are pretreated by roasting. This is one of the most effective ways of rendering refractory gold ores leachable, and it is also a fast pretreatment process compared with bio-oxidation or pressure leaching [4]. According to Zhang et al. (2010) [5], some alternative methods to recover precious metals from tellurides have been proposed including cyanidation with modified conditions (e.g. a higher cyanide concentration than that used in the plant, with oxygen injection or with simultaneous addition of oxygen and lead nitrate [6]) or the use of non-cyanide leaching agents (e.g. thiourea [6] and thiosulfate [4]). Thus developing effective extraction processes for the removal of the Se and Te anions is necessary, allowing the recycling of the cyanide solution back to the leaching process. Ionic liquids (ILs) such as quaternary ammonium salts have recently attracted attention instead of traditional extractants for recovery of metals due to their specific characteristics such as negligible vapor pressures, high thermal stabilities, high range of viscosities, and good selectivity towards metals [7].

ILs have been used successfully to extract rare earth elements [8, 9], heavy metals [10], and platinum group metals [7, 11, 12], all in acidic media. In alkaline media, only the removal of copper from cyanide solutions has been reported [13, 14]. Wei et al. (2016) [7] have used ionic liquid Aliquat 336 to demonstrate that it is possible to selectively extract Au(III), Pt(IV), and Pd(II) from multi-metal solutions.

In accordance with what mentioned above, the main purpose of this work was to explore the feasibility of using quaternary ammonium salts such as tallow trimethyl ammonium chloride (commercial name: Quartamin TPR), hexadecyl trimethyl ammonium chloride (Amine F), and trioctyl methyl ammonium chloride (Aliquat 336) to extract the Te and Se anions from a synthetic aqueous solution similar to the cyanidation effluents produced during the processing of selenides and tellurides.

Alonso-González et al. (2013) [13] have reported that quaternary ammonium salts are compounds that dissociate in aqueous solutions, generating relatively large cations. They are used as emulsifies, frothers, and detergents; and in the mineral processing industry, they are employed as collectors for non-metallic minerals in flotation and as extractants in the solvent extraction techniques for metals recovery. It has been found that quaternary ammonium salts extract metal-CN complexes successfully, and do not react with free cyanide [13, 14], allowing the recycling of the cyanide solution back to the leaching process.

2. Thermodynamic aspects

The chemistry of refractory minerals associated with gold-tellurium and silver-selenium is relatively complex when cyanide is present in the system. These minerals dissolve slowly in the alkaline solutions of cyanide despite the fact that the mechanism has been poorly investigated and not fully understood [3]. Marsden and House (2006) [1] have mentioned that tellurium and selenium do not form stable complexes with cyanide; in this work, the distribution diagrams were constructed for the systems Te-CN-H_2O and Se-CN-H_2O.

It is important to know the concentration of the Te and Se species in the system. The relative concentration of each species depends on the total concentration of tellurium and selenium, temperature, and pH. Figures 1(a)-(b) show distribution diagrams of the species for the synthetic solutions used in this work: 23 mg/L Te (1.57×10^{-4} M), 20 mg/L Se (2.53×10^{-4} M), and a molar ratio metal:CN^- = 1. The removal of these anions with quaternary ammonium salts was conducted in alkaline pH in order to avoid the loss of free cyanide as $HCN_{(g)}$.

From the data for the diagrams displayed in Figure 1, the amount of each species in equilibrium can be obtained for each pH value. It can be seen that $HSeO_3^-$ is present at pH 8 and decreases when the pH increases, the predominant species being SeO_3^{2-} in the case of tellurium complexes at the same pH range, the predominant species are $HTeO_3^-$ and TeO_3^{2-} at different percentages (see Table 1).

The global extraction reactions considered for the tellurium ($HTeO_3^-$, TeO_3^{2-}) and the selenium (SeO_3^{2-}, $HSeO_3^-$) species, and three quaternary amines (R_4N^+) are shown in Eqs. (1) and (2).

$$xTeO_3^{2-}{}_{(aq)} + yHTeO_3^- + 3xy(R_4N^+)_{(org)} = xTeO_3(R_4N)_{2(org)} + yHTeO_3(R_4N)_{(org)} \quad (1)$$

$$xSeO_3^{2-}{}_{(aq)} + yHSeO_3^- + 3xy(R_4N^+)_{(org)} = xSeO_3(R_4N)_{2(org)} + yHSeO_3(R_4N)_{(org)} \quad (2)$$

where $HTeO_3^-$, TeO_3^{2-}, $HSeO_3^-$, and SeO_3^{2-} are the species in the aqueous phase, whose concentration is calculated from the thermodynamic analysis (Figure 1); x and y are the molar fraction of each complex at the pH of the solution; R_4N^+ is the extractant in equilibrium with the remaining aqueous tellurium and selenium species; $TeO_3(R_4N)_{2(org)}$, $HTeO_3(R_4N)_{(org)}$, $HSeO_3(R_4N)_{(org)}$, and $SeO_3(R_4N)_{2(org)}$ are the tellurium-amine and selenium-amine complexes in the organic phase. The distribution coefficient, D, for tellurium and selenium may be expressed as:

$$D = \frac{\sum[Te]_{org}}{\sum[Te]_{aq}} = \frac{[TeO_3(R_4N)_2]_{(org)} + [HTeO_3(R_4N)]_{(org)}}{[TeO_3^{2-}]_{(aq)} + [HTeO_3^-]_{(aq)}} \quad (3)$$

$$D = \frac{\sum[Se]_{org}}{\sum[Se]_{aq}} = \frac{[SeO_3(R_4N)_2]_{(org)} + [HSeO_3(R_4N)]_{(org)}}{[SeO_3^{2-}]_{(aq)} + [HSeO_3^-]_{(aq)}} \quad (4)$$

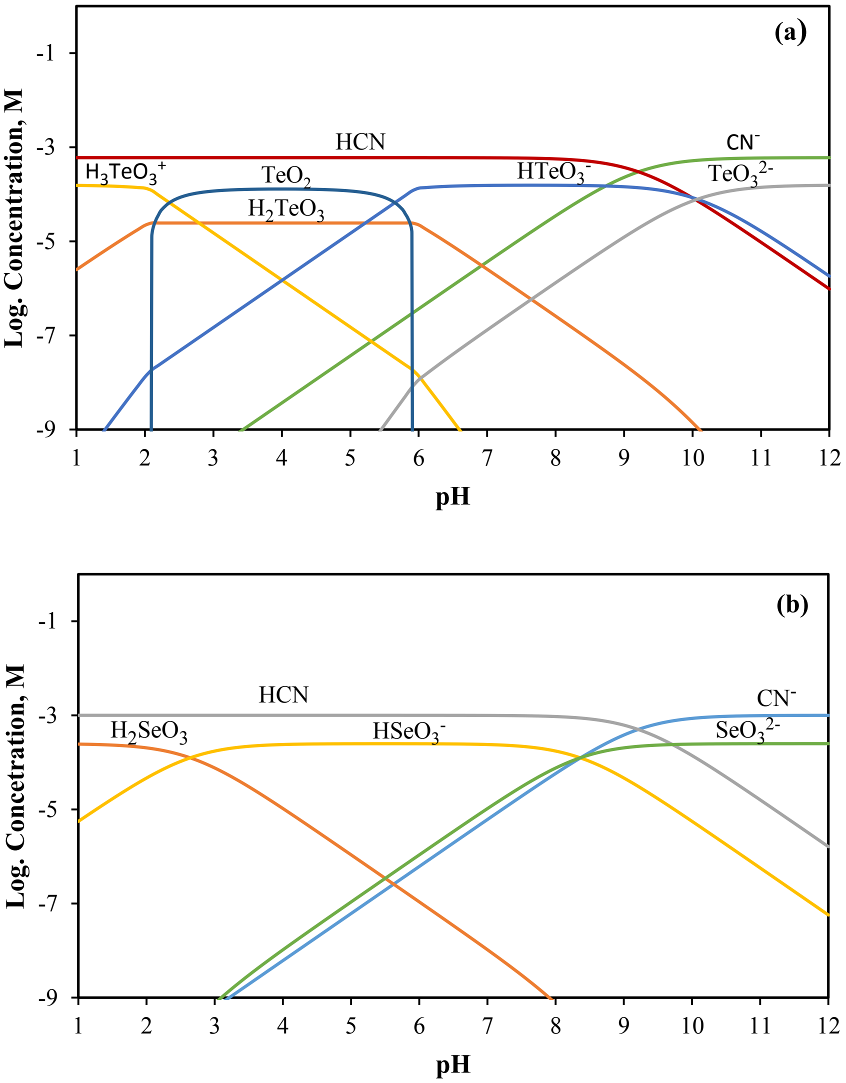

Figure 1. Speciation diagrams for a solution containing 23 mg/L of tellurium and 20 mg/L of selenium at 25 °C. Molar ratio metal:CN^- = 1; (a) Tellurium-cyanide-water system, (b) Selenium-cyanide-water system.

Table 1. Percentage and molar concentration of tellurium complexes at the pH range used in this experimental work.

Complexes	pH = 8		pH = 9		pH = 10		pH = 11		pH = 12	
	Molar	%	Molar	%	Molar	%	Molar	%	Molar	%
TeO_3^{2-}	1.29×10^{-6}	0.82	1.15×10^{-5}	7.32	7.24×10^{-5}	46.22	1.41×10^{-4}	90.13	1.48×10^{-4}	94.37
$HTeO_3^-$	1.55×10^{-5}	98.82	1.48×10^{-4}	94.37	8.32×10^{-5}	53.06	1.70×10^{-5}	10.84	2.00×10^{-6}	1.01
SeO_3^{2-}	7.60×10^{-5}	30.39	2.03×10^{-4}	81.37	2.44×10^{-4}	97.76	2.49×10^{-4}	99.76	2.50×10^{-4}	99.97
$HSeO_3^-$	1.74×10^{-4}	69.61	4.66×10^{-5}	18.64	5.60×10^{-6}	2.24	5.71×10^{-7}	0.23	5.73×10^{-8}	0.02

3. Experimental

3.1. Aqueous solution

The aqueous solution (synthetic) used in this work simulated the composition of an effluent of cyanidation solution with dissolved Se and Te. It was prepared with TeO_2 and SeO_2 reagent grade dissolved in sodium hydroxide, and sodium cyanide in a molar ratio CN^-: metal 4:1 (all reagents provided by Sigma-Aldrich). Deionized water was used to prepare the solutions, and the pH was adjusted using sodium hydroxide and sulfuric acid solutions. The chemical compositions of the solutions used were: a) Te 23 mg/L and total cyanide 16.31 mg/L; b) Se 20 mg/L and total cyanide 26.36 mg/L.

3.2. Organic solution

The organic solution (extractant + modifier + solvent) was prepared using trimethylpentane (J.T Baker) as the organic solvent, the modifier nonylphenol (Sigma-Aldrich) was added to avoid the formation of a third phase, in a molar ratio extractant/modifier = 1 for all the tests. Three quaternary ammonium compounds were evaluated as extractants: tallow trimethyl ammonium chloride, hexadecyl trimethyl ammonium chloride, and trioctyl methyl ammonium chloride, with a concentration of 0.022 mol of extractant per liter of solvent. Table 2 presents the detailed information about these quaternary ammonium salts.

Table 2. Quaternary ammonium salts evaluated for the removal of tellurium and selenium complexes from cyanidation solutions.

	Formula	Molecular weight (g/mol)	Commercial name
Tallow trimethyl ammonium chloride	$C_{18}H_{37}N(CH_3)_3Cl$	347.66	Quartamin TPR*
Hexadecyl trimethyl ammonium chloride	$CH_3(CH_2)_{15}N(CH_3)_3Cl$	329.64	Amine F*
Trioctyl methyl ammonium chloride	$CH_3N[(CH_2)_7CH_3]_3Cl$	404.16	Aliquat 336**

*Chemical Kao
**Sigma-Aldrich

3.3. Methodology

The extraction of the tellurium and selenium anions from a cyanide solution was carried out in a 300 mL glass reactor, hermetically sealed and equipped with internal baffles. The pH was measured with a pH-meter (Thermo Scientific Orion 3 star). 50 mL of the solution was placed in the reactor and mixed with the organic solution with a magnetic stirrer at 1000 rpm for the selected interval of time. Samples of the aqueous phase were taken for Se and Te content analysis. After extraction, the phases were separated by mean of a separation funnel. Some of these tests were performed by varying the volume aqueous/organic (A/O) in ratios of 1, 2, 4, and 8.

The metals in solution were analyzed by atomic absorption spectrophotometry (AAS) using a Varian Spectra 220 FS spectrophotometer. All the standards for the analysis were prepared with a matrix similar to that of the samples (alkaline media and cyanide content). The free cyanide analysis was not performed because the quaternary ammonium salts do not react with CN^-, and its concentration remains constant, as mentioned in the Introduction.

4. Results and discussion

4.1. Effect of pH

The extraction of Te anions ($HTeO_3^-$, TeO_3^{2-}) and Se anions ($HSeO_3^-$, SeO_3^{2-}) was evaluated at five pH values (from 8 to 12) and for a concentration of 0.022 mol/L of the three amines. The results obtained are presented in Figure 2. It can be seen that the removal of Se is more efficient than the removal of Te. For the extraction of Se (Figure 2a), it was observed that the extraction capacity was strongly affected by the pH and that the three extractants evaluated showed a similar behavior; however, Quartamin TPR showed a more extraction capacity than Aliquat 336 and Amine F. At pH 8, 24% of Se was extracted with Quartamin TPR. When the pH was increased to 11, the extraction increased up to 83%. If the pH still increased, the extraction dropped drastically. At pH 11, with Aliquat 336, the maximum removal of Se was 64%, and with Amine F, it was 35%. The behavior of Quartamin TPR suggests that it could be feasible to recover Se as this metal could be stripped from the organic phase in alkaline solutions.

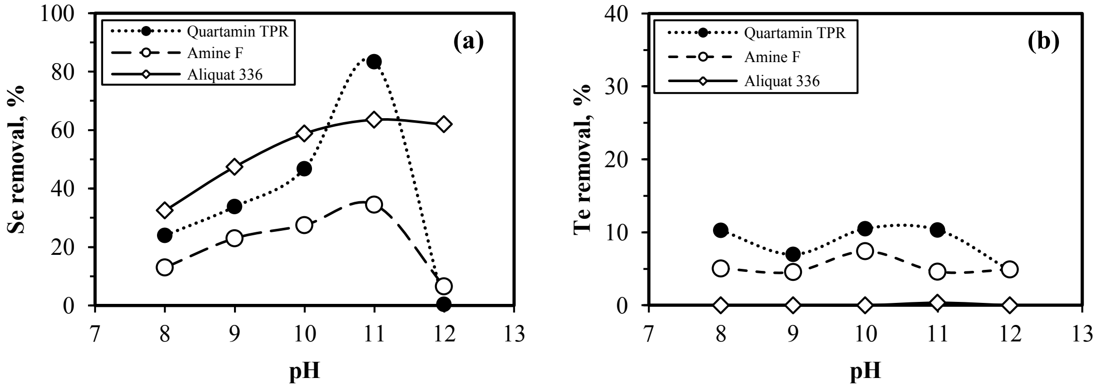

Figure 2. Effect of pH on removal of Se and Te complexes dissolved in cyanide solution at 25 °C (50 mL of aqueous solution ratio A/O = 1, contact time of 10 min, and 1000 rpm). (a) Selenium; (b) Tellurium.

For the Te extraction (Figure 2b), a low removal was observed in the entire range of pH evaluated; the maximum extraction of Te, around 10%, was obtained with Quartamin TPR at pH values between 10 and 11. At pH values higher than 12, a decrease in the Te removal was observed, in a similar way to Se. The poor extraction of Te achieved in this work is similar to the recovery observed by Havezov and Jordanov (1974) [15], who found that Te(IV) extraction depended on the polar nature of the solvent. These authors concluded that Te(IV) could be extracted only if it formed complexes with other compounds in solution such as bromide and iodide. In this work, Te(IV) did not form complexes with any other compound in solution and, in consequence, it showed a low removal.

Although Quartamin TPR is more efficient for the extraction of Se, it is important to notice that if there are both metals (Se and Te) in the cyanide solution, a selective extraction could be obtained using Aliquat 336, allowing the removal of only Se at pH 11 and leaving Te in the aqueous phase.

As already stated from the thermodynamic data in Figure 1, the amounts of Te and Se compounds for each pH value could be estimated. It was assumed that the solubility of the organic reagents (extractants and modifier) in the aqueous phase was negligible and that Se and Te were present only as Te-amine and Se-amine complexes, as described in Eqs. (1) and (2). For the tests presented in Figure 2, the amounts of the Te and Se species were calculated for each pH as well as the distribution coefficients (D). The distribution coefficient indicates the global driving force of the reactions presented in Eqs. (1) and (2). The calculations are presented in Tables 3 and 4. According to Table 3, the distribution coefficients for the removal of Te are low, which concords with the low removal observed in Figure 2(b). Results of the removal with Aliquat 336 were not presented because they were too low (Table 3).

From the analysis of data presented in Table 4, it was found that D increased with increase in pH, achieving a maximum value at pH 11, which indicates that in these conditions, the global driving force for the reaction is higher (D = 4.97). In accordance with the results presented in Figure 2, the maximum Se extraction takes place in these conditions.

4.2. Extraction isotherms for Se and Te in cyanide

Figure 3 shows the extraction isotherms indicating the equilibrium concentration of selenium complexes in the organic and aqueous phase, generated at 25 °C, pH 11, and different A/O ratios (1, 2, 4, and 8). In Figure 3(a), the isotherm for the removal with Quartamin TPR is presented. Additionally, the McCabe-Thiele diagram is plotted and illustrates the number of steps obtained using an A/O phase ratio of 1, which represents the slope of the operating line. The results obtained suggest that two steps are necessary to obtain a concentration of 4 mg/L of Se in the aqueous phase and an organic phase loaded with a concentration of 36 mg/L of Se. It is important to remember that Quartamin TPR is the most efficient quaternary amine for the removal of Se.

Table 3. Distribution coefficient (D) and tellurium-cyanide species in equilibrium (mol/L) for the extraction of tellurium complexes with quaternary amines at different pH values. T = 25 °C, A/O = 1, 1000 rpm, and 10 min of contact time.

pH	$Te_{remaining}$ (mg/L)	$HTeO_3^-{}_{(aq)}$	$TeO_3^{2-}{}_{(aq)}$	$TeO_3(R_4N)_{2(org)}$	$HTeO_3(R_4N)_{(org)}$	D
			0.022 mol/L Quartamin TPR, $[Te]_0 = 23$ mg/L			
8	21.140	1.63×10^{-6}	1.36×10^{-6}	1.55×10^{-7}	1.87×10^{-5}	0.114422
9	21.915	1.62×10^{-4}	1.25×10^{-5}	9.43×10^{-7}	1.21×10^{-5}	0.075014
10	21.086	8.76×10^{-5}	7.63×10^{-5}	8.96×10^{-6}	1.02×10^{-5}	0.117329
11	21.126	1.79×10^{-6}	1.49×10^{-4}	1.71×10^{-5}	2.06×10^{-6}	0.115161
12	22.434	1.77×10^{-6}	1.65×10^{-4}	8.32×10^{-6}	8.23×10^{-8}	0.050192
			0.022 mol/L Amine F, $[Te]_0 = 21$ mg/L			
8	20.669	1.60×10^{-4}	1.33×10^{-6}	7.09×10^{-8}	8.52×10^{-6}	0.053268
9	20.776	1.53×10^{-4}	1.19×10^{-5}	5.70×10^{-7}	7.34×10^{-6}	0.047793
10	20.159	8.38×10^{-5}	7.30×10^{-5}	5.83×10^{-6}	6.70×10^{-6}	0.079915
11	20.768	1.76×10^{-5}	1.46×10^{-4}	7.07×10^{-6}	8.50×10^{-7}	0.048247
12	20.701	1.64×10^{-6}	1.53×10^{-4}	7.89×10^{-6}	8.46×10^{-8}	0.051589

Table 4. Distribution coefficient (D) and selenium-cyanide species in equilibrium (mol/L) for the extraction of selenium complexes with quaternary amines at different pH values. $[Se]_0$ = 20 mg/L, T = 25 °C, A/O = 1, 1000 rpm, and 10 min of contact time.

pH	$Se_{remaining}$ (mg/L)	$HSeO_3^-{}_{(aq)}$	$SeO_3^{2-}{}_{(aq)}$	$SeO_3(R_4N)_{2(org)}$	$HSeO_3(R_4N)_{(org)}$	D
0.022 mol/L Quartamin TPR						
8	15.208	1.34×10^{-4}	5.85×10^{-5}	1.81×10^{-5}	4.15×10^{-5}	0.309508
9	13.240	3.13×10^{-5}	1.36×10^{-4}	6.88×10^{-5}	1.58×10^{-5}	0.504154
10	10.640	3.02×10^{-6}	1.32×10^{-4}	1.15×10^{-4}	2.63×10^{-6}	0.871711
11	3.3310	9.70×10^{-8}	4.21×10^{-5}	2.10×10^{-4}	4.83×10^{-7}	**4.978685**
12	19.915	5.04×10^{-7}	2.52×10^{-4}	0	0	0
0.022 mol/L Amine F						
8	17.400	1.53×10^{-4}	6.70×10^{-5}	1.00×10^{-5}	2.29×10^{-5}	0.149425
9	15.400	3.64×10^{-5}	1.59×10^{-4}	4.74×10^{-5}	1.09×10^{-5}	0.298701
10	14.500	4.11×10^{-6}	1.80×10^{-4}	6.81×10^{-5}	1.56×10^{-6}	0.379310
11	13.100	3.82×10^{-7}	1.66×10^{-4}	8.72×10^{-5}	2.01×10^{-7}	**0.526718**
12	18.700	4.74×10^{-8}	2.37×10^{-4}	1.65×10^{-5}	3.29×10^{-9}	0.069519
0.022 mol/L Aliquat 336						
8	14.340	1.26×10^{-4}	5.52×10^{-5}	2.65×10^{-5}	6.07×10^{-5}	0.480474
9	11.160	2.63×10^{-5}	1.15×10^{-4}	1.04×10^{-4}	2.38×10^{-5}	0.902330
10	8.7400	2.48×10^{-6}	1.08×10^{-4}	1.55×10^{-4}	3.54×10^{-6}	1.429062
11	7.7400	2.25×10^{-7}	9.78×10^{-5}	1.70×10^{-4}	3.93×10^{-7}	**1.742894**
12	8.0800	2.05×10^{-7}	1.02×10^{-4}	1.66×10^{-4}	3.33×10^{-7}	1.627475

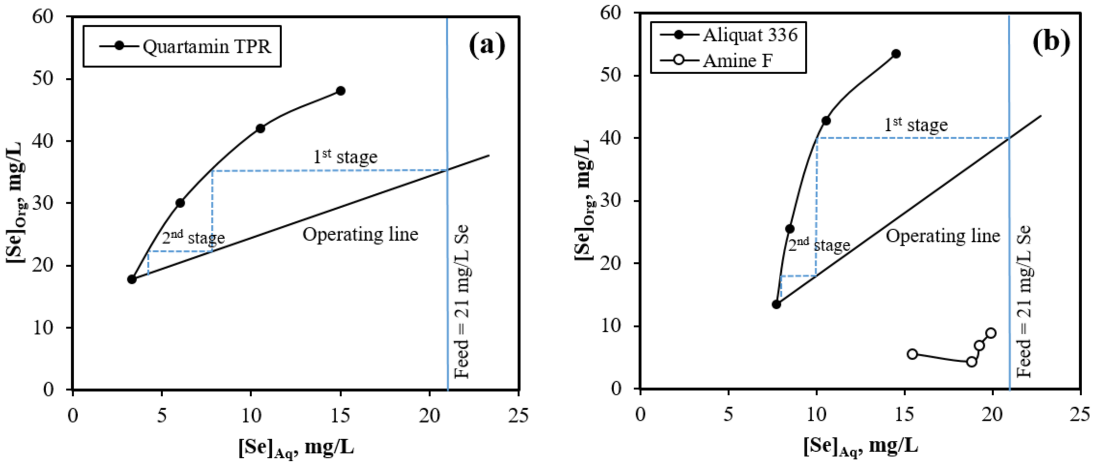

Figure 3. Extraction isotherms for Se removal with quaternary ammonium salts. Extractant concentration of 0.022 M, pH 11, 1000 rpm, contact time = 10 min, 25 ° C, and A/O ratio of 1, 2, 4, and 8; (a) Quartamin TPR; (b) Aliquat 336 and Amine F.

In Figure 3(b), the extraction isotherm for the Se removal with Aliquat 336 and Amine F is presented. According to this figure, Se can be extracted satisfactorily with Aliquat 336 but it is important to mention that the operating line is plotted assuming an A/O ratio of 2, and even under this condition, the theoretical concentration of Se in the aqueous phase must be around 7.5 mg/L. The isotherm for the removal of Se with Amine F does not show a clear tendency due to the low removal obtained. These results essentially agree with the results presented in Figure 2.

The isotherms for the Te removal are not displayed because they do not show a clear tendency, as mentioned above for the removal of Se with Amine F despite the fact that it has been reported that Se and Te present a similar chemical behavior [16]. A very different removal capability for selenium and tellurium was observed with quaternary ammonium salts in alkaline media, the selenium removal being successful with Quartamin TPR.

5. Conclusions

Quaternary ammonium salts can be used to remove successfully dissolved Se from cyanidation solutions in alkaline media. In contrast, the extraction of Te is poor (around 10%). For the Se removal, Quartamin TPR has a better extraction capacity ($[Se]_0$ = 20 mg/L, $[CN]_T$ = 26.36 mg/L and 25 ºC). The extraction increases when the pH is increased, achieving a maximum of 82% of Se extracted al pH 11, and it decreases drastically at pH 12. This behavior can be used to perform the stripping of the loaded organic solution.

Aliquat 336 showed a lower extraction capability than Quartamin TPR; however, it had a higher selectivity to extract Se over Te.

It was found that the distribution coefficient (D) increased with increase in pH, achieving a maximum at pH 11, which indicates that under these conditions, the global driving force for the reaction is D = 4.97.

The McCabe-Thiele diagram indicates that two theoretical extraction stages are necessary to obtain a good extraction of Se complexes using Quartamin TPR, with a ratio A/O = 1. With Aliquat 336, due to its lower extraction capability, it is necessary to use a ratio A/O = 2 to obtain a good extraction of Se in two theoretical stages.

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حذف عناصر تلوریم و سلنیوم در محیط قلیایی در حضور سیانید توسط نمک‌های آمونیوم کواترنر

R. Solis-Rodriguez[1], S. Bello-Teodoro[1], A. Moreno-Báez[2], J.I. Galván-Tejada[2], J.G. Arceo-Olague[2], H. Luna-García[2] and O. Alonso-Gonzalez[1*]

1- Academic Unit of Engineering, Autonomous University of Zacatecas "Francisco García Salinas", Zacatecas, Mexico
2- Academic Unit of Electrical Engineering, Autonomous University of Zacatecas "Francisco García Salinas", Zacatecas, Mexico

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* نویسنده مسئول مکاتبات: omero.alonso@uaz.edu.mx

چکیده:

در حال حاضر، فلزات گران‌بها با سلنیوم (naumannite, Ag_2Se) و تلوریم (calaverite, $AuTe_2$; sylvanite, $(Au,Ag)_2Te_4$) همراه هستند تا گونه‌های مخصوص به سیانید شدن را شکل بدهند. هدف از این پژوهش مقدماتی، مطالعه استفاده از تکنیک استخراج انحلالی برای بازیابی یون‌های تلوریم و سلنیوم از محلول مصنوعی مشابه با فاضلاب سیانیدی برای بازیافت سیانید آزاد به فرآیند است. برای استخراج آنیون‌های سلنیوم و تلوریم، استفاده از امین‌های چهار عنصر (tallow trimethyl ammonium chloride, Quartamin TPR; hexadecyl trimethyl ammonium chloride, Amine F; and trioctyl methyl ammonium chloride, Aliquat 336) مورد ارزیابی قرار گرفت و nonylphenol به عنوان اصلاح کننده فاز آلی (ایزو- اکتان) استفاده شد. نتایج به دست آمده نشان داد که استخراج انحلالی به شدت به pH وابسته است و بازیابی تا بالای ۸۳ درصد از سلنیوم و ۱۰ درصد از تلوریم با Quartamin TPR از دو محلول مصنوعی حاوی ۲۳ میلی‌گرم در لیتر تلوریم و ۲۰ میلی‌گرم در لیتر سلنیوم با یک مولار سیانید: نسبت فلز ۴:۱ در pH برابر با ۱۱، نسبت آب به مواد آلی (A/O) برابر ۱ (V/V) و غلظت استخراج ۰/۰۲۲ مول بر لیتر امکان‌پذیر است. ضریب توزیع حداکثر (D) ۴/۹۷ در pH برابر با ۱۱ به دست آمد. نمودار McCabe-Thiele نشان می‌دهد که دو مرحله استخراج تئوری برای به دست آوردن استخراج خوب از ترکیب‌های سلنیوم با استفاده از Quartamin TPR ضروری است.

کلمات کلیدی: استخراج انحلالی، استخراج تلوریم، استخراج سلنیوم.