



# Impact of silver sulphides on gold cyanidation with polymetal sulphides



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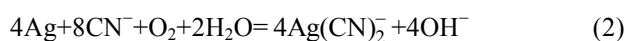
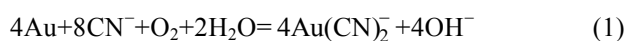
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**Abstract:** Gold leaching was influenced in association with silver and polymetal sulphide minerals. A packed bed was adopted to single out the galvanic and passivation effects with four sets of minerals: pyrite–silica, chalcopyrite–silica, sphalerite–silica and stibnite–silica. Pyrrargyrite enhanced Au recovery to 77.3% and 51.2% under galvanic and passivation effects from pyrite (vs 74.6% and 15.8%). Pyrrargyrite in association with sphalerite also enhanced Au recovery to 6.6% and 51.9% (vs 1.6% and 15.6%) under galvanic and passivation effects from sphalerite. Pyrrargyrite associated with chalcopyrite retarded gold recovery to 38.0% and 12.1% (vs 57% and 14.1%) under galvanic and passivation effects. Accumulative silver minerals enhanced Au recovery to 90.6% and 81.1% (vs 74.6% and 15.8%) under galvanic and passivation impacts from pyrite. Silver minerals with sphalerite under galvanic and passivation effects enhanced Au recovery to 71.1% and 80.5% (vs 1.6% and 15.6%). Silver minerals associated with chalcopyrite retarded Au recovery to 10.2% and 4.5% under galvanic and passivation impacts (vs 57% and 14.1%). Stibnite retarded Au dissolution with pyrrargyrite and accumulative silver minerals. Pyrrargyrite and accumulative silver enhanced gold dissolution for free gold and gold associated with pyrite and sphalerite. Gold dissolution was retarded for gold and silver minerals associated with chalcopyrite and stibnite.

**Key words:** silver mineral; gold cyanidation; packed-bed reactor; sulphide mineral; passivation; galvanic interaction

## 1 Introduction

Gold leaching in aerated alkaline cyanide slurry has been selected as process route in gold industries for more than hundred years. Efforts have been made to improve gold recovery in the cyanide leaching process which include the optimization of reagents addition, such as cyanide/dissolved oxygen concentration, particle size reduction of the ore and significant control of the operational parameters of the cyanidation process [1–3]. Silver is frequently associated with gold, so during cyanidation process, cyanide and oxygen consumption by the dissolution reactions of gold and silver, are described by Eqs. (1) and (2):



Conductive sulphide minerals comprise a large proportion of gold containing ores, and the effects of these minerals on gold dissolution in aerated cyanide solutions have drawn the interest of many researchers. Earlier studies on the dissolution of gold in cyanide

solutions in the presence of sulphide minerals demonstrated that base-metal components, such as copper, iron and zinc, of the sulphide minerals, not only increase significantly the consumption of both cyanide and oxygen, but also have a strong impact on gold leaching kinetics [4–7]. A systematic study was conducted on the kinetics of gold dissolution in the presence of various sulphide minerals, such as pyrite, chalcopyrite, pyrrhotite, arsenopyrite, sphalerite, chalcocite and stibnite, in both air-saturated as well as oxygen-enriched systems. The results demonstrated that the leaching kinetics as well as overall recovery of gold in the presence of polymetal sulphide minerals strongly depends on both the solubility of the sulphide minerals and the cyanide and dissolved oxygen concentration in the solution. Pyrite, chalcopyrite, pyrrhotite and arsenopyrite were found to increase the gold dissolution rate, in an air-enriched as well as oxygen-enriched cyanide solution, while sphalerite, stibnite and chalcocite caused a reduction in the gold dissolution rate [4,5,8–10]. Sulphide minerals are soluble in aerated cyanide solutions to some extent, therefore some sulfur species will be present in the leaching solution as a result of

sulphide minerals dissolution. The presence of such species not only results in high reagent consumption but also affects the kinetics and recovery of gold leaching reaction. It was observed that by the addition of trace amounts of sodium sulphide to the cyanide solution, gold leaching was hindered dramatically, which was attributed to the formation of a  $\text{Au}_2\text{S}$  passive layer on the gold surface. Strategies like pre-oxidation and lead nitrate ( $\text{Pb}(\text{NO}_3)_2$ ) have been adopted to minimize the effect of sulphide ions [5,11–13].

Gold is often associated with silver, and there are numerous gold deposits where the recovered silver grade exceeds that of gold. Metallic silver dissolves anodically in aqueous cyanide solutions, in a similar manner to gold (Eq. (2)). As far as the leaching kinetics is concerned, metallic silver has been found to dissolve faster than gold [9,14–16]. The presence of silver, in metallic form, alloyed with gold or in dissolved form, has a beneficial effect on gold leaching kinetics. In leaching reaction mechanisms, silver has a de-passivating effect on gold cyanidation via a bimetallic corrosion, which is hindered by the formation of a  $\text{AuCN}(\text{s})$  film on the gold surface [2,5,9,17,18]. Under typical cyanidation conditions prevailing in gold leaching, the dissolution rate for silver is usually slower than that for gold. This is because, although silver species, such as native silver, chlorargyrite ( $\text{AgCl}$ ), and iodargyrite ( $\text{AgI}$ ), are found in nature and dissolve readily in cyanide, much more common are the less soluble silver minerals [14]. Silver is frequently associated with polymetal sulphides and sulfosalts, the most significant sulphide phase is known as acanthite ( $\text{Ag}_2\text{S}$ ), while other silver minerals include pyrargyrite ( $\text{Ag}_3\text{SbS}_3$ ), proustite ( $\text{Ag}_3\text{AsS}_3$ ), aguilarite ( $\text{Ag}_4\text{SeS}$ ), tennantite  $\text{Cu}_6(\text{Cu}_4(\text{Fe,Zn})_2)\text{As}_4\text{S}_{13}$  and tetrahedrite  $(\text{Cu,Fe,Ag,Zn})_{12}\text{Sb}_4\text{S}_{13}$  with silver inclusions. As far as the dissolution of these silver minerals is concerned, acanthite tends to dissolve slowly and requires an excess of cyanide, while the other sulfosalts are even more refractory in nature with aerated cyanide solution. The sulphide ion that must be oxidized to release the ionic silver, is known to be the principal cause of refractoriness of the silver sulphide and sulfosalt minerals. This phenomenon differentiates the leaching reaction mechanism of silver sulphides and sulfosalts from those involved in metallic phase leaching [10,16,19–22].

Despite plenty of information available on the kinetics of gold dissolution with silver present in native, alloyed and/or dissolved forms, there are not many studies regarding the effect of prominent silver minerals under separate or accumulative impact and in association with sulphide minerals. A comprehensive study would lead to proper understanding of the effect of prominent silver minerals, such as pyrargyrite ( $\text{Ag}_3\text{SbS}_3$ ) and also

the accumulative effect of native silver ( $\text{Ag}$ ), acanthite ( $\text{Ag}_2\text{S}$ ) and pyrargyrite ( $\text{Ag}_3\text{SbS}_3$ ) on the kinetics of Au dissolution as well as the overall recovery for high silver bearing gold ores. In this work, the manner in which the presence of various silver phases and soluble silver affects gold leaching in free state as well as gold associated with sulphide minerals under galvanic and passivation effects was studied. The case with which the silver metal itself is leached from its bearing mineral species while present within silica and sulphide mineral matrices under direct and indirect impact was analyzed.

## 2 Experimental

### 2.1 Materials and reagents

The sulphide-rich ore samples: pyrite (Py), chalcopyrite (Cp), sphalerite (Sp) and stibnite (Sb), depending upon the dominant proportion of the named sulphide mineral therein, tested in this study, were received from Ward's Natural Science. The chemical as well as mineralogical characterizations of these samples have been given elsewhere [9].

The samples were ground and sorted to remove particles coarser than  $106\ \mu\text{m}$  and finer than  $53\ \mu\text{m}$ . Consequently, the same granulometric fraction was used for the different ores, providing a uniform total area per unit-mass for all the cyanidation experiments. Pure gold ( $P_{80}=39\ \mu\text{m}$ , 99.998%), pure silver ( $P_{80}=26\ \mu\text{m}$ , 99.9%, Alfa Aesar, USA), pure silver sulphide (99.9% metals basis, Alfa Aesar, USA) and pyrargyrite mineral (Mineralogical Research Co.), were used in the present study. Solution used in all cyanidation experiments was prepared with distilled water. The reagents such as, sodium cyanide,  $\text{NaCN}$  (98%, Sigma-Aldrich, Canada), sodium hydroxide,  $\text{NaOH}$  (Fisher Scientific, Canada) and boric acid,  $\text{H}_3\text{BO}_3$  (99.5%, Sigma-Aldrich, Canada), used in the present study, were all certified analytical grade.

### 2.2 Equipment and procedures

In the present study, two scenarios were taken into account. Firstly, the effect of pyrargyrite ( $\text{Ag}_3\text{SbS}_3$ ) on gold dissolution was addressed in combination with sulphide minerals. Two arrangements for each sulphide mineral ( $X=\text{Py}$ , Cp, Sp, Sb) were tested in a packed-bed reactor (PBR) using one of the X powders, both the gold and pyrargyrite mineral dispersed within the sulphidic mineral (X), as well as silica layer (Fig. 1). Secondly, the accumulative impact of the prominent silver minerals such as, metallic silver ( $\text{Ag}$ ), acanthite ( $\text{Ag}_2\text{S}$ ) and pyrargyrite ( $\text{Ag}_3\text{SbS}_3$ ), on gold leaching behaviour under direct as well indirect contact with the sulphidic (X) minerals was taken into account as well. The notations  $\alpha$ ,

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