AMMONIACAL CYANIDATION OF IGARAPE BAHIA GOLD COPPER ORES

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ABSTRACT

Igarapé Bahia is today Brazil's biggest gold mine with an annual production of 10 tonnes of bullion. Presently heap leaching is used to process low-grade ore and CIP to treat high-grade, low copper containing ore. However, as the pit progresses in depth,.a marked hydrothermally enriched zone with an estimated 10 millions tonnes of transition ore occurs. Due to the high content of copper of this transition ore, which in turn causes a high consumption of cyanide, gold cannot be recovered by conventional cyanidation.

This study is oriented to the application of the ammonia-cyanide leaching to the processing of Igarapé Bahia gold-copper ore. The influence of process variables such as pH, NaCN and NH_3 concentrations, addition of copper salts, NH_3 conditioning time and leaching time were established with the help of statistical design analyses. Cyanide addition, ammonia addition and their interaction were shown to significantly affect gold extraction while cyanide addition was the only variable affecting cyanide consumption and the extraction of cyanide soluble copper. A quadratic model was shown to properly represent gold extraction as a function of the process variables; linear models adequately represent both cyanide consumption and extraction of soluble copper. Under optimum conditions, 90% gold recovery was obtained in 2 hours of leaching, with cyanide and ammonia consumptions of 1.1 and 4.5 kg/t, respectively.

INTRODUCTION

The Igarape Bahia mine, situated in the Carajas region, Para state, northern Brazil, is operated by Companhia Vale do Rio Doce. It is today Brazil's biggest gold mine with an annual production of 10 tonnes of bullion. The ore is presently recovered from an open pit mine; it is oxidized and contains 0.1% total copper in a form practically inert to cyanide. Today heap leaching is used to process low-grade ore and CIP to treat high grade ore.

As the pit progresses in depth, approaching the transition orebody, the copper content in the ore will increase. These high concentrations of Cu, mostly present as cyanide soluble copper minerals, such as oxides (cuprite and malachite), sulphides (chalcosite, bornite and covellite) and native Cu result in an increase of cyanide consumption. This situation will most possibly render impossible the recovery of gold by means of conventional cyanidation and, therefore, the current plant will eventually have to be adapted to a new process.

Several processes have been developed in the past years to deal with the problems caused by the dissolution of copper minerals during gold extraction. Many of them have shown relative success for a specific application. Nevertheless, a universal solution is still not available. A process based on ammonia-cyanide leaching was successfully used in Mauritania for treating flotation tailings containing 0.8-1.0% Cu and 3.1 g/t Au (Costello et al., 1992). Since then, extensive work has been done with the ammonia-cyanide leach system indicating that, under controlled conditions, the process allows effective gold recovery and low cyanide consumption. The solubility of copper minerals and copper species in solution is dependent on NH_3 and CN^- concentrations, pH and Eh. Controlled additions of ammonia to cyanide solutions are reported to inhibit the leaching of copper minerals and to extract up to 85% Au using as little as 10% of the cyanide compared with conventional cyanidation (Muir et al., 1993).

In the present work the application of ammoniacal cyanidation leaching to the processing of a sample of high copper containing gold ore from Igarape Bahia was studied in laboratory scale. The effect of the following process variables on gold recovery, cyanide consumption and copper dissolution were investigated: cyanide and ammonia concentrations, pH, addition of Cu(II) and ammonia conditioning time. Statistical based methods were applied to both the design of experiments and analysis of the results.

EXPERIMENTAL

Materials

An ore sample from the deep portion of the oxidized zone of Igarape Bahia mine and containing 3.3 g/t Au and a high content of cyanide soluble copper (0.65% of total Cu) was used in all leaching experiments. The ore chemical composition is shown in Table I (Romayna, 2000). This material was also analysed for cyanide soluble copper according to the so-called Red Dome procedure (Lewis, 1990), which consists in reacting the pulverized sample with 1% NaCN at 0.7 wt.% solids for 1 hour. Based on the Cu concentration of the pregnant solution, the cyanide soluble copper (NaCNsolCu) content of the ore is determined. Prior to the leaching tests the ore was ground to 70% below 74 μm, this fine size distribution being used to increase gold liberation.

Mineralogical analyses by optical microscopy, X-ray diffraction and scanning electron microscopy indicated that hematite, goethite/limonite, magnetite, quartz and manganese oxides are the ore main constituents. Azurite and malaquite are the main sources of copper in this ore. The mineralogical composition and the mass distribution of copper in the ore are depicted in Table II (Romayna, 2000).

Other chemicals used in the leaching tests, such as sodium cyanide, ammonium hidroxide, copper sulphate, sodium hidroxide and lime were chemical grade reagents.

Experimental procedure

Leaching tests were carried out in a 1000 mL glass reaction kettle with 4 openings in the cover that enable slurry agitation, collecting of samples and on-line measurements of pH and dissolved oxygen (DO). The slurry was mechanically agitated at 300 RPM with a direct drive overhead motor. All tests were done at room temperature and at a pulp density of 40% (W/V). Cyanide concentrations and pH were adjusted by addition of NaCN and lime, respectively.

At the end of an experiment, the slurry was filtered and the filtrate was analyzed for Au and Cu content. The solid residue was washed with distilled water and then split into three samples, two for Au and one for Cu assay. Free cyanide analysis was done by titration with silver nitrate using rhodanine as indicator. Gold and copper in solutions were assayed by atomic absorption spectroscopy and gold analysis in the leaching residue was carried out by fire assay.

Table I - Chemical analyses of Igarape Bahia ore sample

Element	Content (%)
Fe	49.20
Si	6.48
Mn	4.82
Al	1.71
Total Cu	0.65
NaCNsolCu*	0.10
Ti	0.20
S	0.07
Ca	0.05
Mg	0.04
Au	3.30 g/t
Ag	< 1 g/t
L.O.I.	6.73

* - cyanide soluble copper

Table II - Mineralogical composition of Igarape Bahia ore sample

Mineral	Content (%)	Cu distribution (%)
Azurite	t	36
Malachite	r	15
Mn oxides*	9	23
Goethite	24	15
Hematite	39	10
Magnetite	6	-
Chlorite	t	-
Kaolinite	2	-

r (rare): ~0.2% t (trace): 0.5%

* - minerals group without an established formula

RESULTS AND DISCUSSION

A survey of the published literature (Costello et al., 1992; Muir 1993; Deng and Ma., 1996; Vukcevic, 1997; Zeng et al., 1995) on tiosulphate leaching of gold-copper ores showed that cyanide and ammonia concentrations, pH, pre-conditioning time with ammonia, addition of Cu(II) and dissolved oxygen concentration are the variables that affect most the rate of gold dissolution. Therefore, a first set of experiments using a two-level Placket-Burman factorial design, with 8 runs, 5 real and 2 fictitious variables, was undertaken.

In these runs cyanide concentration, pH, ammonia concentration, addition of Cu(II) and conditioning time were varied, while leaching time, DO, pulp density, ore particle size and temperature were kept constant. Gold extraction, cyanide consumption and the extraction of cyanide soluble copper were selected as responses. The results os this set of experiments indicated that:

- ammonia and cyanide concentrations and conditioning time affect gold extraction (DOC > 90%);
- cyanide consumption is only affected by NaCN concentration;
- similarly, NaCN concentration is the only variable that affects NaCNsolCu extraction, though pH exhibts a DOC very close to 90%.

In light of these findings, a new set of experiments was carried out, in which a complete 2^3 factorial design was chosen with 2 levels for each variable and 4 tests at the central point. The selected variables were A (conditioning time), B (NaCN concentration) and C (NH_3 concentration), while Au extraction, cyanide consumption and the extraction of cyanide soluble copper were again selected as responses. The results of these series of tests are indicated in Table III.

The evaluation of these results was done using the analysis of variance and the Yates' algorithm. They confirm those of the firts set of experiments, in that:

- NaCN and NH_3 concentrations and the interactions between these two variables significantly affect gold extraction. The other effects can be neglected;
- cyanide and ammonia concentrations also affect cyanide consumption. The effect of conditioning time, is negligible and the interaction between the variables can be neglected;
- NaCN concentration is the only variable that has a significant effect on Cu extraction.

In addition, as indicated in Figure 1 - gold extraction as a function NH_3 and NaCN concentrations - the effect of curvature is significant, indicating that a first-order model cannot describe this response in the range studied. By doing additional experiments, in the planning of which the method of the path of steepest ascent was employed, and by

applying the STATISTICA v.4 software for a non-linear regression of the results, the following quadratic expression was derived, which adequately describes the rate of gold extraction:

$$Y = 18.7+67.3*X_1-10.1*X_2-13.9*X_1^2+4.0*X_2^2-3.4X_1*X_2 \quad (1)$$

where:

Y = gold extraction (%)

X_1: NaCN concentration (kg/t)

X_2: NH3 concentration (kg/t)

Copper extraction, on the other hand, follows a linear pattern, as shown in Figure 2. Within the range of variables studied, the following equation describes the extraction of NaCNsolCu as a function of cyanide and ammonia concentrations.

$$\text{Cu extraction} = -4.11+29.1*[NaCN]+0.15*[NH_3] \quad (2)$$

in which [NaCN] and $[NH_3]$ denote the concentrations of cyanide and ammonia (in kg/t of ore), respectively.

Table III - Ammonia-cyanide leaching of Igarape Bahia ore - factorial design and results

Test nº	A	B	C	Au extr. (%)	NaCN cons. (kg/t)	Cu extr. (%)
1	-	-	-	44.9	0.43	9.6
2	+	-	-	46.0	0.39	10.8
3	-	+	-	87.3	2.47	82.0
4	+	+	-	65.6	2.36	83.8
5	-	-	+	78.6	0.26	11.1
6	+	-	+	76.6	0.22	10.2
7	-	+	+	87.1	2.29	84.2
8	+	+	+	85.0	2.33	83.7
9	0	0	0	76.4	1.35	49.6
10	0	0	0	80.3	1.37	46.6
11	0	0	0	82.2	1.35	46.6
12	0	0	0	77.9	1.37	50.3

Further leaching experiments to corroborate the responses predicted by the quadratic model for gold extraction were undertaken. In these experiments, cyanide concentration was kept constant at 2.0 kg/t, while ammonia concentration was varied between 0.5 and 4.0 kg/t. A conventional - that is, without ammonia - cyanidation test was also carried out. The results, shown in Table 4, indicate that Au extraction above 83% can be achieved with cyanide concentrations as low as 2 kg/t. Under similar conditions, conventional cyanidation resulted in a maximum of 81% of gold extraction.

Table 4 - Additional leaching experiments

[NaCN] (kg/t)	[NH_3] (kg/t)	Au extr. (%)	Cu extr. (%)	[Cu] in solution (mg/L)
2.0	4.50	85.2	44.6	278
2.0	3.25	83.3	43.4	291
2.0	0.50	76.6	42.9	274
2.0	-	81.5	42.1	269

Two additional tests were carried out using the optimal conditions determined for leaching the oxide ore, i.e. 2 kg/t NaCN and 4.5 kg/t NH_3 and at longer leaching times (36 hours), pulp density being maintained at 40% and pH at 11.5. The first test was carried out with the addition of O_2 and the second one was without it (air only). These tests were aimed at observing the precipitation of copper along the leaching time and the results are shown in Figures 3 and 4. Gold is leached mostly in the first 2 hours, while copper precipitation appears to start after 2 hours, especially in the absence of pure oxygen. These results also suggest that gold precipitates after 24 hours of leaching. Cyanide consumptions were 1.1 kg/t and 1.6 kg/t at 2 and 8 hours, respectively. According to these results, a maximum gold extraction with lowest cyanide consumption is achieved by reducing the leaching time to 2 hours.

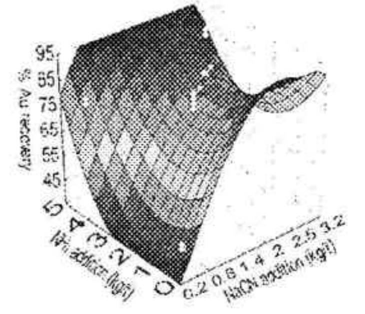

Figure 1 - Gold extraction as a function of cyanide and ammonia concentrations

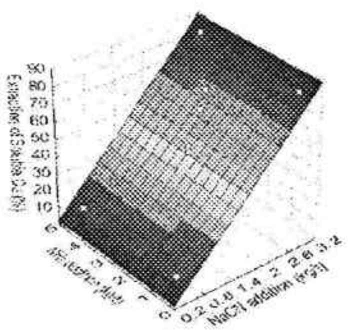

Figure 2 - NaCNsolCu extraction as a function of cyanide and ammonia concentrations

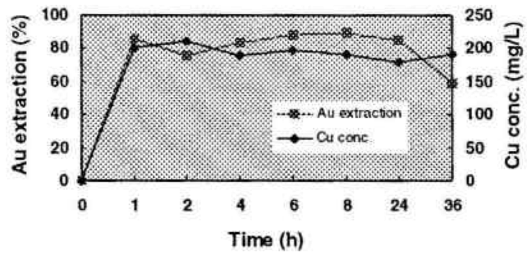

Figure 3 - Kinetics of gold extraction and copper leaching with O_2 under optimal conditions

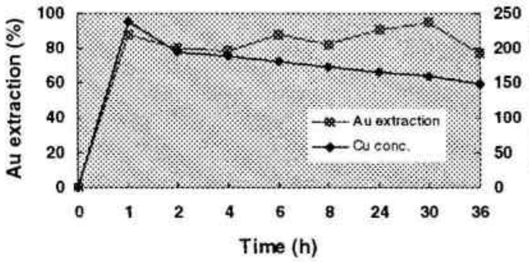

Figure 4 - Kinetics of gold extraction and copper leaching with air under optimal conditions

CONCLUSIONS

Statistical design and analysis of experiments were applied to identify the variables that most affect the ammonia cyanide leaching of a sample of Igarape Bahia oxide ore. The Plackett-Burman design indicated that cyanide and ammonia concentrations and conditioning time have a significant effect on gold extraction, while NaCN concentration was the only variable affecting cyanide consumption and extraction of cyanide soluble copper.

The 2^k complete factorial design with reply in the center points showed that both cyanide and ammonia concentrations as well as their interaction affect gold extraction. Cyanide concentration is the main variable that affects the extraction of copper.

The analysis of variance conducted along the path of steepest ascent indicated that the effect of curvature is significant and therefore, a quadratic model rather than a linear equation more properly represents gold extraction as a function of the process variables. A second order equation was obtained using non-linear regression. A linear model adequately describes the extraction of copper.

The results of the present study indicate that ammonia-cyanide leaching provides gold extractions in excess of 85% of Igarape Bahia ore by using 1.5-2.0 kg/t NaCN and 4.0-5.0 kg/t of NH_3. Additional experiments carried out under optimal conditions showed that gold is leached mostly within the first two hours until a maximum is reached in eight hours. It is to be emphasized that with the use of ammonia both leaching time and cyanide consumption.can be reduced. Over 90% of gold extraction was obtained in less than 2 hours and with cyanide and ammonia concentrations of 1.1 and 4.5 kg/t, respectively.

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