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# Selection of reductants for extracting selenium and tellurium from degoldized solution of copper anode slimes

Fu-yuan ZHANG<sup>1,2,3</sup>, Ya-jie ZHENG<sup>1</sup>, Guo-min PENG<sup>2,3</sup>

1. School of Metallurgy and Environment, Central South University, Changsha 410083, China;

2. Henan Zhongyuan Gold Smelter Co., Ltd., Sanmenxia 472000, China;

3. Key Laboratory of Comprehensive Utilization of Gold Resource in Henan Province, Sanmenxia 472000, China

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**Abstract:** This paper focused on investigating high-efficient reductants of recovering selenium and tellurium from degoldized solution of copper anode slimes. Firstly, the effect of various reductants on recovery rates of Se and Te was investigated based on thermodynamic analysis of various metallic ions in degoldized solution. Secondly, the single factor experiments were made to investigate the effect of the process parameters on recovering Se and Te with hydrazine hydrate. Finally, the hydroxylamine hydrochloride was added to intensify the extraction efficiencies of Se and Te. The results indicated that hydrazine hydrate was the most suitable reductant, and the recovery rates of Se and Te are 71.23% and 76.50%, respectively; the recovery rates of Se and Te were 92.07% and 97.81%, respectively, under the optimal process conditions of hydrazine hydrate dosage of 0.2133 mol/L, H<sup>+</sup> concentration of 4.305 mol/L, reaction temperature of 85 °C and reaction time of 5 h; the recovery rate of Se was 97.59%, and that Te reached up to 100% when hydroxylamine hydrochloride dosage was 1.5116 mol/L.

Key words: degoldized solution; hydrazine hydrate; hydroxylamine hydrochloride; selenium; tellurium; recovery rate

#### **1** Introduction

Copper anode slimes are valuable by-products generated in copper electrolytic refining process, which account for 0.2%-1.0% (mass fraction) of anode copper [1-5]. Approximately 90% of selenium (Se) and tellurium (Te) are obtained from copper anode slimes, which are also one of the most important materials for extracting gold and silver [6-11]. Generally, the conventional process of treatment of copper anode slime includes the following steps [12-15]. Copper anode slimes are firstly pretreated with different methods to remove copper which is harmful for the subsequent procedure. Then, the decopperization residue is used to recover gold and silver by either hydrometallurgy or pyrometallurgy process. During the process, gold is sometimes separated from the leached residue by chlorination followed by precipitating gold. The obtained products are gold dust with high purity and degoldized solution, which still contains large amount of selenium, tellurium and certain amount of gold and platinum group metals.

So far, several techniques have been developed for recovering valuable metals from the degoldized solution, and the most popular ones are zinc dust replacement process [16,17] and sulfur dioxide reduction process [18,19]. The zinc dust replacement process is usually designed with the purpose to recover precious metals, especially gold and platinum group metals with low recovery rates on selenium and tellurium. Meanwhile, zinc dust tends to react with H<sup>+</sup> in degoldized solution to generate H<sub>2</sub>, which is the potential security danger for production. The sulfur dioxide reduction process can not only efficiently capture gold and platinum group metals, but also recover Se and Te in colloidal state. However, sulfur dioxide tends to escape from strong acidic solution, which pollutes the environment.

With the increasing demand of valuable metals and more strict requirements of environmental protection, it is necessary to explore suitable reductant with high extraction efficiencies for Se and Te from degoldized solution. The aim of this work is to investigate the novel

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reduction system for efficiently extracting both Se and Te from degoldized solution. Firstly, the effect of various reductants on recovery rates of Se and Te was investigated to determine suitable reductant for extracting Se and Te. Then, the process parameters in hydrazine hydrate reduction system were studied in a systematic manner. Finally, the combined system of hydrazine hydrate and hydroxylamine hydrochloride was used to intensify the extraction efficiencies of Se and Te.

#### 2 Experimental

#### 2.1 Materials

A sample of copper anode slimes was provided by one of the copper smelters in China. Copper anode slimes were firstly decopperized by high pressure leaching process, and then followed by chlorination process to separate Au and Ag. In subsequent steps, Au was precipitated from the gold-bearing solution with sodium sulfite and the obtained degoldized solution was used as the raw materials in all experiments, wherein  $[H^+]=3.755$  mol/L. Chemical analysis of the solutions was carried out by inductively coupled plasma-atomic emission spectroscopy (Intrepid II XSP, Thermo Electron, USA), and the results are given in Table 1.

 Table 1 Main chemical composition of degoldized solution (mmol/L)

Se	Te	Au	Pt	Pd	Cu	Fe	Cl
3.92	23.60	0.18	0.0095	0.11	8.95	2.34	6536

It can be seen from Table 1 that the degoldized solution was rich in Se (3.92 mmol/L) and Te (23.60 mmol/L), while a negligible amount of precious metals (0.18 mmol/L Au, 0.0095 mmol/L Pt and 0.11 mmol/L Pd) was dissolved in degoldized solution.

#### 2.2 Methods

Accurate amount of degoldized solution was added to the flask, a measured amount of reductant was charged to the flask and heated to a specific temperature under magnetically stirring and the reaction initiated. Two reflux condensers were installed at the top of the flask to minimize the loss of solution due to evaporation. After the required time, the slurries were separated by vacuum filtration immediately. The residues were washed with distilled water and then dried in air oven at 105 °C for weighing. The recovery rates of valuable metals were estimated on the basis of materials balance. AR-grade chemical reagents were used in all experiments.

Chemical compositions of the reduction products were analyzed by X-ray fluorescence analysis (ARL Perform'X, Thermo Electron, USA). The crystalline lattice and the micro morphology of the reduction products were analyzed by X-ray diffraction (D/max-TTR III, Rigaku, Japan) and scanning electron microscope (JSM-6300, JEOL, Japan).

#### **3** Thermodynamic analysis

In copper anode slimes, Se and Te occur as silver and copper selenides and tellurides, while in degoldized solution Se mainly exists as  $SeO_3^{2-}$ ,  $HSeO_3^-$ ,  $H_2SeO_3$ , and Te mainly exists as  $TeO_3^{2-}$ ,  $HTeO_3^-$ ,  $H_2TeO_3$ ,  $H_3SeO_3^+$  [18–21]. The dissociation equations of selenides and tellurides are presented as follows:

$$H_2SeO_3 = HSeO_3^- + H^+, K_{a1} = 2.40 \times 10^{-3}$$
 (1)

$$HSeO_{3}^{-} = SeO_{3}^{2-} + H^{+}, \ K_{a2} = 5.01 \times 10^{-9}$$
(2)

$$H_3 TeO_3^+ = H_2 TeO_3 + H^+, K_{a1} = 1.48 \times 10^{-3}$$
 (3)

$$H_2TeO_3 = HTeO_3^- + H^+, K_{a2} = 4.17 \times 10^{-7}$$
 (4)

$$HTeO_3^- = TeO_3^{2-} + H^+, \ K_{a3} = 1.45 \times 10^{-16}$$
(5)

The total concentration of  $[M (IV)]_T$  in degoldized solution is

$$[M(IV)]_{T} = [MO_{3}^{2-}] + [HMO_{3}^{-}] + [H_{2}MO_{3}] + [H_{3}MO_{3}^{+}]$$
(6)

where  $[M(IV)]_T$  is the total concentration of  $[Se(IV)]_T$  or  $[Te(IV)]_T$ . The effects of pH value on the distribution of Se(IV) and Te(IV) species are depicted respectively in Figs. 1 and 2 according to Eqs. (1)–(6).



Fig. 1 Relationship between mole fraction of Se(IV) species and pH

Apparently, in strongly acidic solution, the main existing form of Se(IV) is H<sub>2</sub>SeO<sub>3</sub>, and that of Te(IV) is H<sub>3</sub>TeO<sub>3</sub><sup>+</sup> when pH $\leq$ 0. In weakly acidic and alkaline solutions, the main existing forms of Se(IV) are HSeO<sub>3</sub><sup>-</sup> and SeO<sub>3</sub><sup>2-</sup>, and those of Te(IV) are H<sub>2</sub>TeO<sub>3</sub>, HTeO<sub>3</sub><sup>-</sup> and TeO<sub>3</sub><sup>2-</sup>.

The results of Table 1 indicate that degoldized solution contains large amounts of Se and Te, and small

amounts of Au, Pt, Pd with  $H^+$  concentration of 3.755 mol/L. It can be concluded that  $H_2SeO_3$  and  $H_3TeO_3^+$  are main existing forms in degoldized solution. In addition, Au, Pt and Pd exist as  $AuCl_4^-$ ,  $PtCl_4^{2-}$  and  $PdCl_4^{2-}$  due to the large amounts of  $Cl^-$  in solution. The standard electrode potential and the actual electrode potential for involved reactions calculated based on Nernst equation and involved ion concentrations are listed in Table 2.



Fig. 2 Relationship between mole fraction of Te(IV) species and  $\ensuremath{\text{pH}}$ 

**Table 2** Electrode reactions and electrode potentials of ions in solution at 25  $^{\circ}$ C

Ion		Standard	Actual
	Electrode reaction	electrode	electrode
	Electione reaction	potential,	potential,
		$arphi^{\Theta}\!/\mathrm{V}$	$\varphi/{ m V}$
$\operatorname{AuCl}_4^-$	$AuCl_4^-+3e=Au+4Cl^-$	1.002	0.864
$PtCl_4^{2-}$	$PtCl_4^{2-}+2e=Pt+4Cl^{-}$	0.758	0.513
$\mathrm{H}_2\mathrm{SeO}_3$	$H_2SeO_3+4H^++4e=Se+3H_2O$	0.740	0.738
$PdCl_4^{2-}$	$PdCl_4^{2-}+2e=Pd+4Cl^{-}$	0.620	0.406
$\mathrm{H_{3}TeO_{3}^{+}}$	$H_{3}TeO_{3}^{+}+3H^{+}+4e=Te+3H_{2}O$	0.558	0.559

It can be seen that  $AuCl_4^{-}/Au$  has the highest actual electrode potential of 0.864 V, besides  $PtCl_4^{2-}/Pt$  (0.513 V),  $H_2SeO_3/Se$  (0.738 V) and  $H_3TeO_3^{+}/Te$  (0.559 V). Relatively, the lowest actual electrode potential is 0.406 V for  $PdCl_4^{2-}/Pd$ .

The actual electrode potential depends on many factors including temperature, ions state and component concentration. Compared with standard electrode potential,  $\varphi(AuCl_4^-/Au)$ ,  $\varphi(PtCl_4^{2-}/Pt)$  and  $\varphi(PdCl_4^{2-}/Pd)$  are largely decreased due to the low concentration of the metallic ions in solution. Furthermore, the actual electrode potentials of various metallic ions arrange as follows:  $\varphi(AuCl_4^-/Au) > \varphi(H_2SeO_3/Se) > \varphi(H_3TeO_3^+/Te) > \varphi(PtCl_4^{2-}/Pt) > \varphi(PtCl_4^{2-}/Pd)$ .

#### 4 Results and discussion

#### 4.1 Effect of reductants

The composition of reduction products depends not only on the reduction behavior of various metallic ions, but also on the reduction capability of the reductant. In this part of the study, the reductants presented in Table 3 were used to investigate the effects of reductants on the recovery rates of Se and Te.

Table 3 Characterization of various reductants (25 °C )

		. /
Reductant	Electrode reaction	$\varphi^{\Theta}/\mathrm{V}$
$H_4N_2{\cdot}H_2O$	$N_2+2H_2O+4H^++2e=2HONH_3^+$	-1.87
Zn	Zn <sup>2+</sup> +2e=Zn	-0.763
Fe	Fe <sup>2+</sup> +2e=Fe	-0.440
HONH <sub>3</sub> Cl	$N_2 + 5H^+ + 4e = H_2 NNH_3^+$	-0.23
$SO_2$	$SO_4^{2-}+4H^++2e=SO_2+2H_2O$	0.138
Cu	Cu <sup>2+</sup> +2e=Cu	0.340

The occurrence of the reduction reaction was determined by the comparison of the electrode potential between reductants and metallic ions. By comparing Table 3 with Table 2, it can be found that all the candidates can meet the demand of reduction reaction. Therefore, it can be concluded that Zn, Cu, SO<sub>2</sub>, Fe,  $H_4N_2$ · $H_2O$  and HONH<sub>3</sub>Cl all can be adopted as reductants to recover Se and Te from degoldized solution.

In our previous investigations [18,19], the recovery rates of Au, Pt and Pd in degoldized solution virtually reached 100%. Hence, the variation of recovery rates of Se and Te with respect to various reductants is given in Table 4 when a series of experiments were carried out at 40 °C for 3 h, and then at 80 °C for 1 h.

 Table 4 Effect of reductants on recovery rates of Se and Te

		,,	
Reductant	Dosage/ (mol·L <sup>-1</sup> )	Recovery rate of Se/%	Recovery rate of Te/%
Zn	0.2	37.07	36.84
Fe	0.2	14.63	32.77
Cu	0.2	16.78	32.17
HONH <sub>3</sub> Cl	0.2	80.76	34.08
$H_4N_2{\cdot}H_2O$	0.2	71.23	76.50
$SO_2$	Saturation	33.90	37.79

According to Table 4, the highest recovery rates of Se and Te were respectively 71.23% and 76.50% with  $H_4N_2$ · $H_2O$ . HONH<sub>3</sub>Cl exhibited the highest recovery rate of Se as 80.76%, whereas the recovery rate of Te was only 34.08%. After examining the experimental results, it

was found that  $H_4N_2 \cdot H_2O$  was the most appropriate reductant for recovering Se and Te from degoldized solution. Even though the electrode potential of  $H_4N_2 \cdot H_2O$  was -0.23 V, the liquid-liquid reaction in  $H_4N_2 \cdot H_2O$  system increased the effective contact area of the particles, resulting in increasing the collision probability of the reaction particles, which was in favor of reducing Se and Te.

## 4.2 Effect of reaction parameters on recovery rate in $H_4N_2$ · $H_2O$ reduction system

 $H_4N_2$ · $H_2O$  was chosen as the reductant for the following experiments. Effects of relevant parameters such as  $H_4N_2$ · $H_2O$  dosage, reaction temperature,  $H^+$  concentration and reaction time were reported below. 4.2.1 Effect of  $H_4N_2$ · $H_2O$  dosage

The influence of  $H_4N_2 \cdot H_2O$  dosage on the recovery rates of Se and Te was investigated in a range of 0–0.5 mol/L, as shown in Fig. 3. The required amount of  $H_4N_2 \cdot H_2O$  to reduce Se and Te in degoldized solution was initially examined at the following parameters: reaction temperature of 85 °C and reaction time of 1 h.



Fig. 3 Effect of  $H_4N_2{\cdot}H_2O$  dosage on recovery rates of Se and Te

It could be seen from Fig. 3 that the recovery rates of Se and Te increase to 72.79% and 74.72% at  $H_4N_2 \cdot H_2O$  dosage of 0.2133 mol/L. Beyond this point, increasing  $H_4N_2 \cdot H_2O$  dosage to 0.4267 mol/L caused a significant increase of Te recovery rate being 98.77%, whereas the increase of  $H_4N_2 \cdot H_2O$  dosage did not lead to any significant change in the recovery rate of Se. Considering the slight difference of Se recovery rate obtained in the  $H_4N_2 \cdot H_2O$  concentration range of 0.2133 to 0.4267 mol/L, the following experiments were carried out at  $H_4N_2 \cdot H_2O$  dosage of 0.2133 mol/L.

Based on the Nernst equation, it can be calculated that the electrode potentials of  $H_4N_2$ · $H_2O$  were -0.1736, -0.1781, -0.1807 and -0.1825 V when  $H_4N_2$ · $H_2O$  dosages were 0.1067, 0.2133, 0.3200 and 0.4267 mol/L,

respectively. The electrode potential of  $H_4N_2 \cdot H_2O$  gradually decreased with increasing  $H_4N_2 \cdot H_2O$  dosage, resulting in the increase of the reduction capability. 4.2.2 Effect of reaction temperature

The effect of reaction temperature on recovery rates of Se and Te was investigated by varying the temperature from 20 to 95 °C, as shown in Fig. 4. In these series of experiments,  $H_4N_2$ · $H_2O$  dosage was 0.2133 mol/L and the reaction time was 1 h.



Fig. 4 Effect of reaction temperature on recovery rates of Se and Te

Increasing reaction temperature initially caused a slow contribution on the recovery rates of Se and Te below 45 °C. Then, the recovery rates of Se and Te rapidly increased to 76.26% and 78.09% when the temperature increased from 45 to 85 °C. There was a negligible difference between 85 and 95 °C. Therefore, further tests were carried out at 85 °C.

4.2.3 Effect of H<sup>+</sup> concentration

The effect of  $H^+$  concentration from 3.755 to 4.580 mol/L on the recovery rates of Se and Te was researched under the conditions of  $H_4N_2 \cdot H_2O$  dosage of 0.2133 mol/L and reaction temperature 85 °C, in which  $H^+$  ions was adjusted by sulfuric acid. The results are shown in Fig. 5.

Figure 5 showed that the recovery rate of Se increased, but that of Te decreased gradually with increasing H<sup>+</sup> concentration. When H<sup>+</sup> concentration increased from 3.755 to 4.580 mol/L, the recovery rate of Se increased from 35.24% to 81.23%, and the corresponding electrode potential  $\varphi$ (H<sub>2</sub>SeO<sub>3</sub>/Se) increased from 0.738 to 0.744 V, which accelerated the reduction reaction of Se.

Conversely, the recovery rate of Te decreased from 99.04% to 73.61% with  $H^+$  concentration varying from 3.755 to 4.580 mol/L. This unexpected situation was thought to have occurred because of importing sulfate radical which converted Te to sulfuric acid oxygen tellurium (TeOSO<sub>4</sub>) [22]. The transformation of existing

form of Te increased the resistance of reduction reaction, which resulted in the decrease of the recovery rate of Te with increasing  $H^+$  concentration. Therefore,  $H^+$  concentration of 4.305 mol/L was chosen as the optimal condition.



Fig. 5 Effect of H<sup>+</sup> concentration on recovery rates of Se and Te

#### 4.2.4 Effect of reaction time

The effect of reaction time on recovery rates of Se and Te was inspected in the range of 0.5 to 5 h under following conditions:  $H^+$  concentration of 4.305 mol/L,  $H_4N_2 \cdot H_2O$  dosage of 0.2133 mol/L and reaction temperature of 85 °C. The results are shown in Fig. 6.



Fig. 6 Effect of reaction time on recovery rates of Se and Te

Apparently, the increase in reaction time boosted the recovery rates of Se and Te considerably. As the reaction time was 5 h, the recovery rates of Se and Te reached 90.44% and 100%, respectively. It can be concluded that longer reaction time could promote the recovery rates of Se and Te in degoldized solution. Therefore, 5 h was regarded as the optimal time.

According to the above results, the optimal process conditions of the reduction reactions in  $H_4N_2$ · $H_2O$  system were  $H_4N_2$ · $H_2O$  dosage of 0.2133 mol/L, H<sup>+</sup> concentration of 4.305 mol/L, reaction temperature of

85 °C and reaction time of 5 h. Under these optimal conditions, the recovery rates of the valuable metals were 92.07% for Se, 97.81% for Te, 100% for Au, 100% for Pt and 100% for Pd. The compositions of reduction products are listed in Table 5. The mass fractions of Se, Te, Au and Pd were respectively 6.721%, 56.96%, 0.4930% and 0.4409%. The reduction products were costly according to the compositions.

Se	Te	Cu	Au	Pd
6.721	56.96	15.07	0.4930	0.4409

The XRD pattern of reduction products is given in Fig. 7. Only elemental Te and  $Cu_2(NO_3)(OH)_3$  were detected. However, no other mineral phases were identified due to the small amount of them, which was in agreement with the chemical compositions of reduction products shown in Table 5. In reduction process, nitrogen in  $H_4N_2 \cdot H_2O$  was oxidized as  $NO_3^-$ , and reacted with  $Cu^{2+}$  to generate  $Cu_2(NO_3)(OH)_3$ . Hence, copper appears as  $Cu_2(NO_3)(OH)_3$  phase in reduction products.



Fig. 7 XRD pattern of reduction products in  $H_4N_2$   $H_2O$  system

The micro morphology of the reduction products in  $H_4N_2 \cdot H_2O$  system is shown in Fig. 8, it can be seen that the reduction products were columnar type.

### 4.3 Effect of combined reduction system on recovery rates of Se and Te

In order to intensify the recovery rates of Se and Te, HONH<sub>3</sub>Cl was added in the  $H_4N_2 \cdot H_2O$  system. The recovery rates of Se and Te as a function of HONH<sub>3</sub>Cl dosage are given in Fig. 9. The experiments were conducted at  $H_4N_2 \cdot H_2O$  dosage of 0.2133 mol/L, H<sup>+</sup> concentration of 4.305 mol/L, reaction temperature of 85°C and reaction time of 5 h. Figure 9 showed that the recovery rate of Se was significantly affected by HONH<sub>3</sub>Cl dosage. The recovery rates of Se and Te both increased up to 97.59% and 100% respectively when HONH<sub>3</sub>Cl dosage was 1.5116 mol/L. Apparently, the combined system promoted the recovery rates of Se and Te compared with  $H_4N_2$ · $H_2O$  system due to the increase of the reactant concentration in unit volume.



Fig. 8 SEM image of reduction products in  $H_4N_2$ · $H_2O$  system



Fig. 9 Effect of HONH<sub>3</sub>Cl dosage on recovery rates of Se and Te

The main phases of reduction products in combined system were elemental Te and  $Cu_2(NO_3)(OH)_3$  according to XRD analysis as shown in Fig. 10. The phases of the other metals were not identified due to their low content, confirmed by the analysis of chemical compositions of reduction products shown in Table 6. The micro morphology of the reduction products in combined system presented columnar type as shown in Fig. 11. According to the above results, it could be concluded that the characteristic of the reduction products in combined system was in accordance with that of reduction products in H<sub>4</sub>N<sub>2</sub>·H<sub>2</sub>O system.

By taking advantages of both  $H_4N_2 \cdot H_2O$  system and HONH<sub>3</sub>Cl system, high recovery rates of Se and Te up to 97.59% and 100%, respectively, can be obtained using such a combined system which showed prospect for efficient extraction of Se and Te from degoldized solution.

**Table 6** Chemical compositions of reduction products incombined system (mass fraction, %)

Se	Te	Cu	Au	Pd
3.865	72.78	9.82	0.8323	0.4548



Fig. 10 XRD pattern of reduction products in combined system



Fig. 11 SEM image of reduction products in combined system

#### **5** Conclusions

1) The effect of various reductants (namely Zn, Cu, SO<sub>2</sub>, Fe,  $H_4N_2$ · $H_2O$  and HONH<sub>3</sub>Cl) on recovery rates of Se and Te was investigated based on the thermodynamic analysis of various metallic ions in degoldized solution of copper anode slimes. The results indicated that the recovery rates were 71.23% and 76.50% for Se and Te, respectively by using  $H_4N_2$ · $H_2O$ , which was adopted as the reductant for recovering Se and Te from degoldized solution.

2) By optimizing the process parameters of the reduction reaction in  $H_4N_2 \cdot H_2O$  system, the recovery rate of Se reached 92.07% and that of Te was 97.81% under the optimal process conditions of  $H_4N_2 \cdot H_2O$  dosage of 0.2132 mol/L, H<sup>+</sup> concentration of 4.305 mol/L, reaction temperature of 85 °C and reaction time of 5 h. XRD results revealed that the main phases of the reduction products were elemental Te and Cu<sub>2</sub>(NO<sub>3</sub>)(OH)<sub>3</sub>, and the mass fractions of Cu, Se, Te, Au and Pd were 15.07%,

6.721%, 56.96%, 0.4930% and 0.4409%, respectively.

3) By adding HONH<sub>3</sub>Cl into the H<sub>4</sub>N<sub>2</sub>·H<sub>2</sub>O system, the recovery rate of Te reached 100% and that of Se was 97.59% when HONH<sub>3</sub>Cl dosage was 1.5116 mol/L, which demonstrated that the combined system could efficiently extract Se and Te from degoldized solution. The main phases of the reduction products were elemental Te and Cu<sub>2</sub>(NO<sub>3</sub>)(OH)<sub>3</sub>, and the mass fractions of Cu, Se, Te, Au and Pd were 9.82%, 3.865%, 72.78%, 0.8323% and 0.4548% respectively, which was in accordance with H<sub>4</sub>N<sub>2</sub>·H<sub>2</sub>O system.

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### 沉金后液回收硒、碲还原剂的选择

张福元<sup>1,2,3</sup>,郑雅杰<sup>1</sup>,彭国敏<sup>2,3</sup>

1. 中南大学 冶金与环境学院, 长沙 410083;

2. 河南中原黄金冶炼厂有限责任公司, 三门峡 472000;

3. 河南省黄金资源综合利用重点实验室, 三门峡 472000

摘 要: 以某铜阳极泥氯化分金后的沉金后液为原料,研究能从中高效回收硒和碲的还原剂。首先,对沉金后液中有价元素的还原反应进行了热力学分析,在此基础上研究不同还原剂体系对沉金后液中硒和碲回收率的影响; 然后,采用单因素实验研究水合肼还原体系中,各工艺条件对硒和碲回收率的影响;最后,在水合肼还原体系中加入盐酸羟胺来强化对硒和碲的还原效果。结果表明,水合肼对硒和碲均有良好的还原效果,硒和碲的回收率分别为71.23%和76.50%;在水合肼用量为0.2133 mol/L、H<sup>+</sup>浓度为4.305 mol/L、反应温度为85 ℃、还原时间为5h条件下,硒和碲的回收率分别达到92.07%和97.81%;当盐酸羟胺浓度为1.5116mol/L时,硒回收率为97.59%, 碲回收率达到100%。

关键词:沉金后液;水合肼;盐酸羟胺;硒;碲;回收率

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