

ENHANCING GOLD EXTRACTION FROM COPPER BEARING ORES^①

Deng, Tong Ma, Yun
*Institute of Chemical Metallurgy,
Chinese Academy of Sciences, Beijing 100080*

ABSTRACT Ammoniacal cyanidation of a copper bearing gold ore was investigated. Gold extraction of up to 97% was achieved by introducing complex agent of copper, stabilizing agent of iron and other modifications, compared to less than 30% by conventional cyanidation under otherwise identical conditions. The mechanism involved was discussed.

Key words: Copper Gold Ammoniacal cyanidation

1 INTRODUCTION

Gold ores are often associated with copper to more or less extent and their cyanidation for gold extraction presents challenge due to the following reaction of copper minerals with cyanide:



As indicated by this equation, one mole of Cu(II) oxidizes 1 mole and combines 3 moles of cyanide, this reduces the concentration of free cyanide for gold dissolution. In general, the ores containing 0.3%~0.5% Cu in the form of oxide or >1% Cu in the form of sulfide are not amenable to conventional cyanidation and some modifications are required to improve the gold extraction from such ores.

There are two ways to modify the cyanidation of copper-gold ores, either to extract both gold and copper by cyanidation, followed by recovering gold, copper and releasing the associated cyanide for reuse, or to improve gold cyanidation by coupling ammonia to cyanide when copper is present. This work adopted the ammoniacal cyanidation process to treat a gold ore containing copper oxide with success.

2 EXPERIMENTAL RESULTS

The sample for tests contains approximately 0.5% Cu in the form of oxide and 50g/t gold. The ore was ground and then subjected to 24 h rolling bottle test for gold extraction.

2.1 Effect of Ammonia

As seen from Table 1, only 28.6% of gold in the ore was extracted by conventional cyanidation using 4 g/L (or 12 kg/t ore) NaCN which is at least 2~3 times of typical cyanide consumption in gold milling. A large amount of copper, on the other hand, was also dissolved, leading to little free cyanide available for gold extraction. A reasonable gold extraction was achieved only when the sodium cyanide dosage was as high as 15 g/L, or 45 kg/t ore, which is not commercially acceptable in gold milling.

Introduction of ammonia into leaching systems has proven^[1-3] to be favorable to gold cyanidation in the presence of copper and the species for gold dissolution in this case was proposed to be $[\text{Cu}(\text{CN})_3(\text{NH}_3)_3]^{2-}$, therefore, the effect of ammonia on the gold cyanidation from the copper bearing ore was tested at a fixed ammonia to cyanide molar ratio of 1:1. Table 1 shows a significant im-

① Supported by National Natural Science Foundation of China; received Jul. 2, 1994, accepted Aug. 29, 1994

provement of gold cyanidation was made by ammonia addition. Even with half of the cyanide consumption of conventional cyanidation, much higher gold extraction was obtained if ammonia was added.

Table 1 Improvement of gold extraction of copper bearing ore by ammoniacal cyanidation

| NaCN /g·L ⁻¹ | NH ₃ /mol·L ⁻¹ | Cu in solution /mg·L ⁻¹ | Molar ratio (CN/Cu) | Au extraction (%) |
|----------------------------|---|--|---------------------------|-------------------------|
| 1 | 0.02 | 434 | 3.0:1 | 17.1 |
| 2 | 0.04 | 798 | 3.3:1 | 38.8 |
| 4 | 0.08 | 1233 | 4.2:1 | 77.2 |
| 3.8 | 0 | 1356 | 3.6:1 | 28.6 |
| 15 | 0 | 1321 | 14.8:1 | 93.2 |

2.2 Effect of Copper

It was also found^[1] that copper in proper amount is favorable, even necessary to cyanidation of gold in the presence of ammonia, therefore the effect of copper on the ammoniacal cyanidation of gold was examined. Table 2 lists results of the tests in which copper was initially added at copper to cyanide molar ratio of 1:4.

Table 2 Effect of copper on ammoniacal cyanidation of gold*

| S/L (V/W) | NaCN | | Cu in solution /mg·L ⁻¹ | | Au extraction (%) |
|--------------|--------------------|---------------------|------------------------------------|-------|-------------------------|
| | /g·L ⁻¹ | /kg·t ⁻¹ | initial | final | |
| 3:1 | 4 | 12 | 0 | 1233 | 77.2 |
| 3:1 | 4 | 12 | 1270 | 968 | 89.6 |
| 3:1 | 5 | 15 | 1588 | 1275 | 97.3 |
| 1.6:1 | 1.9 | 3 | 595 | 366 | 67.6 |
| 1.6:1 | 3.8 | 6 | 0 | 738 | 67.4 |
| 1.6:1 | 3.8 | 6 | 1191 | 513 | 90.5 |
| 1.2:1 | 3.8 | 4.5 | 1191 | 600 | 86.8 |
| 1.2:1 | 5 | 6 | 1588 | 800 | 90.0 |

* NH₃ was added at NH₃ to CN molar ratio of 1:1 in all the tests.

Remarkable improvement of ammoniacal cyanidation of gold was observed when copper was initially added in a proper amount as seen from Table 2. For example, the gold extraction was increased from 77% to near 90% due to the introduction of copper into the ammonia-cyanide mixed solution of 4 g/L NaCN, and to 97% or more as the concentration of NaCN

was increased further to 5 g/L. Likewise, the gold extraction by ammoniacal cyanidation with 3.8 g/L NaCN at liquid to solid ratio of 1.6:1 with or without initial addition of copper was 90.5% and 67.5%, respectively, which confirms that it is a mixed cyanoammonia complex of copper that is responsible for gold dissolution on ammoniacal cyanidation.

2.3 Effect of Liquid to Solid Ratio

All the tests above were run at liquid to solid ratio of 3:1. Although the addition of ammonia and copper together enhanced gold cyanidation to a great extent, the cyanide consumption at this liquid to solid ratio was still too high to be accepted. A possible way to save cyanide consumption further is to decrease liquid to solid ratio. Table 2 shows clearly that gold extraction of 90% was obtained with around 4 g/L NaCN at liquid to solid ratio of either 3.0:1 or 1.6:1, but the cyanide consumption was almost halved in the latter. The gold extraction became decreased, however, if the liquid to solid ratio was dropped further, to 1.2:1 for example. This may be related to an insufficient supply of oxygen for gold dissolution in very dense pulp. Furthermore, too small liquid to solid ratio may create operational problems owing to high pulp viscosity, which is particularly true for CIP operation.

2.4 Effect of Iron

As well known, both Fe(III) and Fe(II) combine cyanide to form very stable complex species Fe(CN)₆³⁻ and Fe(CN)₆⁴⁻, respectively. It is obvious that the soluble iron in ores interferes with gold cyanidation even more seriously than copper. Three stabilizing agents of iron, A, B and C, were tested for eliminating the negative effect of iron on the gold cyanidation. As shown by the results in Table 3, the three agents tested were all demonstrated to promote gold extraction evidently. The addition of agent A, for example, increased gold extraction from about 90% to 97% under otherwise identical conditions.

Table 3 Effect of iron and its stabilizers on the gold cyanidation

| L/S (V/W) | Before cyanidation | | | | | After cyanidation | | | | |
|--------------|--------------------|---------------------|----------------------|---------------------|------------|---------------------|---------------------|--------------------|--------------------|----------------------|
| | NaCN | | NH ₃ | Cu ²⁺ | Stabilizer | Cu | Fe | ΣCN ⁻ | CN ⁻ | Au extraction (%) |
| | /g·L ⁻¹ | /kg·t ⁻¹ | /mol·L ⁻¹ | /mg·L ⁻¹ | | /mg·L ⁻¹ | /mg·L ⁻¹ | /g·L ⁻¹ | /g·L ⁻¹ | |
| 1.6 | 3.8 | 6 | 0 | 0 | — | 1 356 | 1 010 | | | 28.6 |
| 1.6 | 3.8 | 6 | 0.08 | 1 250 | — | 513 | 240 | | | 90.5 |
| 1.6 | 4 | 6.4 | 0.10 | 1 296 | — | 1 080 | 790 | 0.94 | | 88.4 |
| 1.6 | 4 | 6.4 | 0.10 | 1 296 | A | 1 640 | 390 | 1.12 | | 97.1 |
| 1.2 | 3.8 | 4.5 | 0.08 | 1 250 | B | 2 050 | | 1.26 | 0.27 | 96.6 |
| 1.2 | 3.8 | 4.5 | 0.08 | 1 250 | C | 2 840 | | 1.15 | 0.44 | 95.9 |
| 1.2 | 3.8 | 4.5 | 0.08 | 1 250 | — | 600 | | 0.69 | 0.22 | 86.8 |

It is seen clearly from Table 3 that the concentration of both copper and iron dissolved on cyanidation was very high in the absence of ammonia, but dropped dramatically as ammonia was added. Copper(I) in mixed copper-cyanide-ammonia (CCA) solutions with the cyanide to copper molar ratio less than 3:1 was found^[4] to be susceptible to oxidation by oxygen to copper(II) which combined in turn ferro-and ferri-cyanide to precipitate Cu₂Fe(CN)₆ and Cu₃[Fe(CN)₆]₂. Since the cyanide to copper and iron molar ratios in these precipitates are less than those in copper-cyanide and iron-cyanide species in the solutions, such precipitation freed cyanide radicals from the copper-and iron-cyanide species in the solutions and thus enhanced the gold extraction. The gold cyanidation was improved further due to the addition of iron stabilizers which released free cyanide from ferro-and ferri-cyanide species by forming stable complexes other than cyanide complexes.

2.5 Effect of NO₃⁻ and Pb²⁺

Nitrate and lead ions were reported to promote gold cyanidation^[5], but such favorite effect was not confirmed in this work.

3 DISCUSSION

It is generally recognised that ammonia is able to improve the gold cyanidation in cupro-cyanide solutions. No consensus has been, however, reached regarding how ammonia does it. A number of observations in this

work are worth while discussing.

A large amount of copper enters into solution during cyanidation of the copper-gold ore without adding ammonia, which consumed cyanide greatly hence caused very poor gold cyanidation unless cyanide was very much excessive over dissolved copper in the solution. For example, with 4 g/L NaCN, the cyanide to copper molar ratio in the solution was reduced to 3.6:1, leading to very small amount of free cyanide and extremely low gold extraction (28.6%). As ammonia was introduced into the solution at NH₃ to CN⁻ molar ratio of 1:1, the gold extraction was three times (77%) as high as that without ammonia using same cyanide consumption, although the differences in amounts of dissolved copper and free cyanide between with and without ammonia were very small (Table 3), which suggested that the species responsible for gold dissolution in ammoniacal cyanidation was not free cyanide but a mixed cyanoammonia complex of copper instead.

It is worth-while to note that the copper concentration in the solution on completion of cyanidation was decreased when copper and ammonia were added simultaneously into the cyanide solution, not only lower than that without adding copper but even lower than half of the copper added initially (Table 2). In other words, no copper in the ore was leached but half of the added copper was precipitated in such case. It is supposed that the precipitate was not copper compounds without containing cyanide, such as copper oxide, because

such precipitation will free cyanide to redissolve the copper compounds. It is safe to suggest that the precipitate has relative low cyanide to copper molar ratio so keep the remained cyanide to copper molar ratio in the solution not less than 3 : 1. As the simple cyanocomplexes of copper are not able to dissolve gold, the species containing copper and cyanide in the solution seems to be a mixed cyanoammonia complex of copper. It was suggested^[2] that such complex is $[\text{Cu}(\text{CN})_3(\text{NH}_3)_3]^{2-}$, which was supposed to be able to dissolve gold.

It is also worthy to mention that the copper concentration in mixed copper-cyanide-ammonia solutions remained very high when an iron stabilizer was used, seen from Table 3. The copper concentration in the final ammoniacal cyanidation solution of the copper bearing ore, for example, was almost equal to the sum of the soluble and initially added copper when the stabilizing agent C was added, which indicated that no any forms of copper compounds, including copper ferrocyanide and copper ferricyanide, were precipitated in this case. Total cyanide (free cyanide and various type of cyanide complexes) concentration was also high in spite of the high copper concentration in the solution. The gold cyanidation was rather good although the free cyanide concentration was low. There was little difference of free cyanide concentration in mixed copper-cyanide-ammonia solutions between with and without adding stabilizing agents of iron. For example, the free cyanide concentration was 0.22 g/L without adding iron stabilizer, compared to 0.27 g/L CN^- with agent B used under otherwise identical conditions. However, the total cyanide concentration of solution in the latter was twice as high as that in the former and the gold extraction was increased by ten percentages (from 86.8% to 96.6%), reflecting that the gold cyanidation in copper-cyanide-ammonia system was depended mainly

on rather total than free cyanide concentration, or more precisely, on a complex cupro-cyanide species, which provides an evidence for the proposal that the mixed ligand species $[\text{Cu}(\text{CN})_3(\text{NH}_3)_3]^{2-}$ is responsible for gold dissolution in the CCA system.

4 CONCLUDING REMARKS

The following conclusions are drawn from this work:

(1) The copper in ores was leached by cyanide and thus consumed it greatly, which is the principal reason why copper interferes with conventional cyanidation of gold.

(2) The introduction of ammonia provided a mixed ligand species $[\text{Cu}(\text{CN})_3(\text{NH}_3)_3]^{2-}$ capable to dissolve gold, hence improved gold cyanidation in the presence of copper, which suggests that the gold leaching does not depend on free cyanide concentration in copper-cyanide-ammonia system.

(3) The addition of copper with ammonia together improved gold cyanidation further.

(4) The serious interference of iron solution with gold cyanidation could be alleviated by using iron stabilizers.

(5) The gold extraction was increased from less than 30% by conventional cyanidation to 97% with the above modifications under otherwise identical conditions.

REFERENCES

- 1 Deng Tong. paper presented at AMIRA sponsors meeting, Dec. 4 1991.
- 2 Deng Tong. Trans Nonferrous Metals Soc of China, 1994, 4(5): 27.
- 3 Muir DM, LaBrooy S R, Cao C. In: World Gold' 89, AIME, Warrendale, 1989, Chapter 44.
- 4 Cooper D, Plane RA. Inorg Chem, 1966, 5(10): 1677.
- 5 Weichselbaum J, Tumilty JA, Schmidt CG. In: AusIMM Annual Conference, Perth-Kalgoorile, May 1989.