GOLD RECOVERY BY A PROPOSED HEAP LEACHING METHOD, CASE STUDY PIQUE MINE, PORTOVELO - ECUADOR

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Abstract

The objective of this study is to analyze the operational feasibility of gold recovery by the heap leaching method - cyanidation, carried out at the benefit plant that processes minerals from the Pique mine, located in the El Tablón sector of the Portovelo canton in the province of El Oro – case study. For this purpose, elemental and metallurgical analysis tests are used, along with technical feasibility tests through cyanidation tests in bottles and leach column. From the bottle test, a 94.4% metallic recovery of gold was obtained as a result, and 90.88% of the column test at a cyanide concentration of 800 ppm for both cases. To reach these results, this method does not require a prior comminution process since the required granulometry is adequate from the removal of the rock material carried out in blasting, it is not necessary for specialized labor to control reagents, it has low energy consumption and requires little water, which considerably reduces production costs. Leaching minerals extracted from the Pique mine, which have associated precious metals, is technically feasible, since the heap leaching method favors the extraction of elements such as gold, regardless of whether these are low-grade minerals where economic resources could be scarce. For the complete implementation of the process, additional highly technical chemical studies are recommended, as well as to specify the dimensioning of the leaching pile and the irrigation system.

Keywords:*< HEAP LEACHING>, <GOLD RECOVERY>, <CYANIDATION>*

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1. INTRODUCTION

The mineral occurrence in Ecuador is highly varied, for the treatment of these it is necessary the conjugation of many factors in the operations to establish the optimal conditions for the control of the process to be carried out, which is of greater importance in mineral processing plants (Marchese, 2018). In Portovelo located in the province of El Oro, the most abundant mineralization is given by the presence of metallic sulfides corresponding to very disseminated and at the same time abundant pyritization of the veins in volcanic rocks and gabbros; these are veins and veinlets of quartz with the presence of sulfides such as pyrite, chalcopyrite, bornite and galena (Marín, 2022).

The exploitation sectors are Paccha, Huayrapungo and Poites. It mainly comprises a well-defined series of porphyritic andesites (formation of polymetallic veins of mesothermal affinity, and precious metal-rich quartz veins of epithermal affinity). Not all gold and silver ores are suitable for cyanidation treatment (Salinas, 2004). The absence or presence of cyanicidal agents, carbonaceous materials that absorb precious metals, and organic substances consume oxygen from the solution, disrupting the efficiency of the reactions, without forgetting that gold and silver must be finely particulated for rapid dissolution (Flores, 2021).

The minerals processing by cyanide is classified as an ideal technique for the recovery of precious metals (gold and silver), especially with the use of experimental models with which the most important variables that allow optimizing mineral recoveries are identified (Hiskey, 1985). In heap cyanidation, the host rock must be porous and permeable to solution, o sufficient exposure of the particles as a product of the crushing occurs; otherwise, the presence of excessive amounts of clay in some minerals makes percolation difficult, this problem is eliminated by agglomeration of the fines (Tecsup, 2009).

Ecuadorian policy is rigorous with the protection of the environment, therefore, chemical reagents that are naturally degradable should be used in operations, for this reason, the use of mercury is prohibited in the refining plants where legal mining is carried out in Ecuador. Column leaching represents a simulation of heap leaching (a daily operating model carried out in the country) on a laboratory scale, allowing to represent the initial conditions related to the mineral and thus define the optimal treatment to install a leaching pad on an industrial scale (Marín, 2022).

Traditionally, the mineral of interest is placed in columns or tanks, so that the contained cyanide solution dissolves gold (Dorey, 1988). A control of the feed granulometric size must be carried out, likewise the concentration levels of cyanide, oxygen and alkalinity to guarantee maximum gold recovery (Torres, 2018). During this process, the cyanide solution is filtered through the ore contained in piles, tanks or columns. The gold is dissolved by the cyanide and subsequently removed from the column or pad. The extraction of gold from the enriched solution is carried out by means of adsorption on carbon or resins (Dorey, 1988).

Finally, knowing that this refining method provides maximum recovery for a wide range of gold ores, including low-grade ores and some refractories (SGS, 2021), the heap leaching method is defined as the main way for this research, which is the most suitable and optimal recovery process for auriferous minerals metallogenically occurred in the Portovelo canton – Ecuador (Marín, 2022).

2. METHODOLOGY

2.1. Metallurgical Essay

For gold and silver grade analysis, metallurgical essays were carried out in the metallurgical laboratory of the Oroconcent company, which has the physicochemical process of elemental analysis called atomic adsorption spectrometry by fire essay, with which the quantity of grams of mineral per ton is determined, or also defined as parts per million of the elements of interest.

2.2. Alkalinity Testing

Experimental Procedure

1. Collect samples from a dump of material from the stock yard brought directly from the mine, reduce the size of the coarse material to a granulometry of 100% - 1/4".

2. Homogenize and quarter the entire sample until obtaining 2 kg.

3. Add 2 Kg of sample to the bottle, as well as 2 L of water (S/L Ratio 1:1).

4. The duration of the test is 8 continuous hours.

5. Place the bottle on the agitation roller for approximately 1 h.

6. After the agitation time has elapsed, allow the solids to settle until the solution clarifies.

7. Measure and record the pH of the clarified solution (natural pH of the mineral).

8. Using the analytical balance, weigh a certain quantity of lime and record the data.

9. Add the lime in the bottle and let it shake on the roller for a period of 2 hours. At the end of this time, let the solids settle until the solution is clarified, then measure the pH.

10. Continue with this sequence until reaching a pH ≈ 11.6.

11. Once the test is finished, separate the pulp from the bottle in a container.

12. Add flocculant and shake, allow solids to settle and discard clear solution, then discard the solids to the waste mound to be sent to the Tailings field.

13. Establish the lime ratio in accordance with the calculation shown in Table 1.

Table 1: Lime ratio to establish pH of 11.6.

Samples	Lime (g)	Accumulated Lime (g)	Ratio (Kg/Ton)
1	1.725	1.725	1.725/2.00 = 0.8625

→ Lime Ratio = 0.8625 Kg. Lime / Ton of mineral

2.3. Bottle Cyanidation Test

Experimental Procedure

1. Pulverize 1kg of material, homogenize it and quarter it, weigh 500 g for bottle assay and send 500 g to Chemical Laboratory for Au readings.

2. Add the 500 g sample to the bottle, then add 750 ml of water (S/L Ratio 2:3).

3. Leave the mixture in the roller agitator for a period of 1h.

4. After the time has elapsed, let the solids settle and measure the natural pH of the mineral.

5. Add a dose of lime, depending on the mineral's acidity.

6. Place the bottle on the roller agitator for half an hour.

7. Once the stirring time has been completed, settle the solids and measure the pH of the solution.

8. Add lime to the bottle if the pH is less than 11 until reaching a pH of 11.6.

9. Condition the 3% cyanide solution to carry out the bottle test.

10. According to the quantifications established for the test, add the required quantity of 3% NaCN solution; place the bottle on the agitation roller.

11. Bottle assay controls are every 4 hours up to a total of 72 hours to assess the highest percentage of Au extraction.

12. Turn the roller off after 4 hours of agitation, allow the solids to settle and take a 40ml sample from the clarified solution, 10 ml to titrate the NaCN concentration and 30 ml to send to the Chemical Laboratory for reading by Au.

13. Quantify the pH of the clarified solution. If the pH is less than 11, add a quantity of lime to the bottle. Likewise, if the NaCN concentration is less than the initial concentration, make the respective NaCN adjustment. Carry out the calculation to compensate with the solution prepared at 3% NaCN.

14. Once finished, evacuate the solids from the bottle into a container, add water and flocculant, shake it and let it settle, subsequently discard the clarified solution. Repeat the wash a minimum of 3 times to ensure removal of residual NaCN in the solids.

15. Pour the solids (rubble) into a container, finally send to Chemical Laboratory for Au readings.

2.4. Column Cyanidation Test

Experimental Procedure

1. Install the containers to be used for the irrigation, pregnant and barren solution.

2. Place the carbon columns in the discharge of the leach column, while locating a rich solution sampler before it enters the coal column.

3. Add the required amount of water to the container designated for the irrigation solution. This solution is calculated according to the diameter of the column and the irrigation rate for a 24-hour time.

4. Add according to the calculations made for the test, lime and sodium cyanide concentration at a pH of 11.6 to the irrigation solution.

5. Regulate the flow of irrigation solution entering the column according to the irrigation rate established for the test.

6. Record the irrigation start time.

7. Record the drainage time of the first drop of the solution and thereby determine the percolation rate of the mineral.

8. After 24 hours of irrigation, proceed to quantify the volume of percolated barren solution, if this solution is less than the irrigation start volume, adjust the irrigation solution, as well as the pH and NaCN concentration to the initial test conditions.

9. From the pregnant and barren solution, take a sample, and send to the Chemical Laboratory for Au, pH and NaCN analysis.

10. Start the column irrigation again and continue with the procedure every day.

11. The leaching cycle ends when the Au values in the pregnant solution are below 0.010 ppm. Once the process is complete, the column is washed with water only, always taking samples of pregnant and barren solution until the concentration of NaCN in pregnant is less than 10 ppm. The barren solutions back into the irrigation solution, with the objective of recirculating the cyanide solution by adding the amount of additives required to equal the initial concentration.

12. Subsequently, drain the solution from the column, removing the carbon columns, leaving the solution free.

13. Finally, after having drained the column, proceed to unload the rubble for their corresponding metal essay.

3. RESULTS

3.1. Metallurgical Essay

All the tests were carried out in the metallurgical chemical laboratory of the company. For the alkalinity and cyanidation tests in the bottle, 6 kg of a dump of material (approx. 30 tons) were sampled, followed by quartering it and taking it to comminution processes (jaw crusher) to reduce its size (< 2cm). The sample was dried on stoves over low heat. 1kg was taken to be sent to the chemical laboratory for the gold grade analysis, which is represented in table 2.

Table 2: Gold Law Results.

RESULTS OF ORE GRADES IN THE CHEMICAL LABORATORY		
N°	CODE	Au (g/Ton)
1	SAMPLE TEST PIQUE	0.53

3.2. Alkalinity Testing

The ore is prepared for alkalinity tests, which will help us to have knowledge of the reagent consumption to take the first metallurgical test required for the heap leaching project as a starting point. The ore is prepared for alkalinity tests, which will help us to have knowledge of the reagent consumption to take the first metallurgical test required for the heap leaching project as a starting point.

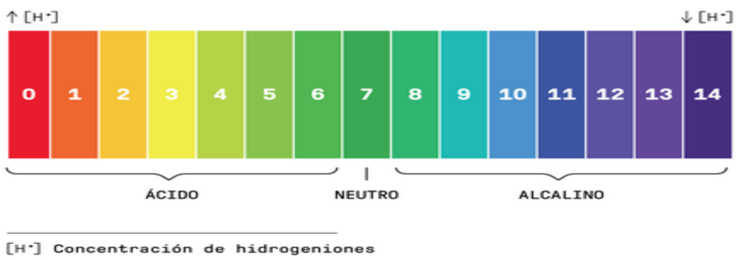
As the next point, the sample was weighed and the amount of water in the bottle was added, this was done in duplicate, in the first hour the natural pH (6.30) was taken, for a total agitation time of 8 hours, obtaining accumulated lime for the averages of sample 1 and sample 2, 1.75 and 1.7 respectively, giving an average of 1,725 lime with which the rate calculation was established according to the equation mentioned in the previous chapter, thus the following table shows a summary of this analysis (Table 3).

Table 3: Lime rates at 11.6 for heap leaching.

RATIOS DE CAL A 11.6 PARA LIXIVIACIÓN EN PILAS						
TEST	MINERAL	ALTERATION	Natural pH	Accumulated Lime (g)	Shaking Time	Cal rate pH 11.6 (kg/Ton)
AGITATION IN BOTTLE	PIQUE	SATQC	6.30	1.725	8 hours	0.8625

It can be observed that the PIQUE mineral at a natural PH gives us a reading of 6.30 which allows us to interpret that it is slightly acid on the scale of 1 - 14.

Natural PH
6.30



The lime rate for a PH of 11.6 is 0.8625 Kg Cal/Ton of mineral, which is favorable for the heap leaching process.

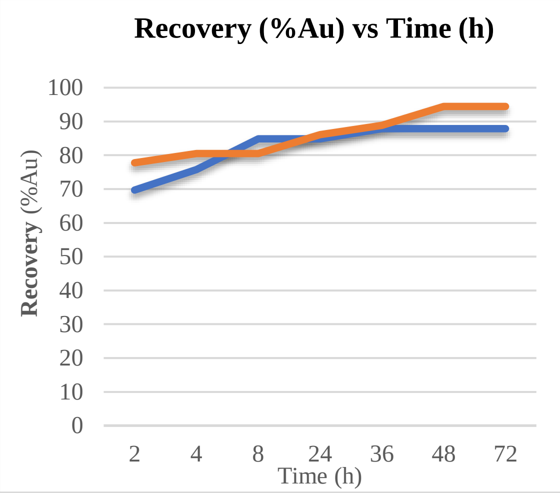
3.3. Bottle Cyanidation Test

In the first instance, 2.5 kg of sample was pulverized in the ball mill, followed by homogenizing and quartering it. 500g was sent to the laboratory, the rest was used to perform the test in duplicate to reduce errors and estimate the most realistic values possible. Subsequently, the sample was tared in the bottles with water in a 2:3 S/L ratio. Next, the bottles were placed in the roller shaker according to the times established in the previous chapter, it is worth mentioning that before starting to count hours of agitation, the mass values of the reagents were established to reach the concentrations required for the test, followed by their control. The gold recovery results according to the bottle test are shown in the following table 4:

Table 4: Gold recovery results in bottle test.

BOTTLE CYANIDATION TEST										
TEST PARAMETERS			TIME				REAGENT CONSUMPTION			
Mesh granulometry - 200			Start date:	17/8/2021	End date:	20/8/2021	NaCN:	0.153	Kg/Tn	
Mineral weight, Kg	0.5	0.5	Start Time:	08:20	End time:	08:20	Lime:	2.9	Kg/Tn	
Solution volume, L	0.75	0.75								
Dilución	1.50	1.50								
Mineral pH	6.3	6.3								
	B1	B2								

	TEST B1						TEST B2					
Agitation H	NaCN ppm	NaCN 3% Aggregate, ml	PH	Lime, g Aggregate	grades Au, ppm	Recovery % Au	NaCN ppm	NaCN 3% Aggregate, ml	PH	Lime, g Aggregate	grades Au, ppm	Recovery % Au
0	200	3.50	11.6	1.30			750	20.50	11.6	1.30		
4	175	1.20	11	0.05	0.23	69.70	775	0.50	11	0.05	0.28	77.78
8	250	-	11.3	-	0.25	75.76	800	-	11.3	-	0.29	80.56
12	200	-	11	0.05	0.28	84.85	750	0.80	11	0.05	0.29	80.56
24	200	-	11	0.05	0.28	84.85	760	1.00	11.3	-	0.31	86.11
36	175	1.20	11	0.05	0.29	87.88	800	0.25	11	0.05	0.32	88.89
48	225	-	11	0.05	0.29	87.88	800	-	11.3	-	0.34	94.44
72	200	-	11	-	**0.29**	**87.88**	800	-	11	-	**0.34**	**94.44**
TOTAL		**5.90**		**1.55**				**23.05**		**1.45**		



	RESUME	
	TEST B1 Au (g/Tn)	TEST B2 Au (g/Tn)
TAIL GRADE	0.06	0.03
LIQUID GRADE	0.44	0.51
TOTAL	0.50	0.54
% RECOVERY	**87.88**	**94.44**

The results of the test on bottles at different concentrations of NaCN, it can be appreciated that the percentage of recoveries of the Silicified Andesite Tuff alteration with Quartz and Calcite content (SATQC), they are between 87.88% and 94.44 % at NaCN concentrations of 200 and 800 ppm, respectively.

3.4. Column Cyanidation Test

In the first instance, the leaching column was installed with the respective containers for the pregnant, irrigation, activated carbon and barren solution. Then proceeded to prepare the irrigation solution at a concentration of 800 ppm of NaCN, for which 16 g of it was needed in 20 liters of water. At the same time, the flow rate (Q) was also calculated for a 24-hour drip time, resulting in Q = 10.6 ml/min. The control of the reagents (NaCN and Lime) and pH was carried out every day that the test is executed in the irrigation, pregnant y barren solution, in these last two, the Au grade analysis was also carried out (in the coals until they are saturated). In the following table 5, the results of this metallurgical test can be seen.

Tabla 5: Summary of Au extraction percentages according to the metallurgical balance.

OPERATION DATA	
metallurgical code	**LMPC-01**
Sample	**TASCC**
particle size	**100% -1 ½ " (3.81 cm)**
Humidity (%)	**1.12**
Percolation speed (m/day)	**1.02**
Lime rate (kg/Ton)	**0.8625**
Initial dry bulk density (kg/m³)	**1816**
Flow rate (ml/min)	**10.6**
Cyanide Concentration (ppm)	**800**
Total Lime Consumption	**0.638**

EXTRACTIONS SUMMARY		
Analizada		
Head (g/Ton)	**Gravels (g/Ton)**	**Extraction (%)**
Au	Au	Au
0.28	0.026	90.71

Calculated (Extraction in solutions and gravel)		
Calculated head (g/Ton)	**Gravels (g/Ton)**	**Extraction (%)**
Au	Au	Au
0.282	0.026	90.78

(kg/Ton)	
Total Cyanide Consumption (kg/Ton)	**3.724**
Mineral water (L)	**0.84**
Column diameter (cm)	**28.5**
Column height (cm)	**79**
Initial height of ore (m)	**0.64**

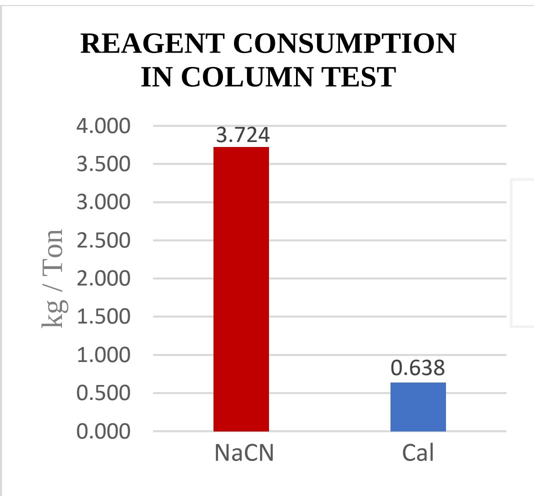
Calculated (Coal and gravel extraction)		
Calculated head (g/Ton)	**Gravels (g/Ton)**	**Extraction (%)**
Au	Au	Au
0.294	0.026	91.16

REAGENT CONSUMPTION		
NaCN:	3.724	Kg/Ton
Cal:	0.638	Kg/Ton

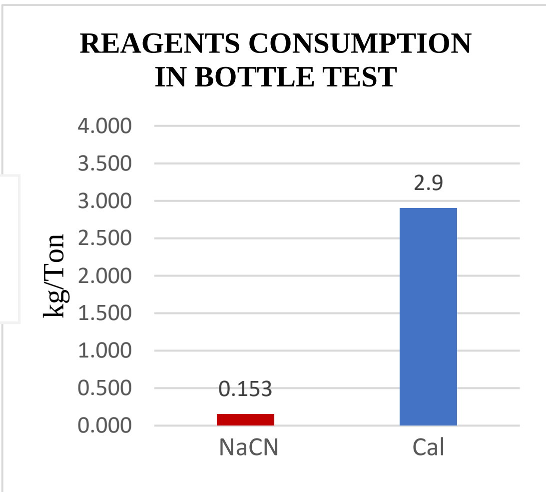
Table 6: Gold recovery results according to coal analysis

Coals							**Gravel**			**Balance**	
Carbon Column	**wet weight**	**Humidity**	**Dry weight**	**Au g/Ton coal**	**Metal parcial en Au**	**Total Metal in Coal (Au)**	**Dry weight**	**Au grade**	**Metal in rubble (Au)**	**Total Metal (Au)**	**Au recovery**
	(g)	**(%)**	**(g)**				**kg**	**g/Ton**	**g**	**g**	**%**
1	2600	39.62	1569.88	12.66	0.01987	0.01987	74.160	0.026	0.002	0.022	91.16

The Au recovery of the SATQC material reached 90.71% according to the head analyzed (solids), 90.78% extraction of Au with calculated head and 91.16% extraction of Au in coals and rubble (Table 6), in 10 days leaching at a cyanide concentration of 800 ppm. Reagent consumption of column test compared to bottle test:



VS



According to the test, it presents a consumption of 0.638 Kg Lime / Ton of Mineral and 3.724 Kg NaCN / Ton of Mineral.

4. CONCLUSIONS AND RECOMMENDATIONS

Once the investigation has been carried out, a 94.4% metallic recovery of gold is obtained at a cyanide concentration of 800 ppm, using the cyanidation method by means of the bottle test. It is important to mention that the heap leaching method used in the investigation, since it does not require pretreatment of the material (comminution) before the cyanidation process, reduces grinding costs because from the start of the material there is an ideal granulometry (1.5 - 3/4 inches) for the process.

The percentage of gold extracted during the application of the column test is 90.88% at a cyanide concentration of 800 ppm, providing an economically profitable process due to low consumption of reagents, including lime; It is important to mention that the proposed method is applicable mainly for low grades, including tailings material containing a minimum percentage of mineral of interest.

It is recommended to take into consideration the appropriate materials and parameters for the leaching process, such as the 2-head peristaltic pump with a controlled flow of 0-120 ml/min, pvc tubes with a diameter of 17.5 inches by 3 meters in length, and non-woven geotextile type 1600 of an area = 1 m^2, to obtain a representative and replicable quantification of the results of the Heap Leach method obtained.

It is suggested that, for the final obtaining of the gold anode, pregnant solution from leaching operations must be treated in various ways to precipitate dissolved metal values and recover them in solid form. These include electrolytic deposition, metal ion transfer, chemical precipitation, solvent extraction in combination with electrolytic and chemical methods, and carbon adsorption combined with electrolysis.

Finally, it is concluded that the material extracted from the Pique mine does not contain cyanicidal agents, which requires low cyanide consumption in the gold extraction process, generating higher economic profitability for plants that use this method with a mineral congruent on this investigation. Therefore, it can be concluded that the heap leaching method is technically feasible for implementation in refining plants in Ecuador, prioritizing those located in the province of Oro, which have the metallogenesis of the Pique Mine case study that has been carried out.

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