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Flotation and cyanidation of a semi-refractory gold ore

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ABSTRACT

Beneficiation of a low-grade gold ore was studied by column flotation. The quality of the concentrates obtained by flotation column was found to be much superior compared to that of conventional flotation cells. Effect of this enrichment on cyanidation was investigated in the laboratory. Effect of different variables viz., pre-aeration, airflow rate, cyanide dosage, pH of the pulp, concentrate grade etc. were studied. The study indicated the reduction in cyanide consumption with high-grade gold concentrates used in the cyanidation. The results were further confirmed by conducting large-scale cyanidation tests.

Keywords: Gold ore; Column flotation; Cyanidation; Refractory ore

1. INTRODUCTION

Kolar Gold Fields owned by M/s. Bharat Gold Mines Limited (BGML) is well known for its gold reserves for over 100 years. Besides deep mining, the grade of the ore gradually depleted over the years and hence, the cost of production has increased and to reduce the cost of production, the company decided to increase its milling capacity and also considered flotation columns to be incorporated in their beneficiation circuit.

Column flotation technology is gaining wider acceptance among mineral industries worldwide because of its technological superiority over conventional froth flotation (Michael and Ian, 1989; Donald and Harold, 1991; Bhaskar Raju *et al.*, 1993). Column flotation was adopted to process sulphidic gold ore at the Harbour Lights mine in Leonora, Western Australia, the Three Mile Hill gold deposit of Goldfan Ltd., located near Coolgardie, Austin Gold Venture in Nevada, Asamera's Cannon Mine in Washington and Echo Bay's McCoy Mine in Nevada. In all these cases, column cells were used for cleaning the rougher concentrates (Subramanian *et al.*, 1988).

Cyanidation is the main process used worldwide for the extraction of gold. The theoretical stoichiometry indicates that to dissolve the gold contained in a typical ore, only 3 to 4 grams of cyanide per ton of mineral should be consumed; nevertheless, typical cyanide consumption ranges from 300 to 2000g/t. It is worth mentioning that the largest loss of cyanide occurs through the formation of thiocyanate and cyanide complexes with copper, zinc and iron (Byerley and Enns, 1984). The cyanide leaching mechanism was recognized by early investigators to be electrochemical in nature (Kudryk and Kellog, 1954).

The present paper describes the beneficiation of low-grade gold ore by flotation columns and the implications of improved metallurgy on subsequent cyanidation.

2. EXPERIMENTAL

2.1. The gold ore

The mineralogical assay of gold ore revealed that the ore is semi-refractory containing both free and refractory gold approximately in the ratio of 80:20. About 85-90% of gold was locked in arsenopyrite and loellingite grains. Though the grain size of gold particles ranges from one micron to hundred microns, most of the particles were found to be in the range of 2 to 20 microns. The cyclone overflow from the mill was used in the present test work.

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2.2. Flotation column

Preliminary tests were conducted in a laboratory size flotation column with an internal diameter of 0.074m and a height of 7m. Large-scale tests were conducted in a semi-commercial scale flotation column with an internal diameter of 0.5m and height 14m. A single loop controller connecting differential pressure transmitter (DPT) and the tailing discharge valve is adopted to maintain the interface between froth and slurry. Magnetic flow meters are used to measure slurry flow rates. Online electro-pneumatic valves with timer are also installed for automatic sample collection. The column was installed as rougher-cum- cleaner. The schematic diagram of flotation column installed in the plant circuit is shown in Figure 1. The standard test procedure established by Finch *et al.*, (1992), was adopted throughout the test work.

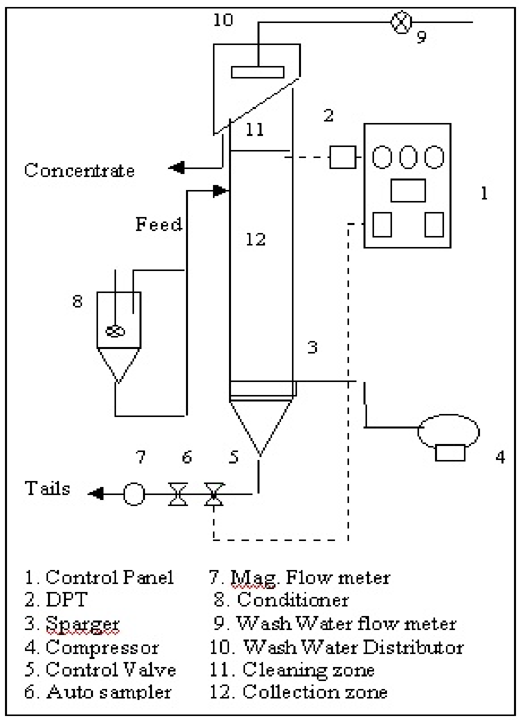

Figure 1. Schematic diagram of semi commercial flotation column

2.3. Cyanidation

Laboratory scale cyanidation tests were carried out with about 5 litres of slurry (Concentrate of flotation column) in a container fitted with a stirrer and an air inlet. pH of the slurry was adjusted with known quantity of lime. Required quantity of cyanide was also added. After stipulated time, the slurry was removed, filtered, washed, dried and the residue and pregnant liquor were analysed for gold by fire assay method.

Large-scale cyanidation and carbon adsorption test were conducted in CIP tanks with a minimum of 0.5 ton of column concentrate in each test. The CIP tank is provided with aeration lines. After cyanidation, both the residue and liquor samples were collected for estimation of gold dissolution. Required quantity of activated carbon was added to study the carbon adsorption efficiency with liquors of high gold concentrations.

3. RESULTS AND DISCUSSION

3.1. Flotation

During the first phase, 0.074m-dia laboratory size flotation column was installed within the plant premises and the amenability of the flotation column as a rougher-cum-cleaner was studied. Entire amenability test work was conducted on a sample drawn directly from mill cyclone overflow, which is free from reagents and re-circulation loads.

Batch type experiments related to optimization of various reagents and column parameters were conducted and the optimum conditions obtained are given below:

Soda ash	: 1.00kg/t	Air velocity	: 0.0116m/s
Sodium Silicate	: 0.50kg/t	Wash water velocity	: 0.00078m/s
Copper Sulphate	: 0.40kg/t	Feed velocity	: 0.011m/s
Amyl xanthate	: 0.04kg/t	Froth depth	: 0.4m
Pine oil	: 0.015kg/t	Residence time	: 400sec.
pH	: 8.0	d80	: 75μm

High-grade concentrates assaying 30-50ppm of gold was obtained by flotation column whereas conventional cells have yielded barely 5-10ppm of gold concentrates. The recoveries were found to be more or less same in both the cases. Also, it is apparent that around 40% of the solids report to concentrate by conventional flotation, resulting in poor grades, whereas weight of the concentrate is below 10% by flotation column.

The 0.5m diameter semi-commercial column was operated parallel to the flotation circuit of the plant. Concentrates ranging from 35-60ppm of gold with a recovery of 70-90% were achieved. Fig.2 shows the comparative weights of concentrates produced by conventional flotation circuit and flotation column at equivalent recoveries. The salient feature is that the weight of the concentrate obtained by column is 2-10% as compared to 40-50% obtained in the case of conventional flotation.

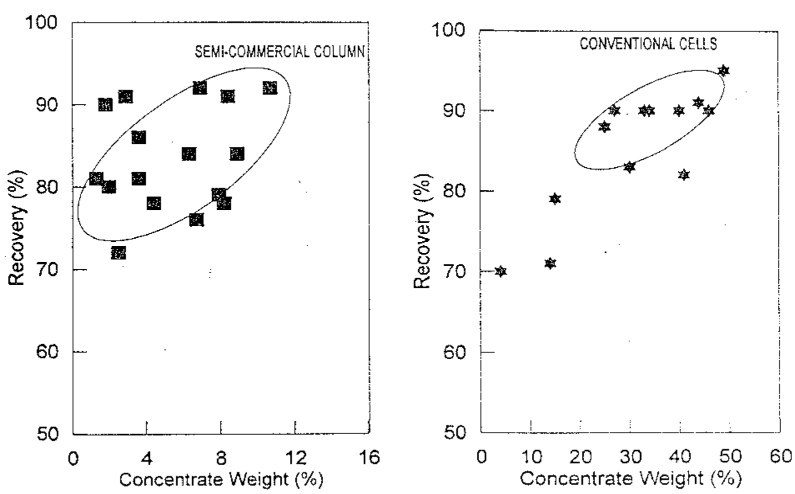

Figure 2. Concentrate weight vs Recovery – Comparison between semi commercial column and conventional cells

The wash water introduced from the top of the column could effectively displace the entrained gangue in the froth phase. It is anticipated that the reduction in concentrate weight with less gangue should benefit the downstream operations particularly in reduction of cyanide consumption, which in turn, will reflect in the overall economics of the plant.

3.2. Cyanidation

3.2.1. Effect of aeration

From the ore mineralogy it is apparent that the concentrate produced from flotation column should contain considerable amounts of base metal sulphides. Alkaline pre-aeration is the major option to treat semi-refractory sulphide ores (La Brooy and Komosa, 1992). Pre-aeration reduces the oxygen demand during cyanidation by passivating the surface of pyrrhotite by transforming Fe(II) to Fe(III), which reacts sluggishly with cyanide. A set of experiments was carried out to study the effect of pre-aeration on the cyanidation of column concentrates at three different conditions and the results are presented in Table 1. From the results it is clear that this concentrate requires pre-aeration in the presence of lime at pH 10.0-10.5 to achieve the highest gold dissolution. The presence of lime during the reaction not only controls the pH of the slurry but also provides sufficient cations to precipitate arsenic and iron as a mixture of calcium and ferric arsenates (Canterford and Bhappu, 1988).

Table 1
Effect of pre-aeration on gold dissolution (Solids: 50%, NaCN: 5kg/t, pH: 10.5)

Pre-aeration conditions	Feed g/t, Au	Residue g/t, Au	Pregnant liquor g/t, Au	% Recovery Au
Without pre-aeration (with lime+CN)	74.5	25.0	54.0	66.4
Pre-aeration for 4h without lime addition	74.5	55.0	27.0	26.2
Pre-aeration for 4h with lime addition	66.0	3.7	31.1	94.4

The role of oxygen in the dissolution of gold is very important. In order to bring about the oxidation of base metal sulphides, an oxidant is required. Although oxidizing agents such as sodium peroxide, potassium permanganate, bromine, chlorine, etc. have been used, adequate aeration will give results as good as those of chemical oxidizers, at a lower cost. In practice neither the concentration of O_2 nor that of free cyanide alone are importance, but it is their molar ratio, which is critical, and ideally it should be 6. It was also pointed out that the dissolution of gold is controlled by the diffusion (mass transfer) of both the dissolved oxygen and the cyanide ions through the boundary layer of the solid-liquid interface (Yannopoulos, 1991).

3.2.2. Effect of cyanide dosage

The cyanide concentration is a critical variable in cyanidation and cementation of precious metals. It could be seen from Figure 3 that the rate of gold dissolution increases linearly with increase in cyanide concentration until a maximum is reached above which further increase in cyanide dosage does not increase gold dissolution, but instead has a retarding effect. The decrease in dissolution at high cyanide dosage could be due to the slight increase of the solution pH. The results indicate that the optimum cyanide dosage is 3.5-5.0kg/t for concentrates of 50-70ppm of gold.

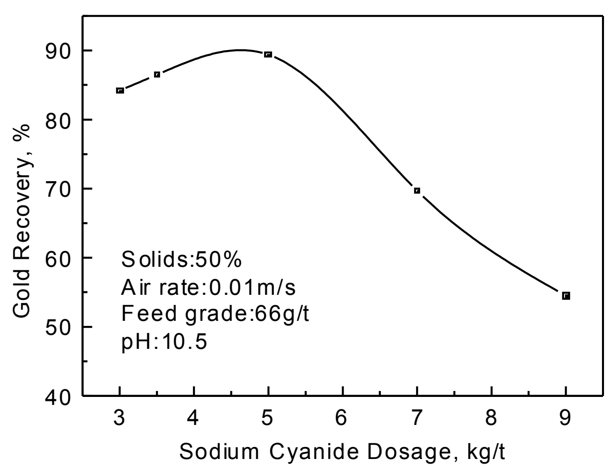

Figure 3. Effect of variation in NaCN dosage on gold dissolution

3.2.3. Effect of percent solids

Variation in specific gravity (% solids) of the pulp is supposed to have physico-chemical ramifications as far as the cyanidation kinetics are concerned. Specific gravity of the pulp is an indicator of the tonnage load on a plant. Figure 4 shows the effect of solids to liquid ratio on the dissolution of gold from column concentrate. It is evident that an increase in pulp dilution results in improved gold dissolution within the range of test conditions. The decrease in gold dissolution at higher pulp densities could be due to decrease in oxygen mass-transfer rate to the pulp.

3.2.4. Effect of concentrate grade

With the above analysis, experiments were conducted with different grade of gold concentrates under identical test conditions. The results of the same are presented in Figure 5. The results clearly indicate the advantages of using high-grade gold concentrates in cyanidation. Gangue components in relatively low grade and refractory gold ore concentrates can consume cyanide and oxygen in competition with gold (Linge, 1992). Therefore, it is anticipated that high-grade concentrates consume less cyanide than the low grade ones.

Based on the experimental results, the following benefits are expected in the down stream operations of gold extraction by using high-grade concentrates generated from flotation column

i. Less cyanide consumption – less amount of cyanide in final effluents
ii. Less weight of the material to be handled during cyanidation – low capital cost, ease in operation, reduction in energy requirements, etc.
iii. Less water requirement, less volume of pulp to be handled - reduction in the reaction vessel volumes.

Under such conditions, lower cyanide dosage mean high cyanide molar concentrations in the pulp. This should result in increased gold dissolution rate under considerably reduced cyanide consumption for unit weight of gold produced.

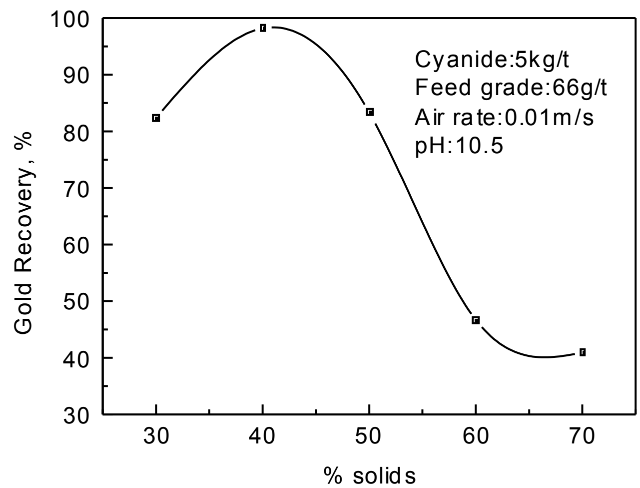

Figure 4. Effect of variation in percent solids on gold dissolution

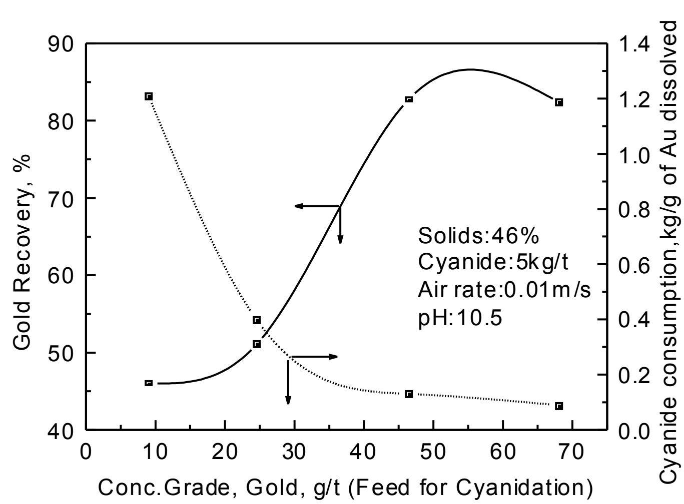

Figure 5. Effect of variation in conc. grade on gold dissolution

3.2.5. Large scale testing in CIP tanks and pachuca

Initially cyanidation tests were carried out in CIP tanks to simulate laboratory scale cyanidation. The test conditions and the results are shown in Table 2. During the cyanidation period, the pH of the pulp and free cyanide in the slurry was continuously monitored and maintained. The results clearly indicate that it is possible to achieve over 90% gold dissolution. From the results, it is also observed that the cyanide consumption is less with high grade of concentrates. To confirm these results, two more cyanidation tests were conducted in 1.5 ton capacity Pachuca, where the liquor was separately processed for gold production. The dissolution data along with the gold realised in these tests are given in Table 3. These results confirm the expected benefits in cyanidation if the concentrate is produced by flotation column.

Table 2
Results of cyanidation in CIP tank (Pre-aeration time: 6h, Cyanidation time: 12h, Carbon added after: 18h, Carbon contact time: 1.5h)

Description	Test-I	Test-II	Test-III
Column flotation conc. qty., ton	0.50	0.50	0.50
Au in conc., ppm	50	58	45
NaCN, kg	3	3	3
Lime, kg	18	18	20
pH	10.5	10.5	10.5
Au in residue, ppm	0.9	3	3
Amount of Au dissolved, g	24.6	27.5	21.0
Au recovery, %	98	95	93
Cyanide consumption, g/g of Au dissolved	122.2	109.1	142.9

Table 3
Results of cyanidation in Pachuca (Pre-aeration time: 6h, Cyanidation time:24h)

Description	Test-I	Test-II
Column flotation conc. qty., ton	1.63	1.5
Au in conc., ppm	72	120
NaCN, kg	7	10
Lime, kg	38	30
pH	10.5	10.5
Au in residue, ppm	7.0	4.0
Amount of Au dissolved, g	106.3	174.0
Bullion, g	105	165
Au recovery, %	90	96
Cyanide consumption, g/g of Au dissolved	65.9	57.5

4. CONCLUSIONS

The quality of concentrate generated by flotation column was superior compared to that of conventional flotation cells. Flotation columns eliminate nearly 90% of the gangue whereas the rejection of gangue is only about 50% in conventional cells. Concentrates with gold content of 50g/t can be achieved in flotation column as against 10-15g/t concentrates produced by conventional cells. Systematic laboratory scale cyanidation studies were carried out with the high-grade concentrates to establish the optimum conditions. The results clearly indicated the reduction in cyanide consumption. This was further confirmed on large-scale cyanidation tests with about 90% gold dissolution during leaching. Thus, the relative advantages of flotation column *vis-à-vis* conventional flotation should contribute to the overall improvement in economics of gold processing operations.

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