Recovery of copper and precious metals from chalcopyrite low grade ores - choice between flotation or microorganisms leaching

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ABSTRACT: The conventional flotation technologies cannot provide fair results when to applied to very low grade ores or to "refractory" ores. This class include intimate and nonuniform mineral associations, with partialy oxidized minerals and high secondary mineral content and also high soluble salt content, pre-activated minerals because of the excessive permeability of the deposit and of the intense circulation of waters with heavy metal ions etc. Bacterial oxidation as a means to the recovery of metals from sulphidic deposits has been used for thousands of year. One of the major use of biooxidation is the leaching of copper or the liberation of refractory gold where this is encapsulated in pyrite. In the Bucim copper mine Macedonia, porphiritic type, the final product from flotation is the copper concentrate consisting 20% Cu, 21 g/t gold and 25 g/t silver, with appropriate recoveries: 88% for copper, 60% for gold and 35% for silver. The carried out investigations of the leaching in the agitated tank involve microorganisms, tiobacillus ferro-oxidans and thiobacillus thio-oxidans. The achieved results are following: copper recovery 95%, gold recovery from 70-85% and silver recovery from 70-80%.

1. INTRODUCTION

Bucim copper and gold mine is the unique mine in the Republic of Macedonia located in the southern part of country on the south-west slopes of the Plackovica mountain. The mine is situated 130 km from the Republic capital - Skopje, 13 km from Radovis, and 2.5 km from the road connecting Stip with Strumica.The unique copper mineralization of a porhiric type is occurring in the gneisses to their contact with the andesites. The mineral content decreases gradually with increasing distance from the contact and occurs principally as fillings and coatings on fracture plans. Andesites are barren in general, however, copper mineralization associated with fractures and joining is found in the andesites as well.After 1979 the first tones of the copper concentrate are product. Since that time to this day the Bucim mine permanent has realised a good production - financing results including itself in the leader country companies. Mine of the open type is the basis characteristic of the Bucim mine. The mine is equipped with modern mechanisation making possible about the high productivity and good operating conditions for the operators. The process includes drilling and blasting, then blasted ore is transported towards primary crushing while the tailing on the mine disposal. The mineral Processing and ore concentration processes cover the following technological operations: primary, secondary and tertiary crushing, screening and storing, grinding and classification, flotation concentration, regrinding, thickening and filtering and finally the tailing removal in tailing pond.

The technological parameters of the average (1982 - 1994) production of 3,486,036 t/y are followed:

Q	mined ore, t/y	3,486,036
H_2O	(%)	2
Q	treated dry ore, t/y	3,416,315
Cu	Cu content, (%)	0.27
C/Cu	Cu concentrate, t/y	43,878
k/Cu	grade, (%)	18 -20
R/Cu	Cu-recovery, (%)	88
T	tailing, t/y	3,372,438
t/Cu	Cu in tailing, (%)	0.03
R/Au	Au - recovery, (%)	60
R/Ag	Ag - recovery, (%)	35
k/Au	Au in concentrate, g/t	21
k/Ag	Ag in concentrate, g/t	25
Tp	available time, h/y	8,760
Tef	effective time, h/y	7,270
Tb	effective time, (%)	83

2. BIOHYDROMETALLURGY AS AN EXTRACTION TECHNOLOGY FOR METALS

The last years have seen a growing interest in fun- damental biohydrometallurgical phenomena, and a slow but steady increase, both in the range of ap- plications and in the sophistication of the new tech- nology. Biohydrometallurgy is applied on an unpre- cedented scale throughout the world to scavenge Cu from low-grade materials such as waste rocks, and to a lesser extent to extract uranium minerals. The com- mercial use of biohydrometallurgical processes to extract gold from refractory ores is also on the way.

Additionally, the ability of microorganisms to reco- ver metals from solutions is increasingly finding ap- plication in various industries but mainly in the tre- atment of industrial effluents.

The mechanisms through which micro-organisms oxidize sulphide minerals are complex and are not fully undersood. Nonetheless, two mechanisms, ter- med **direct oxidation** and **indirect oxidation**, have been identified (a variety of micro-organisms are associated with the bacterial leaching of minerals). Direct oxidation, refers to reactions which are direct- ly catalysed by micro-organisms (reactions: 1,2,3). Indirect oxidation, refers to reactions which utilize the oxidation properties of ferric iron and may be re- presented by the reaction of the type (4).

It may be shown that reaction (4) proceeds in two stages, one of which is catalysed by bacteria , (5&6)- *Thiobacillus ferro-oxidans or Thiobacillus thio-oxi- dans and Leptospirilum ferro-oxidans.*

The oxidation of ferrous iron to ferric iron:

$$2Fe^{2+} + \frac{1}{2}O_2 \xrightarrow{\text{bacteria}} 2Fe^{3+} + H_2O \quad (1)$$

The oxidation of pyrite and sulphur:

$$2FeS^{2+} + \frac{15}{2}O_2 + H_2O \xrightarrow{\text{bacteria}} Fe_2(SO_4)_3 + H_2SO_4 \quad (2)$$

$$S_8 + 12O_2 + 8H_2O \xrightarrow{\text{bacteria}} 8H_2SO_4 \quad (3)$$

$$FeS_2 + 2Fe^{3+} + 3O_2 + 2H_2O \longrightarrow 3Fe^{2+} + 2SO_4^{2-} + 4H^+ \quad (4)$$

$$FeS_2 + 2Fe^{3+} \longrightarrow 3Fe^{2+} + S^0 \quad (5)$$

$$2S^0 + 3O_2 + 2H_2O \xrightarrow{\text{bacteria}} 4H^+ + 2SO_4^{2-} \quad (6)$$

3. LABORATORY INVESTIGATIONS OF THE COPPER SELECTIVE FLOTATION IN THE STANDARD AND NEW OPERATING CONDITIONS

The representative samples from the Bucim mine were with the average Cu - contend from 0.33 - 0.36 %. The laboratory scale tests from the selective copper flotation were made for the copper mineral chalcopyrite with present gold and silver, depending on different reagent regimes and the reagents consumption using the same conditions to determine the optimal conditions for recovery in rougher selective concentrate.

Table 1.

Test N°	GRINDING Collector (g/t)	CONDITIONING Collector (g/t)
1	KEX:KBX=1:1	NaIPX
2	ORFOM-C 0800	NaIPX
3	KEX:KBX=1:1	NaIPX
4	KEX:KBX=1:1	NaIPX
5	ORFOM-C 0800	ORFOM-C 0800
6	PENFLOT-3	PENFLOT-3
7	ORFOM-C 0800	NaIPX
a	(PENFLOT-3)	(PENFLOT-3)
b		

Table 1a.

Test N°	FLOTATION Collector (g/t)	Frother (g/t)
1	NaIPX	Dow - 250
2	NaIPX	Dow - 250
3	ORFOM-C 0800	Dow - 250
4	NaIPX 15 g/t ORFOM-C 0800 10 g/t	Dow - 250
5	ORFOM-C 0800	Dow - 250
6	PENFLOT-3	Dow - 250
7	NaIPX	Dow - 250
a	(PENFLOT-3)	Dow - 250
b		

Table 2. Results obtained from test N°-1

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag
Feed	0.35	0.54	1.10	100	100	100
C	5.19	6.80	7.60	90.8	77.3	41.4
T	0.03	0.13	0.70	9.2	22.7	58.6
∑	0.35	0.54	1.10	100	100	100

Table 3. Results obtained from test N°-2

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag
Feed	0.35	0.40	1.13	100	100	100
C	5.01	5.40	7.60	90.4	85.8	42.2
T	0.04	0.06	0.70	9.6	14.2	57.8
∑	0.35	0.40	1.13	100	100	100

Table 4. Results obtained from test N°-3

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag

Feed	0.33	0.34	1.12	100	100	100
C	4.72	4.40	7.40	89.8	80.8	41.4
T	0.04	0.07	0.70	10.3	9.2	58.6
∑	0.33	0.34	1.12	100	100	100

Table 5. Results obtained from test N°-4

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag
Feed	0.33	0.52	1.11	100	100	100
C	4.85	5.70	7.40	90.2	80.7	41.2
T	0.03	0.09	0.70	9.8	9.3	58.8
∑	0.33	0.52	1.11	100	100	100

Table 6. Results obtained from test N°-5

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag
Feed	0.36	0.51	1.09	100	100	100
C	3.94	5.20	5.90	91.2	82.6	45.4
T	0.03	0.10	0.65	8.8	17.4	54.7
∑	0.36	0.51	1.09	100	100	100

Table 7. Results obtained from test N°-6

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag
Feed	0.33	0.50	1.10	100	100	100
C	3.57	4.70	6.00	89.7	77.9	45.4
T	0.04	0.12	0.65	10.3	22.1	54.6
∑	0.33	0.50	1.10	100	100	100

Table 8. Results obtained from test N° - 7a

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag
Feed	0.34	0.45	1.13	100	100	100
C	18.8	20.2	21.2	76.2	63.2	26.3
m 1	4.20	9.20	9.00	10.3	17.5	6.8
m 2	0.38	0.60	2.80	3.9	4.8	8.5
T	0.03	0.07	0.70	9.56	14.5	58.4

Table 9. Results obtained from test N°-7b (rougher + 2 cleaning)

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag
Feed	0.35	0.62	1.08	100	100	100
C	16.9	22.8	19.0	72.4	55.8	26.8
m 1	2.88	10.3	6.30	10.7	22.0	7.8
m 2	0.44	0.55	2.10	6.1	4.4	9.7
T	0.04	0.12	0.65	10.8	17.8	55.7

4. INDUSTRIAL SCALE INVESTIGATIONS OF THE COPPER SELECTIVE FLOTATION IN THE STANDARD AND NEW OPERATING CONDITIONS

The one month copper ore twice from the Bucim mine was treated industrial by selective scheme of flotation by aim to recovery chalcopyrite and present gold and silver, depending on different reagent regimes (standard: KEX:KBX or NaIPX).

The results obtained by these investigations are given on the followings tables with contemporary industrial technological indicators.

Table 10. Results obtained from selective Cu flotation at reagent regime: standard

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag
Feed	0.28	0.38	1.12	100	100	100
C	19.7	14.2	24.5	87.5	55.0	29.3
T	0.04	0.18	0.80	12.5	45.0	70.7
∑	0.29	0.38	1.12	100	100	100

Note: 128,000 t

Table 11. Results obtained from selective Cu flotation at reagent regime: new

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag
Feed	0.27	0.39	1.10	100	100	100
C	20.8	16.0	27.5	88.7	63.5	33.8
T	0.03	0.14	0.74	11.3	36.5	66.2
∑	0.27	0.39	1.10	100	100	100

Note: 128,000 t

Table 12. Results obtained from selective Cu flotation at reagent regime: standard

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag
Feed	0.25	0.49	1.15	100	100	100
C	18.5	21.1	25.2	86.0	58.0	30.5
T	0.03	0.21	0.81	14.0	42.0	69.5
∑	0.25	0.49	1.15	100	100	100

Note: 235,000 t

Table 13. Results obtained from selective Cu flotation at reagent regime: new

	Grade (%) or g/t			Recovery (%)		
	Cu	Au	Ag	Cu	Au	Ag
Feed	0.25	0.48	1.17	100	100	100
C	19.3	23.2	26.1	87.5	64.3	35.2
T	0.03	0.17	0.77	12.5	35.7	64.8
∑	0.25	0.48	1.17	100	100	100

Note: 235,000 t

5. LABORATORY INVESTIGATIONS OF THE LEACHING AND BIOLEACHING

The laboratory investigations of the copper sulphide (chalcopyrite) leaching is carried out by conventional method: **ammoniacal leaching.** The leaching of

the presence gold and silver is carried out by method of **cyanidation.** The reactions are following:

Cu^{2+} =>>> $Cu(NH_3)^{2+}_4$

Au =>>> $Au(CN)^-_2$

Ag =>>> $Ag(CN)^-_2$

The laboratory investigations from bioleaching for the chalcopyrite and presence precious metals - gold and silver are carried out by Ferro-oxidans: Thioba - cillus and Leptospirilum.
Cumulative laboratory results are given on the next table - recoveries for Cu, Au and Ag.

Table 14. Laboratory cumulative results

Conditions	Recovery (%)		
	Cu	Au	Ag
Leaching	93.4	84.7	75.4
Thiobacillus fero-oxidans	96.5	86.8	81.2
Leptospirilum fero-oxidans	95.4	84.7	85.0

6. CONCLUSION

In spite of relatively low grade mined ore over the both intensive laboratory scale and industrial technological investigations ore obtained a fairly good results achieving the significant copper recovery and significant improved gold and silver extraction.

Varied ratio of different applied collectors in the grinding, conditioning and flotation circuit gives the following optimal laboratory scale results:

Conditions	Recovery (%)		
	Cu	Au	Ag
Standard	90.85	77.27	41.36
New-Orfom C0800	91.18	82.66	45.43
New-Penflot - 3	92.50	77.26	48.71
Varied	90.35	85.82	42.20

Contemporary parallel industrial scale investi-gations give the following optimal results:

Conditions	Recovery (%)		
	Cu	Au	Ag
Standard	87.50	55.02	29.30
New	87.50	64.25	35.20

The evident disproportional between laboratory scale results and industrial scale results are appeared on the Au and Ag recoveries. Firstly, the treated ore in the laboratory scale tests is richer (0.33 - 0.36 % Cu) than treated ore in the industrial scale tests (0.246 - 0.285% Cu). It may be explained because of unpleasant and sharp smell (ORFOM - C 0800 and PENFLOT - 3) in the flotation plant. For that reason the collector producer must remove this unpleasant appearance.
It's evident advantage of the achieved results by leaching and bioleaching for the porphiritic type of ore relating to the conventional flotation using standard or new reagent regime.

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