

FLOTATION OF A SILICATED OXIDE COPPER-COBALT ORE FROM THE FUNGURUME DEPOSIT

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ABSTRACT

The Fungurume deposit is one of the most important ore reserves located in the Katanga Province of the Democratic Republic of Congo. In this area, oxidised copper mineralization is mainly malachite, with the presence of pseudomalachite, chrysocolla and cuprite in varying proportions. Cobalt occurs primarily as heterogenite. The Fungurume orebody is characterised by a high copper silicate (chrysocolla) content of about 25 % of total copper. Silicate species are known to be difficult to float. For this reason, it was necessary to develop a suitable flotation method in order to produce a concentrate which can readily be amenable to efficient metallurgical processing.

Laboratory investigations on the flotation of silicate bearing oxidised copper-cobalt ores have been carried out on an ore sample from the Fungurume deposit. This ore contained 0.90 % Co as heterogenite and 9.06 % Cu as malachite (74 % of Cu content), chrysocolla (24 %) and sulphide copper (2 %). The gangue minerals were mainly siliceous. Flotation tests have been performed by applying two different methods: direct flotation with fatty acids and sulphidizing flotation with the use of a combination of collectors. Hydrolysed palm oil has been used as collector in the first series of experiments. In the second series, after superficial sulphidization with sodium hydrosulphide (NaHS), potassium normal -butyl xanthate (PNBX) has been used as the main collector, strengthened by a secondary collector, an emulsion of a fatty acid bearing mixture. Operating conditions have been optimised. Flowsheet simulation tests have also been conducted.

From the test results, it has been confirmed that, with a well suited combination of reagents, the sulphidizing flotation method is most effective for the treatment of silicated oxide copper-cobalt ores. Flotation recoveries of about 94.8 % Cu and 90.1 % Co in a concentrate assaying in average 17.5 % Cu and 1.5 % Co were recorded. A standard rougher-scavenger circuit has been recommended, since cleaning flotation will induce important metal loss in tailings.

INTRODUCTION

The Fungurume orebody contains silicated copper up to more than 25% of the oxidised copper minerals. Mineralogical studies on the ore sample used in this work revealed the presence of copper as malachite, pseudo-malachite, chrysocolla and traces of copper sulphide. Cobalt is present as heterogenite (Banza,1993).

It is known that chrysocolla is resistant to flotation because of its negative zeta-potential in the presence of usual copper flotation reagents. Many studies have been carried out to recover copper from ores with a high chrysocolla content by using some complexing type reagents like potassium laurylhydroxamate as collector (Ngoy, 1977; Simanga, 1971). Recently, efforts have been made to develop new chelating type collectors for the flotation of all copper minerals including refractory ones like chrysocolla (Barbaro, 1997; Fuerstenau, 2000). It has been demonstrated that the currents which arise at points of contact between minerals having different potentials have an effect on reactions with various agents (Glembotshi, 1972). It is also well known that addition of a nonpolar reagent to a heteropolar one improves the flotation results and that the adhesion force between a bubble and a particle increases with the concentration of the nonpolar reagent alongside the contact perimeter bubble-particle (Klassen, 1963). The combination of polar and nonpolar reagents was therefore applied in this study in order to increase the recoveries of cobalt and copper values including chrysocolla.

EXPERIMENTAL

Ore samples

The ore sample used in this study was a composite from different levels of the Fungurume deposit whose chemical composition is given in Table I.

Table I: Chemical composition of the ore sample, Assay in % (tot: total, mal: malachite)

Cu _{tot}	Cu _{mal}	Co _{tot}	MgO	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃
9.06	6.71	0.90	3.46	49.44	0.33	1.87

From the mineralogical analysis, predominance of malachite (74 % of Cu content) in the ore has been confirmed, followed by chrysocolla (24 %) and copper sulphide (2 %). The gangue minerals are mainly quartz and iron oxide like goethite and limonite, with very little dolomite. Cobalt is present as heterogenite.

The liberation studies indicated that good liberation can be achieved when grinding the ore to 30% + 200 mesh (74 µm); but the ore presents a strong tendency to build fine particles during milling. A size distribution analysis confirmed that about 50 % of copper and cobalt is present in fine particles under 400 mesh (38 µm).

Reagents and test procedures

The reagents were added to the flotation pulp as aqueous solutions, except the frother Senfroth G41 which was used without previous dilution. In sulphidizing flotation, sodium hydrosulphide (NaHS) was used as sulphidizing agent, potassium normal-butyl xanthate (PNBX) as the main collector, strengthened by an emulsion of a mixture containing 90 wt % gasoil and 10 % hydrolyzed palm oil as secondary collector. Sodium carbonate (Na₂CO₃) was added to this mixture in the proportion of 10 % of gasoil quantity to stabilise the emulsion. Sodium silicate (Na₂SiO₃) was used as dispersant and depressant of gangue minerals. In the flotation test series with fatty acids, the collector was a mixture of hydrolysed palm oil (72 %), gasoil (24%) and tall oil (4%) to which Na₂CO₃ (10% of gasoil quantity) was added. In this case, addition of frother was not necessary, since the fatty acid collector also exhibits frothing properties.

After grinding at 30 % + 200 mesh, the specific weights of the pulps were adjusted before flotation at about 1350 g/l. Flotation was performed with a mechanical laboratory machine at natural pH 9.5 for 12 minutes.

RESULTS AND DISCUSSION

Direct Flotation with fatty acids

With Na₂SiO₃ 600 g/t and Na₂CO₃ 1000 g/t added, the influence of palm oil addition is shown in [figure 1](#). Higher copper and cobalt recoveries can be achieved only by higher palm oil dosage. Maximum recoveries of

94.3% Cu and 85.9% Co were recorded at a palm oil dosage of 1700 g/t, but the concentrate grades were very low. Because of the very low selectivity, flotation with palm oil was excluded for this kind of ore.

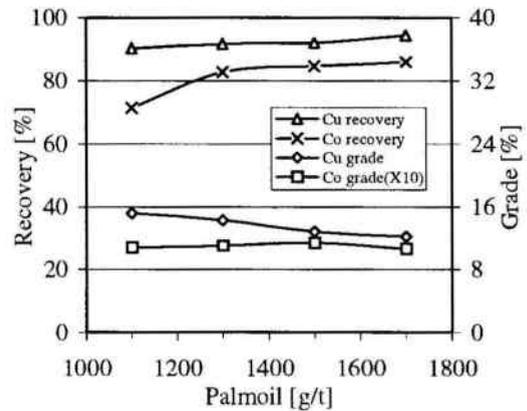


Fig. 1: Effect of palm oil addition on copper and cobalt flotation

Sulphidizing flotation

Effect of sodium hydrosulphide

The results shown in [figure 2](#) were achieved with a dosage of 400 g/t PNBX, 150 g/t of the mixture, 250 g/t Na₂SiO₃, 30 g/t Senfroth G41 and 400 g/t Na₂SiO₃. Best results were recorded at 4000 g/t NaHS: 94.8 % Cu and 90.1 % Co were recovered in a concentrate assaying 17.5 % and 1.5 % respectively.

At higher NaHS dosage, flotation decreased for both copper and cobalt. These facts are also demonstrated in [figure 3](#) where copper recovery-copper grade correlation curves are presented.

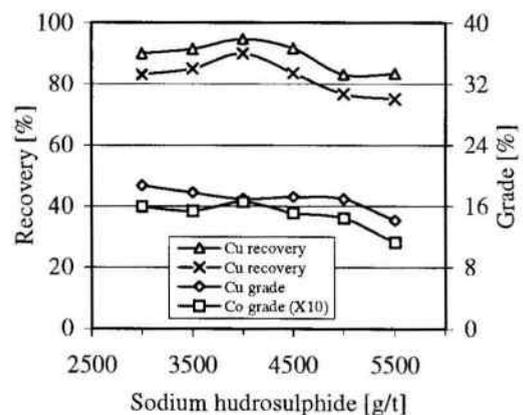


Fig. 2: Effect of NaHS dosage on copper and cobalt flotation

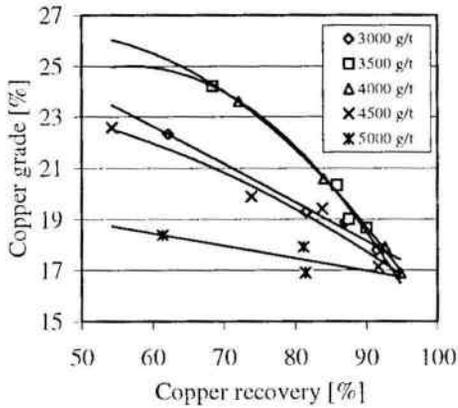


Fig. 3: Copper recovery-copper grade correlation curves at different NaHS dosages

Mineralogical observation of the tailings has shown about 50 % of unfloted copper in form of chrysocolla, the remainder being malachite which was to nearly 30 % impregnated in gangue.

Effect of the collector PNBX

Results of the flotation tests carried out with 250 g/t Na_2SiO_3 , 150 g/t mixture, 30 g/t Senfroth G41 are shown in figure 4. Dosage of NaHS was 10 times that of collector, as required in the industrial praxis. The recoveries increased to more than 95 % Cu and 90 % Co with increasing PNBX quantities. At PNBX dosage higher than 500 g/t, increase of copper and cobalt recoveries was very slow.

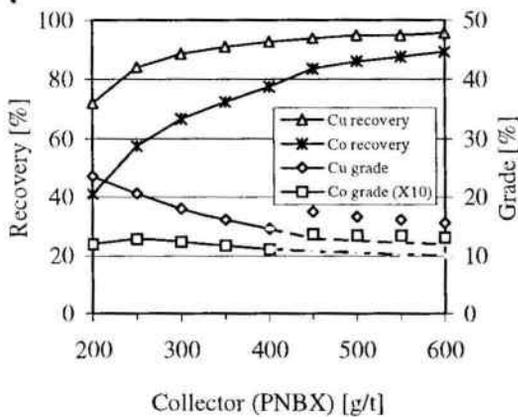


Fig. 4: Effect of PNBX on copper and cobalt Flotation

Effect of the secondary collector mixture

Results of flotation tests using 4000 g/t NaSH, 500 g/t PNBX and 250 g/t Na_2SiO_3 by varying dosage of the secondary collector mixture are presented in figure 5.

The effectiveness of addition of this mixture to the flotation system was clearly demonstrated. Without the mixture, both copper and cobalt recoveries were under 70 %. By Adding 150 g/t of mixture, copper and cobalt recoveries respectively increased to 94.8 and 90.1 %. Further addition induced a depressing effect.

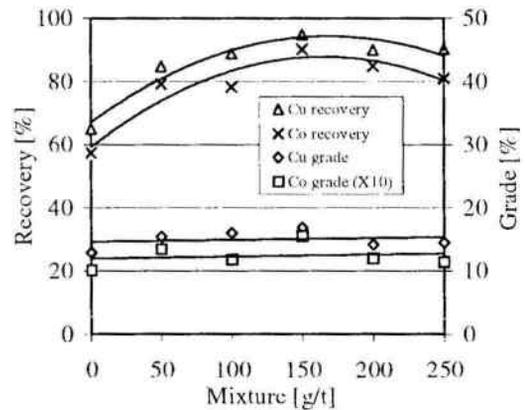


Fig. 5: Effect of the secondary collector mixture on copper and cobalt flotation

Effect of depressant

The effect of Na_2SiO_3 as depressant is presented in figure 6. This result was achieved with reagents dosages of 4000 g/t NaHS, 500 g/t PNBX and 150 g/t mixture. Best result was recorded at 250 g/t Na_2SiO_3 . In excess, this reagent usually gives fragile air bubbles and affects unfavourably the flotation.

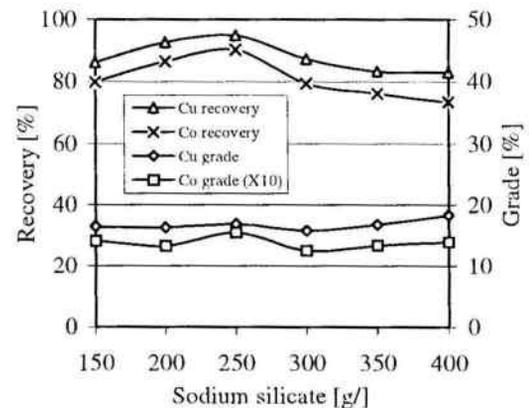


Fig. 6: Effect of sodium silicate on copper and cobalt flotation

Simulation of flotation flow sheet

Two different flotation circuits have been simulated for the sulphidizing flotation (figures 7 and 8). The following reagents combination has been applied in all cases: 4000 g/t NaHS, 500 g/t PNBX, 250 g/t Na₂SiO₃, 150 g/t mixture and 30 g/t Senfroth G41. In the first cleaning, 10 % of total reagents quantities has been added and 5 % in the second cleaning stage.

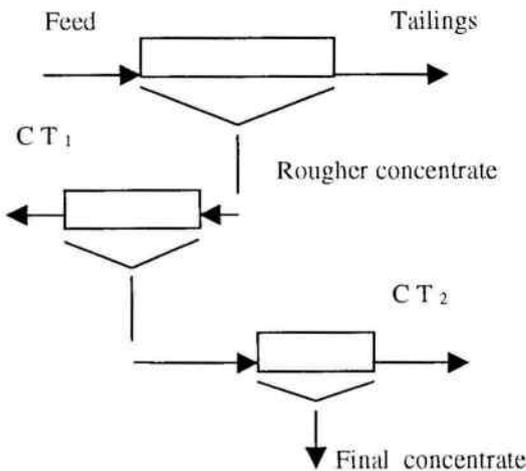


Fig. 7: Flowsheet with two-stage cleaning of the rougher concentrate (CT: cleaner tailings).

The results of simulation tests are given in [Tables II and III](#) respectively.

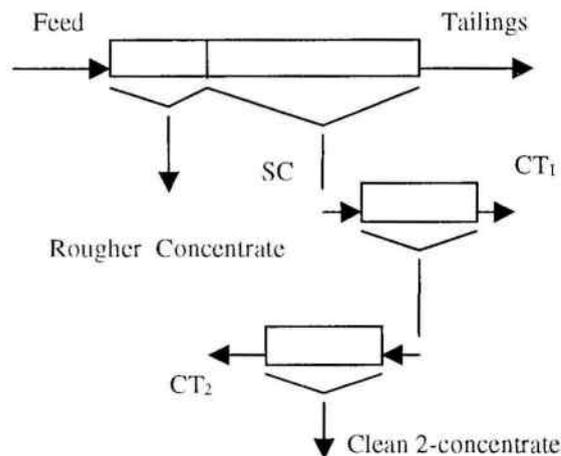


Fig. 8: Flow sheet with two-stage cleaning of the scavenger concentrate (SC)

The two-stage cleaning of the rougher concentrate ([figure 7](#)) increased the copper grade to 29 %, but metal loss in cleaner 2-tailings was high: 25.3 % Cu and 22.0 % Co. This reduced the recovery from 94.8 % to 53.2 % Cu and from 89.0 % to 36.1 % Co.

Table II: Result of two-stage cleaning of the rougher concentrate

Concentrate	Assay, %		Recovery, %	
	Cu	Co	Cu	Co
Rougher	17	1.3	94.84	89.03
Cleaner 1	24	1.7	78.46	58.08
Cleaner 2	29	1.8	53.18	36.06

Table III: Result of two-stage cleaning of the scavenger concentrate

Concentrate	Assay, %		Recovery, %	
	Cu	Co	Cu	Co
Rougher	22.0	1.6	70.54	62.86
Scavenger	9.5	1.0	24.30	26.44
Cleaner 1	18.0	1.8	10.28	10.58
Cleaner 2	25.6	2.6	5.61	5.84

On the other hand, one cleaning stage of the rougher concentrate yielded a good quality concentrate (24 % Cu, 1.7 % Co) with metal recoveries of 78.46% Cu and 58.08% Co. The cleaner 1-tailings could be recycled to the rougher circuit, without damaging the quality of flotation feed. Only one cleaning stage was therefore sufficient to obtain a concentrate containing 24 % Cu and 1.7 % Co.

By applying the flotation flowsheet in [figure 8](#), rougher flotation followed by a two-stage cleaning of the scavenger concentrate, a final concentrate assaying 25.60% Cu and 2.64% Co could be produced which could be mixed to the rougher concentrate (22.10 % Cu, 1.61 % Co). Such a flowsheet that would include feeding of cleaner 1-tailings to the rougher flotation and

Cleaner 2-tailings to the feed of the first cleaning stage is recommendable. Mixing the concentrate from cleaner-2 stage with the rougher concentrate would give a concentrate with 22.3 % Cu content and 1.68 % Co, the respective recoveries being 76.15 % and 68.70 %. Nevertheless, it must be pointed out that with 9.5 % Cu and 1.0 % Co the scavenger concentrate exhibited nearly the same grade as the rougher flotation feed. It was therefore advisable to avoid any cleaning of the scavenger concentrate. This product would better be recycled to the rougher flotation feed in order to yield a final rougher concentrate (standard rougher-scavenger circuit).

CONCLUSION

From the above, it can be concluded that floatability of the Fungurume ore is very good, despite the presence of copper silicate to the extent of up to 25 %.

Direct flotation with fatty acid collector like palm oil shows very low selectivity.

Sulphidizing flotation using 3500 to 4000 g/t NaSH, 400 to 500 g/t PNBX, 130 to 170 g/t mixture, 230 to 270 g/t Na_2SiO_3 , by natural pH of about 9.5 and with a flotation time of 12 minutes yields approximately 94.8% Cu and 90.1 % Co in a concentrate containing in average 16.9 % Cu and 1.5% Co. Chrysocolla recoveries of more than 80 % have been achieved. The use of a fatty acid containing mixture as secondary collector induces an improvement of copper and cobalt recoveries of about 15 %.

A standard rougher-scavenger circuit has been recommended for optimum flotation results, since cleaning flotation would lead to important metals losses in tailings.

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