

Processing technologies for gold-telluride ores

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Abstract: Gold telluride ores are important gold refractory ores due to the presence of sulfides and other gangue materials. The classification and main physical properties of gold telluride ores were described, and possible treatment methods including flotation, leaching, and oxidation were reviewed. The results show that flotation procedures are much easier for gold tellurides compared to other refractory gold-bearing ores. For the conventional cyanide leaching process, pretreatment such as oxidation is required to achieve high gold recovery. Roasting is a relatively simple but not environment-friendly method; bio-oxidation technology seems to be more suitable for the oxidation of flotation concentrate. Other treatment methods involve cyanide leaching, thiourea leaching, ammoniacal thiosulfate leaching, carbon-in-pulp, and resin-in-pulp, all of which are less commonly utilized.

Keywords: gold-tellurides; flotation; leaching; oxidation

1. Introduction

Gold occurs primarily in its native form and secondarily as gold solid-solution of which tellurides are an example [1]. Gold extraction from tellurides has attracted increasing attention over the past decades. Gold tellurides have been commercially treated in Kalgoorlie (Western Australia), Vatukoula (Fiji), Cripple Creek (Colorado), and Kirkland Lake (Ontario). The first modern treatment of gold-telluride ores was performed in 1891 in the Cripple Creek goldfield near the Rocky Mountains in Colorado. Kalgoorlie, in Western Australia, had the honor of being the second major goldfield, and tellurides were successfully processed to extract gold. In a modern gold processing plant, the recovery can be up to 98% with the aid of the latest concentration and smelting techniques. A successful gold recovery strategy relies on a fundamental understanding of the ore mineralogy and its chemical/physical behaviors under various leach, flotation, and oxidation conditions. An overview of the processing techniques/options for gold telluride ores was given and their advantages and limitations were discussed in this paper.

2. Classification of gold-telluride ores

It was well known that gold was commonly associated with tellurium minerals. The cooccurrence of tellurium with noble metals such as gold and silver was attributed to the semi-metallic nature of tellurium. The composition varied significantly from different tellurium minerals. For instance, gold-telluride ores could be classified into six mineral groups: calaverite (AuTe_2), sylvanite [$(\text{Ag,Au})_2\text{Te}_4$], montbrayite [$(\text{AuSb})_2\text{Te}_3$], krennerite [$(\text{Au}_{1-x}\text{Ag}_x)\text{Te}_2$], petzite (Ag_3AuTe_2), and muthmannite [$(\text{Ag,Au})\text{Te}_2$].

The physical properties and deposit location of these six minerals are tabulated in Table 1. Among them, Calaverite was the simplest and most common association of tellurium with gold. It was also the most common gold bearing mineral apart from native gold.

3. Processing options

Unlike free gold, gold tellurides do not undergo rapid dissolution in the conventional alkaline cyanide leach solution. Therefore, alternative treatments must be applied to

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break down the gold-telluride structure and release free gold. The general processing methods are: oxidation, flotation, and leaching.

3.1. Oxidation

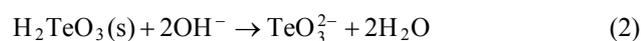
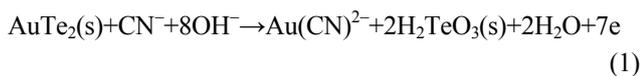
Generally, gold ores can be classified into two categories: the 'free milling' and 'refractory' ores. Free milling ores are those that require only conventional physical pre-treatment, such as grinding and sulfide flotation, to liberate the free

gold and obtain a concentrate for further cyanidation. Refractory ores, however, require fine grinding and a further pre-treatment step, such as roasting and pressure oxidation, to render the gold ores amenable to extraction. Usually, gold telluride ores appear to be refractory as they are always associated with pyrite and other sulfides. This would 'lock' the gold and give rise to elevated cyanide consumption. For this reason, oxidative pre-treatments are generally conducted to improve gold recoveries.

Table 1. Physical properties and deposit location of main gold-telluride minerals [2]

Mineral	Formula	Colour	Specific gravity	Mohs hardness scale	Location
Calaverite	AuTe ₂	Silver white to brassy yellow	9.10-9.30	2.5-3.0	Cripple Creek (USA); Nagyag (Romania); Kirkland Lake Gold District and Rouyn District (Canada); Kalgoorlie (Australia).
Sylvanite	(AgAu)Te ₂	Steely gray to silver gray	8.20	1.5-2.0	Cripple Creek (USA); Nagyag (Romania); Bigstone Bay and Kirkland Lake Gold District (Canada); Kalgoorlie (Australia), Vahatala (Fiji).
Montbrayite	(AuSb) ₂ Te ₃	Creamy white to yellowish white	9.94	2.5	Robb-Montbray (Canada); Enasen (Sweden); Changjin (China); Voronezhsky Massif (Russia).
Krennerite	(Au _{1-x} Ag _x)Te ₂	Silver white to blackish yellow	8.53	2.5	Sacărămb, Nagyag, and Szekerembe (Romania).
Petzite	Ag ₃ AuTe ₂	Bright steel gray to iron black	8.70-9.14	2.5	Kalgoorlie (Australia); Viti Levu (Fiji).
Muthmannite	(Ag,Au)Te ₂	Pale bronze	11.04	2.5	Sacărămb (Romania).

The presence of gold telluride minerals may render an ore refractory, the extent of this depends on the telluride mineral present and the mineralogical association [3]. Gold, silver, and gold/silver-telluride minerals in ores dissolve more slowly than native gold in cyanide solutions, which results in less efficient gold extraction [4]. Similarly, cyanide leaching tests on synthetic calaverite (AuTe₂) and sylvanite (AuAg)Te₂ result in lower gold recoveries [5]. Jayasekera *et al.* [6] studied the dissolution of calaverite electrochemically in both acidic and alkaline media. It showed that the slow dissolution rate in alkaline cyanide solutions was due to the formation of a passivating film of H₂TeO₃ that protected the mineral surface from further oxidation (see Eqs. (1) and (2)), and this film dissolved at higher pH.



Major gold deposits containing tellurides occur in Colorado (USA), Vatukoula (Fiji), and Kalgoorlie (Western Australia). As mentioned above, fine grinding, the extension of leach residence time or the excessive addition of lime has

been used to overcome the refractory nature of tellurides. These methods can possibly enhance the recovery of gold, however, the consumption of reagents and energy should be taken into account. The current practice at Kalgoorlie Consolidated Gold Mines Pty Ltd. (KCGM) is to produce a sulfide-telluride concentrate that is fluid-bed roasted. The resulting calcine is leached with cyanide and the gold is recovered by the carbon-in-pulp (CIP) process [7]. A few chemical oxidative pre-treatments have been investigated to improve gold recoveries, including bromocyanidation, leaching with thiourea, and pressure cyanidation. However, these pre-treatments have not been developed to commercial application.

3.1.1. Roasting

Roasting is the simplest and most frequently used oxidative process. Roasting consists of heating the ores/concentrates below the fusion point in contact with air, oxygen, water vapor, carbon, sulfur, or chlorine. This aims to produce the desired chemical and/or physical change that will be beneficial to downstream processing for the recovery of the metal [8]. Roasting may be realized through one of the following processes: oxidizing roast, volatilizing roast, chloriding roast, sulfatizing roast, magnetizing roast, reduc-

ing roast, carburizing roast, and sintering or blast roasting. The high temperature can sufficiently decompose the tellurides and leave behind the valuable gold residue.

One concern with the procedure is that during oxidation roasting, pyrite and other sulfide minerals will emit poisonous gas such as SO₂. For example,



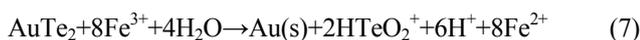
A further issue is that a considerable amount of gold may deposit on the internal wall and other parts of a roaster, and this gold can only be collected when the roaster is shut down [9]. These two factors are the primary concerns when roasting gold telluride ores.

3.1.2. Bio-oxidation

A more promising method of gold telluride pre-treatment is bio-oxidation. As an alternative pre-treatment to roasting for refractory gold concentrates, its advantage lies in the elimination of toxic gaseous emissions. It simply uses the capability of acidophilic chemolithotrophic bacteria to oxidize pyrite and arsenopyrite and release the gold or gold telluride trapped within their grains. The gold can then be complexed by cyanide in an oxidizing, alkaline environment (see Eqs. (4) and (5)), and extracted/recovered by the carbon-in-leach (CIL) or carbon-in-pulp (CIP) technology.



Climo *et al.* [10] investigated the bio-oxidation of a pyritic refractory gold concentrate, in which some of the gold occurred as gold telluride (calaverite). The chemical and bio-oxidative pre-treatments of the concentrate under different conditions were compared. The mechanism is illustrated in Eqs. (6) and (7). It was found that the mechanism of oxidation was an indirect one, in which the role of bacteria was to regenerate the ferric which consumed during the oxidation of telluride.



This was further proven [10] by leaching the synthetic (iron-free) calaverite sample with a mixture of bacteria (*Thiobacillus ferrooxidans*, *T. thiooxidans*, *T. caldus*, and *Leptospirillum ferrooxidans*) in an iron-free medium; no direct oxidation was observed. It also showed that bacteria did not oxidize calaverite directly in an iron-free medium. The bacteria oxidized Fe²⁺ into Fe³⁺, and ferric ions (Fe³⁺) oxidized telluride. The gold (Au⁰) was left during the oxida-

tion process.

Bio-oxidation of refractory gold ores in heaps [11] and of flotation concentrates in stirred reactors [12] are proven technologies applied all over the world on a commercial scale, while in Australia, three bio-oxidation plants have been operated successfully: Harbour Lights (1992-1994), Youanmi (1994-1997), and Wiluna (1993-current). All the three are in Western Australia. Three further plants are planned or under construction, at Beaconsfield Gold Mine (Tasmania), Perseverance Gold Mine (Victoria), and Maud Creek (Northern Territory) [9].

3.2. Flotation

Gold tellurides float well [13-15], however, their recoveries are likely to be compromised by the presence of soluble heavy-metal salts [16]. These soluble salts can increase the hydrophilicity of the mineral surface and result in a decrease in floatability. Collectors such as xanthates or 2-mercaptobenzothiazole (MBT) are frequently used to improve the recovery and flotation kinetics of telluride minerals. Similar rates of flotation for different tellurides were obtained when potassium amyl xanthate (PAX) was used as the collector [15]. It should be noted that the overall recovery of gold is not only determined by the collectors used, but also the modifiers (*e.g.* lime) employed [16].

A classic example of an integrated telluride-flotation circuit is the Emperor Mine in Fiji, where telluride minerals were selectively floated in the 1970s and 1980s [17]. The telluride flotation was conducted in a standard rougher, cleaner, and recleaner circuit. As shown in Fig. 1, the rougher is in the condition that the feed for this circuit is new feed and cleaner tailings; the cleaner is in the condition that the feed for this circuit is rougher concentrate and recleaner tailings; and the recleaner is in the condition that the feed is cleaner concentrate. Lime was added to depress the flotation of sulfide minerals [14]. A small amount of frother polyoxypolyene glycol ether (ICI Teric 407) was introduced at a rate of 0.03 kg/t to the flotation circuit at pH 9 [15]. The resulting telluride concentrate was collected after adding a small amount of sodium silicate as a gangue slime depressant. Soda ash was added to the flotation tailings as the pH regulator to maintain pH at 9.5 prior to conditioning the slurry with xanthate and frother. Sulfide concentrate was then floated and reground before cleaning. Usually the cleaned concentrate was roasted before the cyanide-leaching circuit to remove pyrite and other sulfides, which might otherwise have caused high consumption of cyanide.

In Ref. [13], Smith reported that tellurides could be pref-

entially floated in reference to sulfides in the absence of collectors. Only copper sulfate and frother (Aerofroth 65) were used in his tests. It was also concluded by Smith [18] that the telluride concentrate grade could be further improved by introducing an additional stage of cleaning. The experiments provided the evidence of the intrinsic floatability of tellurides, which could be further enhanced if the flotation were performed in a slightly acidic medium.

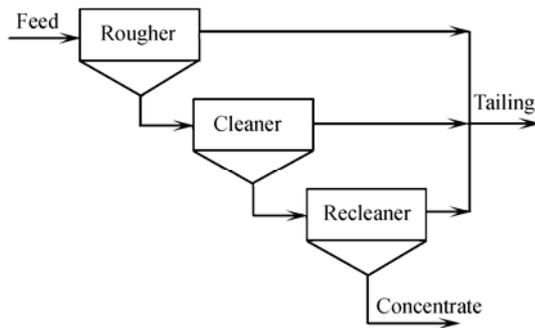


Fig. 1. A simplified flowsheet of telluride flotation in Emperor Mine in Fiji.

This method was further explored by Yan and Hariyasa [15] who studied the flotation of tellurides in the North Kalgoorlie samples. The effects of collector type and pH on the recovery were studied. Fig. 2 shows that the telluride floats in the absence of a collector at pH 8, therefore, the rate is slow and the maximum recovery is only around 74%. However, under the same conditions, the recovery of gold can be up to 88% by using frother (Teric 401) only. There are significant increases in gold recovery by introducing some collectors. Preferred collectors are sodium ethyl xanthate (SEX), potassium amyl xanthate (PAX), and AP 407. Other collectors, AF211, AF208, AP 407, and AP 3477 result in the reduction in gold recoveries and flotation rate. The impact of pH on the recovery of telluride varies for each of the collectors used. Typical curves showing the infinite recovery of tellurium vs. pH are shown in Fig. 3. The pH value has little effect on the infinite tellurium recovery when PAX was used as the collector, but when AF 211 was used as the collector, the final tellurium recovery decreases dramatically in the pH range 8-11. The relevant collectors and frothers are tabulated in Table 2.

3.3. Leaching

3.3.1. Cyanide leach

Leaching is a process that dissolves valuable metals contained in ores into solutions. The cyanide leach is commonly employed in the treatment of gold ores. The cyanidation reaction of gold is as follows:



While the rich gold telluride ores can be treated directly in this manner, the leaching process cannot be carried out with ease for low grade telluride ores. In general, only 80% of the gold can be extracted without pretreatment. However, following bacterial oxidation pretreatment, 98% of the gold may be amenable to cyanide extraction [10].

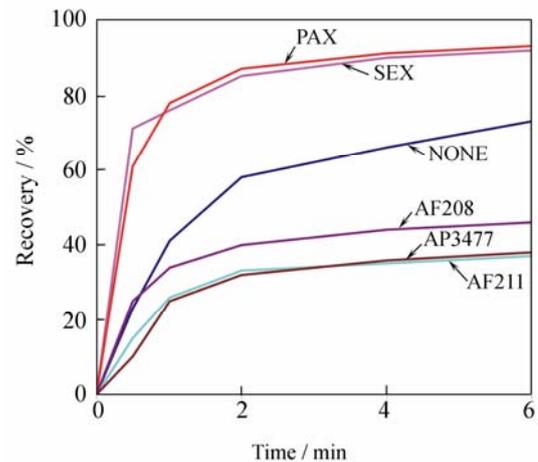


Fig. 2. Effect of collector type on the time-recovery curve for tellurium flotation in the conditions of 50 g/t collector, 20 g/t Teric 401, 100 g/t copper sulfate, and pH 8.0 [15].

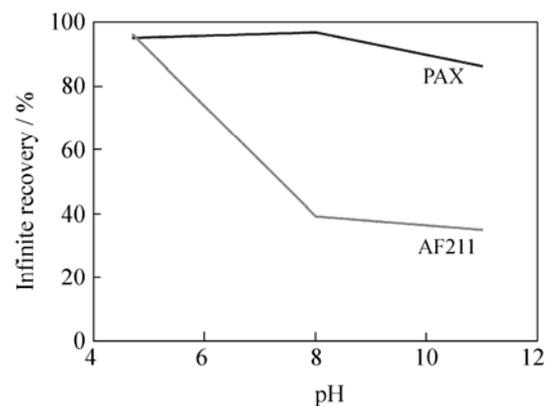
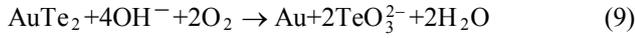


Fig. 3. Effect of pH on the infinite recovery of tellurium in the conditions of 50 g/t collector (PAX or AF211), 20 g/t Teric 401, 100 g/t copper sulphate [15].

The direct leaching of telluride ores has long been problematic for researchers and operators to seek a means of recovering gold by cyanide leaching of gold-telluride ores without any oxidative pre-treatment. Some gold-bearing minerals such as the sulfides (containing Cu, Fe, and Sb) will enter the solution and consume cyanide. Usually, the purpose of pre-oxidation is to eliminate such factors that may result in extra consumption of cyanide. In an alkaline

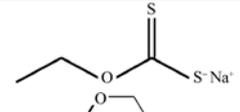
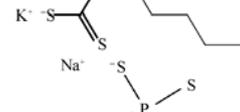
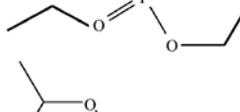
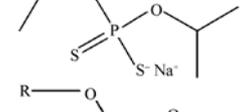
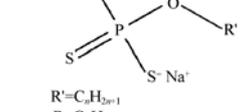
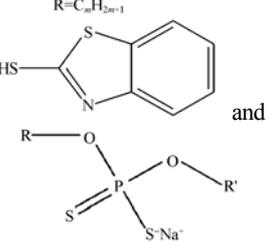
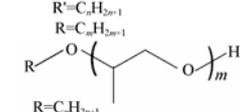
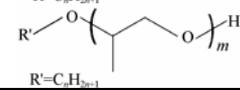
cyanide solution, the gold telluride is leached *via* the following reactions, which involve the formation of tellurite ions or tellurate ions.



Ellis provided a very detailed plant cyanide leaching process for gold telluride minerals. About 23% of the gold in a KCGM concentrate was gold tellurides, mainly calaverite (AuTe_2) with small amounts of petzite (Ag_3AuTe_2) [4]. Ellis [19] introduced an extra oxidative step using hypochlorite leaching immediately after leaching with 0.1wt% NaCN at a pH value of 9.2 for 24 h. Lime was used to adjust pH, and the leaching conditions were changed to a lower

cyanide concentration. According to the report, several repeated oxidation steps were needed for particle sizes larger than 10 μm . Pleysier *et al.* [20] also examined the leaching process of gold telluride ores from a KCGM flotation concentrate sample. The leaching process was affected by the presence of sulfides, which appeared to cause precipitation of free tellurium from the solution. Once tellurium precipitated out, it would cover the surface of the mineral particles, and it was hard to redissolve due to the difficulty in breaking the strong Te–Te bonds. It was much easier to dissolve the gold telluride after oxidation, as this process involved the breakage of weaker Au–Te bonds. Tellurium precipitation was thus generally detrimental to cyanide leaching processes and hindered the dissolution ratio of gold, if it occurred before dissolution of the gold was complete.

Table 2. Collectors and frothers commonly used for telluride flotation

Name	Use	Chemical name	Formula	Manufacturer
SEX	Collector	Sodium ethyl xanthate		Qingdao L.T. Chemical Co., Ltd.
PAX	Collector	Potassium amyl xanthate		Qingdao L.T. Chemical Co., Ltd.
AF 208	Collector	Sodium diethyl dithiophosphate/sodium di-secondary butyl dithiophosphate		American Cyanamid Co.
AF 211	Collector	Sodium diisopropyl dithiophosphate		American Cyanamid Co.
AP 3477	Collector	Dithiophosphate type		American Cyanamid Co.
AP 407	Collector	Mercaptobenzothiazol and aerofloat promoter		American Cyanamid Co.
Teric 401	Frother	Polyoxypropylene glycol ether		ICI Australia Pty, Ltd.
Teric 407	Frother	Polyoxypropylene glycol ether		ICI Australia Pty, Ltd.

The gold-bearing telluride at Emperor (Fiji) is mainly montbrayite (AuTe_3). Its treatment includes flotation, oxida-

tion (with alkaline calcium hypochlorite), and cyanidation [21]. In another example, fine grinding, longer leach time,

and/or adding excessive lime have been used to improve the gold recoveries from tellurides [22]. In Cripple Creek, Colorado, free micron-sized gold particles are generally associated with pyrite and its oxidation products. Gold also exists as tellurides in this region, mainly calaverite, with lesser amounts of krennerite—(Au,Ag)Te₂, sylvanite—(AuAg)Te₂, and petzite—Ag₃AuTe₂ [23]. This type of ore can be treated using similar pretreatment; however, it was noted that this deposit was also amenable to direct treatment by the CIP process [10].

Theoretical studies of the cyanide leaching of gold tellurides have made significant progress over recent decades. Early studies focused on the removal of polysulfides and ionic tellurium species from solution to reduce undesired precipitation of element tellurium [9]. The utilization of lead salts is beneficial for the removal of polysulfides. It is believed that lead nitrate can react with gold to produce AuPb₂, AuPb₃, and metallic lead. This dramatically speeds up the gold dissolution in a cyanide solution [24].

Deschenes *et al.* [25] investigated the influence of mineral composition on the cyanidation of sulfide ores. They used lead nitrate and oxygen to alleviate the detrimental impact of sulfides on gold ores. It was found that lead nitrate was detrimental to cyanide leaching if it was not administered properly; it was capable of inhibiting the gold dissolution and increasing the cyanide consumption. It was believed that lead nitrate could prevent the passivation of the gold surface and stabilize metallic sulfide dissolution by the passivation of the particle surface [25-26]. Calaverite is usually characterized by its exceedingly slow dissolution rate in cyanide solution. Deschenes *et al.* [27] suggested that high lime concentration with the addition of lead nitrate and the injection of oxygen would improve the leaching rate. This was further verified in experiments using KCGM gold flotation concentrates [28]. It was found that under the above conditions, the cyanide consumption could be reduced from 15 kg/t to 3.5-4.0 kg/t.

Fig. 4 shows that increased oxygen aeration does not improve leaching kinetics, and the final gold recovery is almost the same (about 95%). In addition, the increase in oxygen injection results in slightly higher cyanide consumption [25].

The effects of lime concentration and lead nitrate concentration on the leaching rate are shown in Figs. 5 and 6, respectively. Obviously, the use of high lime concentration is necessary to achieve a high leaching rate. It is also found that the higher lead nitrate concentration only slightly im-

proves the leaching rate. This result seems to disagree with the findings of Deschenes *et al.* [26] who concluded that lead nitrate has a significant impact on the initial leaching rate of a gold ore containing both tellurides and sulfides [26]. They proposed that the interaction of very fine particles with plenty of oxygen in the pulp prevented the lead from eliminating the negative effect of the dissolution of sulfide [27].

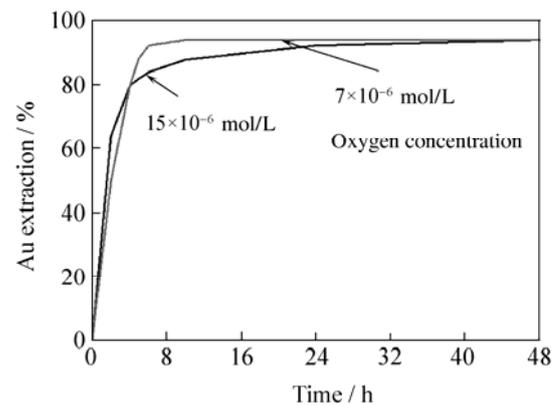


Fig. 4. Effect of oxygen concentrations on the gold leaching of a low sulfide-bearing gold ore (cyanidation: pH 11.1, 550 mg/L NaCN, 48 h).

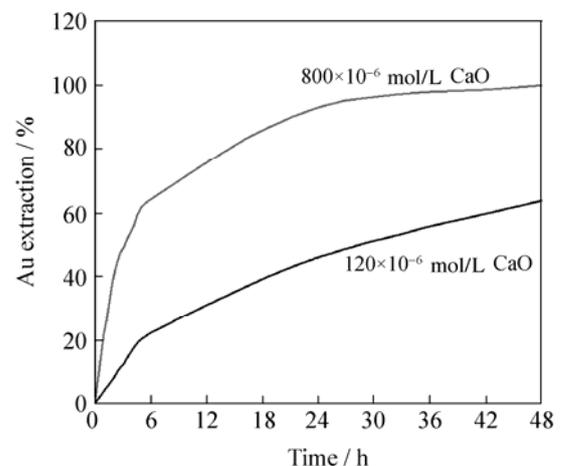


Fig. 5. Effect of lime concentration on the leaching kinetics of calaverite (8×10^{-6} mol/L O₂; 500 mg/L NaCN; 500 g/t lead nitrate; AuTe₂: 57 g/t; 10 μ m powder) [28].

3.3.2. Thiourea leach

Thiourea (SC(NH₂)₂) is an organic compound that can be dissolved in water to form a stable aqueous species, which can react with gold (I) to produce a complex in acidic solutions [29]. Thiourea leaching possesses numerous advantages over the cyanidation process, especially in achieving higher leaching rates and being less affected by the presence of some species that can inhibit cyanidation [30]. Under acidic conditions, thiourea decomposes to formamidine

disulfide, while gold complexes with two thiourea molecules, forming $\text{Au}(\text{SC}(\text{NH}_2)_2)_2$ [31].

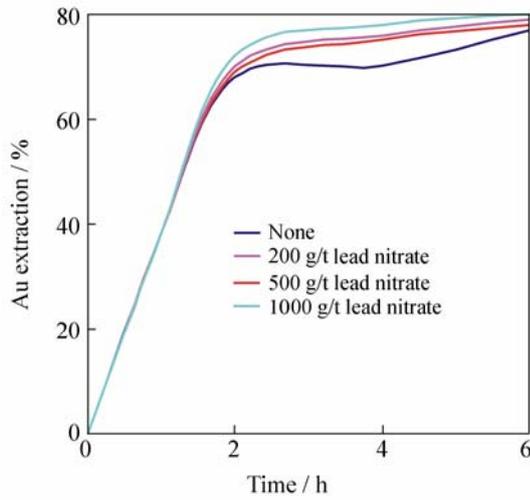
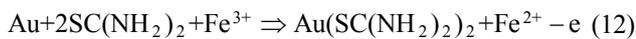


Fig. 6. Effect of lead nitrate concentration on cyanidation of the Fimiston concentrate (pretreatment: 30 h, 0.14 L/min air; CaO: 20 kg/t; cyanidation-CaO: 1.2 g/L, 10×10^{-6} mol/L O_2 ; NaCN: 4-7 g/L; carbon: 15 g/L) [28].

An advantage of thiourea leach lies in its suitability for the treatment of refractory gold-bearing ores in acidic media. As described earlier, refractory telluride ores generally require oxidative pretreatment prior to leaching. A bio-oxidative pretreatment is frequently used for this purpose, and it is commonly performed in highly acidic solutions. However, the cyanidation process is generally carried out in alkaline conditions. In this case, an intermediate neutralization step must be introduced to adjust the pH prior to cyanide leaching [30]. Thiourea leaching can be carried out in acidic conditions, so concentrates can be treated directly following bio-oxidation [32].

To obtain higher leaching rates, an oxidative leaching environment is required [32], and the oxidative reagent (ferric ion or hydrogen peroxide) is also able to oxidize thiourea. The oxidation product, formamidine disulfide, can serve as an active oxidant as well, by way of the reverse reaction as shown in Eq. (11). The thiourea leach of gold in acid thiourea-ferric sulfate solution is shown in Eq. (12) [33].

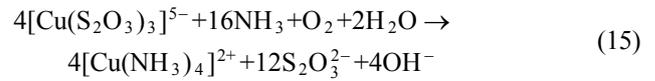
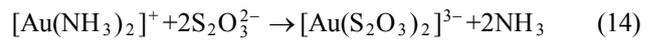
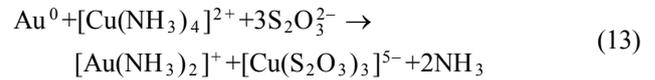


3.3.3. Ammoniacal thiosulfate leach

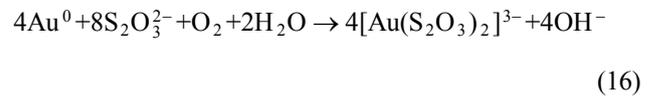
Another leaching method for telluride ores is ammoniacal thiosulfate leach. In comparison with conventional cyanide leach techniques, the merits of this technology include lower

environmental pollution, lower costs, greater efficiency, and more effective lixiviant of thiosulfate anion [34]. Ammoniacal thiosulfate leach seems to be less affected than cyanidation by the contamination of other cations [36], thiosulfate leaching can be used to treat tellurides containing high levels of carbonaceous content in contrast to cyanide leaching [35]. Its drawback is the utilization of volatile and toxic ammonia [34]. Nonetheless, this method is of interest to metallurgists worldwide in spite of its complex and unclear mechanism.

Although gold tellurides can dissolve in a thiosulfate solution, their dissolution rate is very slow, so a common approach is to roast gold tellurides prior to the ammoniacal thiosulfate leach, which reduces the gold tellurides to metallic gold and makes them more amenable to a thiosulfate leach. The main reaction equations are as follows [34].



The overall reactions:



The primary role of ammonia in the thiosulfate solution is to stabilize Cu(II) [35] and also to prevent the dissolution of iron oxides, silica, silicates, and carbonates, which are the main gangue minerals in gold bearing ores [37]. The main purpose of copper ions in thiosulfate leach solutions is to increase the gold dissolution rate. Oxygen and/or some other oxidants are employed specifically to oxidize copper (I) into copper (II) for further gold leaching [35].

Aylmore [36] used the thiosulfate leaching method to treat gold tellurides, and leached the concentrate with a solution containing 0.8 M $\text{S}_2\text{O}_3^{2-}$, 0.05 M Cu^{2+} , and 4 M NH_3 , which resulted in over 90% gold recovery. Pretreatments such as ultrafine milling and roasting before thiosulfate leach were able to further increase the gold recovery. The optimum leach time was less than 24 h, beyond which the previously dissolved gold would start to precipitate.

3.4. CIP and resin-in-pulp (RIP) processes

CIP and RIP are considered downstream processes to pu-

rify the gold leach solution. They share similar extraction mechanisms, relying on a physical adsorption process and associated recycling of the carbon or resin.

Generally, a counter current decantation (CCD) unit is needed to separate the gold solution from the solid tails after gold tellurides are leached. The gold will then be recovered from the pregnant solution by solvent extraction or electro-winning. The “bottleneck” in this series of stages is the CCD solid-liquid separation step.

The main advantage of CIP and RIP is to use carbon and

resin to capture gold directly from the leach slurry without going through the time-consuming solid-liquid separation stage, which reduces the overall processing time.

The CIP/RIP extraction mechanism is outlined in Fig. 7. The carbon or resin absorbs gold-cyanide complex ions from the leach slurry (pulp) until it reaches the maximum loading capacity. Carbon or resin particles are generally larger than ore particles, so they can be easily separated from the slurry by screening. The carbon or resin, after being stripped of gold, can be reused in the adsorption circuit.

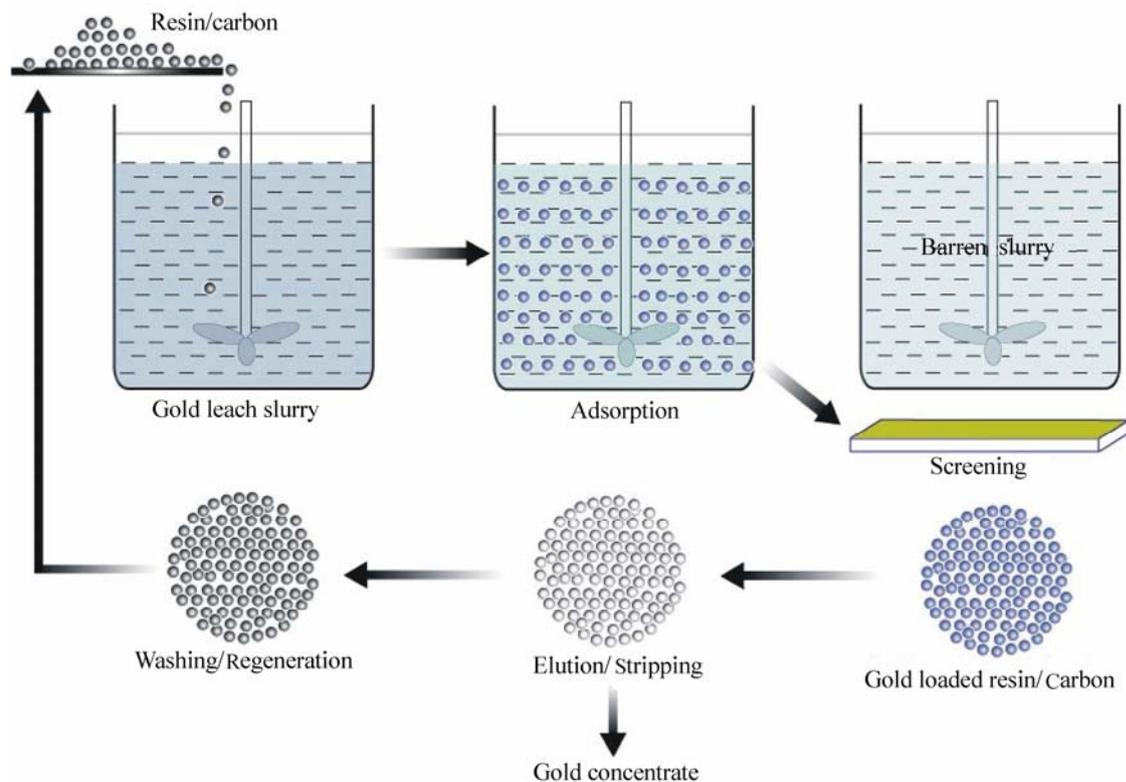


Fig. 7. A simplified schematic presentation of the CIP/RIP process.

For CIP, granular activated carbon is introduced into the solution and stirred with the pulp in a series of 5-7 tanks [38]. Absorbed gold cyanide is eluted with a sodium cyanide (0.1wt%-0.2wt%) and sodium hydroxide (1wt%) solution. Certain organic solvents (*e.g.* alcohols) are frequently employed to increase the elution rate. Subsequently, the granular carbon is reactivated in a kiln (at 600-900°C), cooled down and fed back to the pulp [38]. The trace gold resident in the carbon has little impact on the whole process. For RIP, the recycle process of resin is quite different from that of carbon, due to the dissimilarity of their thermal properties. Resin regeneration requires a chemical reagent to allow the co-occurrence of resin elution and regeneration steps [34]. While adsorption on carbon is non-selective, polymeric res-

ins bearing functional groups are capable of selectively absorbing a specific ion or complex [34].

The two resins, Aurix (from Henkel Australia, bearing guanidine moieties) and Minix (from Minitex of South Africa, bearing tributylammonium groups) are generally used for gold recovery from cyanide solutions [34, 39-40].

4. Concluding remarks

Gold tellurides exist only in a few places worldwide, and relevant research on their treatment is limited. Tellurides possess intrinsic floatability, so the presence of sulfides makes it difficult to separate the tellurides from sulfides. These problems can be solved *via* a flotation step with a proper collector, frother, and a pH regulator prior to telluride

leaching. Some low grade gold telluride ores need to be oxidized prior to cyanide leaching to reduce the consumption of cyanide. The successful development of bio-oxidation as a pre-treatment for gold telluride ores containing sulfides has led to the commercial implementation of bio-oxidation pre-treatments for telluride ores. It is believed that the bio-oxidation mechanism involves a rapid and continuous oxidation of ferrous ions to ferric ions, while the tellurium remains unaffected by the bacteria. The oxidation of telluride is attributed to the ferric ions produced by this bacteria-promoted oxidation reaction. Some other treatments (such as CIP, RIP, thiourea leaching, and ammoniacal thiosulfate leaching) can serve as useful supplementary methods for treating gold telluride ores.

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