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Influence of the Use of Ammonium Sulfate and Citric Acid on the Buoyancy of Minerals in Copper-Cobalt Plant Process (Case of 635 Deposit Fed at Kambove Concentrator)

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ABSTRACT
The objective pursued in this work is testing the performance of two new reagents namely ammonium sulfate and citric acid, on buoyancy of Kamfundwa ore currently treated at Kambove Concentrator. Optimization tests were conducted in order to determine the optimal doses of reagents commonly used, in this case Sodium hydrosulfide (NaSH), the amylxanthate potassium (KAX), Sodium silicate (Na_2SiO_3), and the mixture fuel-fatty acid. Metallurgical results obtained with these tests were used as reference for further work. Tests with citric acid alone could not improve the metallurgical results obtained under standard conditions, the same finding was observed in tests with ammonium sulfate alone and that performance seemed to be much closer to those of reference tests. We finally realized flotation tests by combining citric acid and ammonium sulfate in order to streamline the synergy of these two reagents. It appears from these tests that at the dose of 600 g / t of citric acid and 400 g / t of ammonium sulfate, metallurgical performance obtained are better than previously. The following results were achieved during the batch flotation tests: 18.87% as copper content of the head concentrate, with a recovery rate of 55.34%, and 10.81% as copper content of the global concentrate; for a copper recovery corresponding to 80.94%. This mixture of citric acid and ammonium sulfate has allowed good selectivity and a reduction of gangue trained to the concentrate.

Keywords: Ammonium sulfate, citric acid, Buoyancy.

1. Introduction

Concentrator of Kambove deals copper-cobalt bearing minerals from several fields including the Kamfundwa operated by GCM primarily for the recovery of copper as malachite. These minerals suffer a crushing followed by wet grinding before being processed by flotation to produce a concentrate of copper and cobalt which is the main feed of hydrometallurgical plant. During flotation, there are three essential conditions for the recovery of a particle concentration. This particle is initially colliding with an air bubble. Then conditions must be favorable, so that the contact is followed by the formation of a bubble-particle

aggregate. Finally, the stability of the aggregate thus formed must be sufficient to counteract the forces to break. These three fundamental conditions or probabilities depend on the size of Particles and bubbles [1]. The realization of these prerequisites' flotation requires the intervention of specific chemical reagents that react either to form on the surface of minerals selective polar envelope, or conversely to form a non-polar envelope [2]. However, the nature and dose of the reagents used in the flotation have a remarkable influence on the metallurgical results obtained [3].
This work aims to evaluate the effects of Ammonium sulfate and citric acid on metallurgical performance obtained. To achieve flotation tests conducted on ore from 635 fill have made in order to firstly determine the optimal dosage rates of commonly used reagents (Sodium hydrosulfide, Sodium Silicate, Potassium amylxanthate, mixture) and on the other hand to show the impact of varying the dosage rates of these two reactants.

2. Materials and Methods

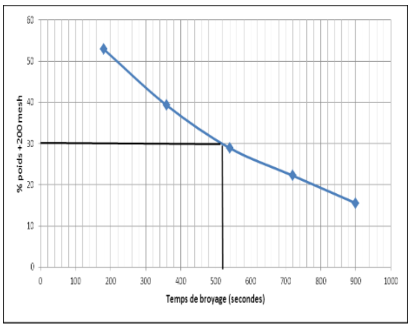
The Geology Department of Gécamines conducted a sampling of the 635 Backfill and made available a batch of 120 kg of ore. This sample was drawn in a systematic way so as to be as representative as possible. Ore received has been subjected to mechanical preparation in order to reduce the mineral to a size more amenable to concentration by flotation. According to the literature the dimensions most favorable for flotation are between 10 and 100 microns [4].
The sample characterization was made in EMT laboratory (Gécamines research department), and the chemical and mineralogical analysis are presented in table 1.

Table 1: Chemical composition of Kamfundwa ore

Element	Assay (%)	Element	Assay (%)
Cu_{Tot}	2,04	CaO_{Tot}	1,88
Cu_{Ox}	1,62	CaO_{sol}	1,54
Co_{Tot}	0,3	Al_2O_3	3,42
Co_{Ox}	0,27	SiO_2	60,90
MgO_{Tot}	3,78	MnO	0,23
MgO_{Sol}	0,27	Fe_{Tot}	1,78
P_2O_5	0,22	Ni	0,01

Optical microscope observation revealed the presence in the sample studied of malachite CuCO3.Cu (OH) 2 and heterogeneity aCoO.bCo2O3. The matrix consists of quartz, talc and iron oxides.
The graphical representation of the results of grinding tests is given in the figure 1.

Figure 1: Diagram of the sample grindability

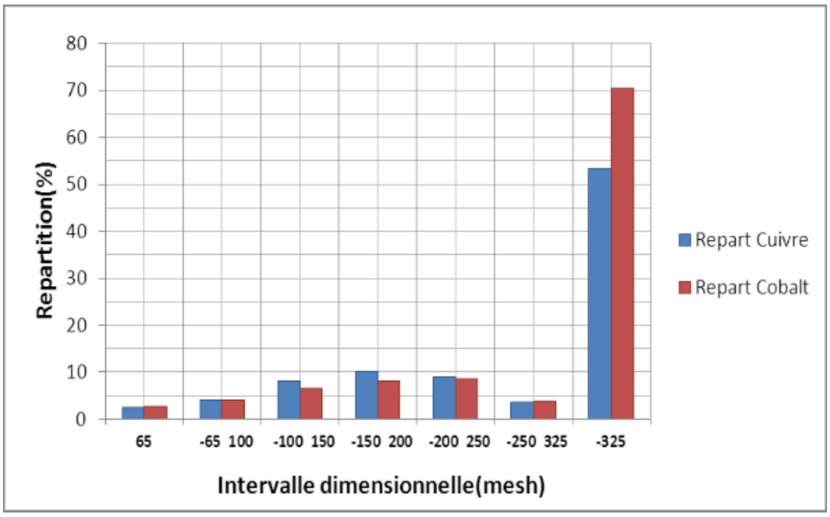


Based on Figure 1, a substantial release minerals Copper and Cobalt is obtained after wet milling time of 8min 40sec.

1. **Size distribution Analysis**

This study determines the distribution of copper and cobalt in different size fractions. The figure 2 shows the results.

Figure 2: Distribution of Copper and Cobalt



Comments:

- The sample assay is 2.04% copper and 0.3% Cobalt;
- The majority of total copper and cobalt is present as total oxidized;
- The grinding time necessary for a good release of valuable minerals is 8minutes 40 seconds;
- The ore has a considerable tendency to the production of fine particles during fragmentation. The fine fraction is rich in Copper and Cobalt.

2. Experimental Procedure

- Screening and weighing of large blocks throughout a jaw crusher, cylinder crusher, roll mill, vibrating sieve of 1/4 mesh and 10mesh, and a 1 ton scale;
- Grinding in a laboratory ball mill with length L = 285 mm, diameter D = 183 mm and speed of 123 revolutions per minute;
- Batch flotation in a laboratory machine Denver;
- Mineralogical analysis in a laboratory stereoscopic microscope;
- Chemical analysis of the samples done by an absorption spectrophotometric method.

In the case of our work, we selected two criteria for evaluating the results of flotation tests include: The content of copper concentrate; and the recovery rate of copper.

The flotation tests performed in the laboratory can be divided into four groups: tests optimizations, tests with citric acid, tests with Ammonium sulfate and tests with citric acid and ammonium sulfate.

3. Test Results

1. **Test optimization**

The tests were designed to find the optimal doses of the following reagents:

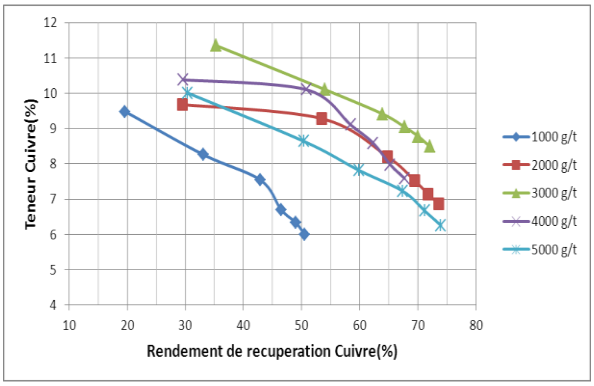
- Sodium hydrosulfide (NaSH);

- The amylxanthate Potassium (KAX);
- Sodium silicate (Na_2SiO_3);
- The mixture diesel/Rinkalore10 (90/10).

3.1.1. Dose optimization NaSH and KAX

To determine the best conditions for sulfidisation and collectibles, we vary the amounts of NaSH from 1000 to 5000 g /t by step of 1000g /t; the KAX dosage rate being 1/10 of that of NaSH used. The figure below shows the influence of dose of NaSH and KAX, and reveals that dosage rates of 3000 g /t NaSH and 300 g /t KAX are optimal.

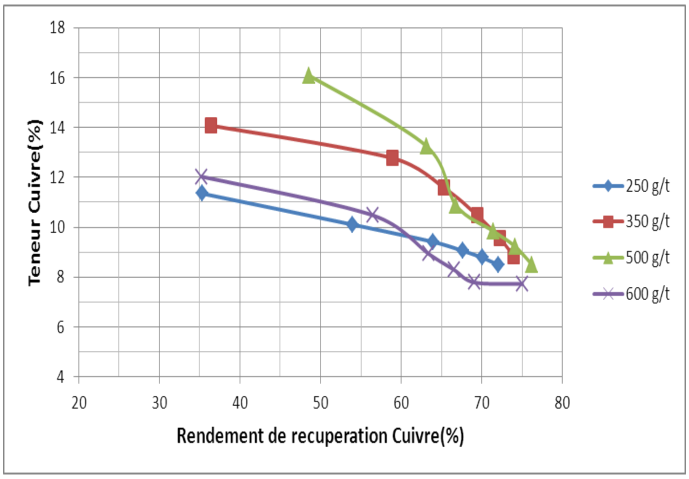
Figure 3: Influence of dose NaSH



3.1.2. Dose optimization sodium silicate

Tests performed at different doses of Sodium silicate (250,350, 500 and 600g / t) show that a dose of 500 g / t given the best metallurgical results. At low doses (250, 350 g / t) and high dose (600 g / t), the decrease in results is due to the lack and excess of depressing

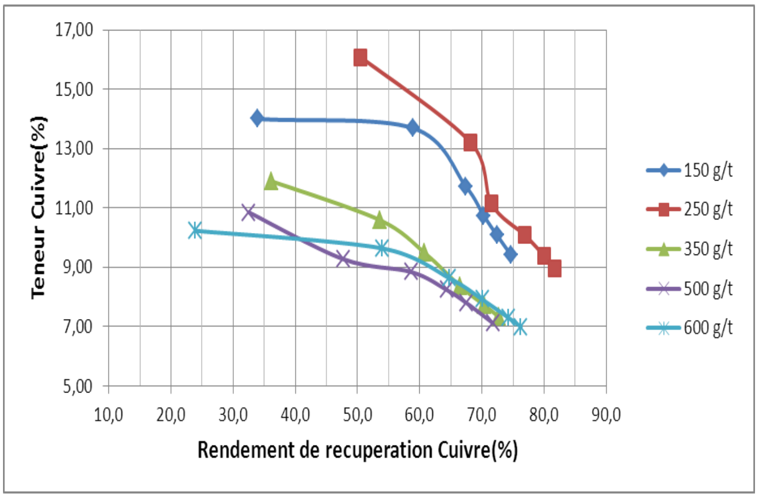
Figure 4: Influence of dose Na2SiO3.



3.1.3. Dose optimization of mixture diesel-Rinkalore10

The figure below shows that the optimal dose of mixture is 250 g /t.

Figure 5: Influence of dose mixture



The tests show that the optimization performed better buoyancy ore is observed at 3000 g /t NaSH and 300 g /t KAX, 500 g /t Na_2SiO_3 and 250 g /t mixture. The results obtained under these conditions are given in the table below:

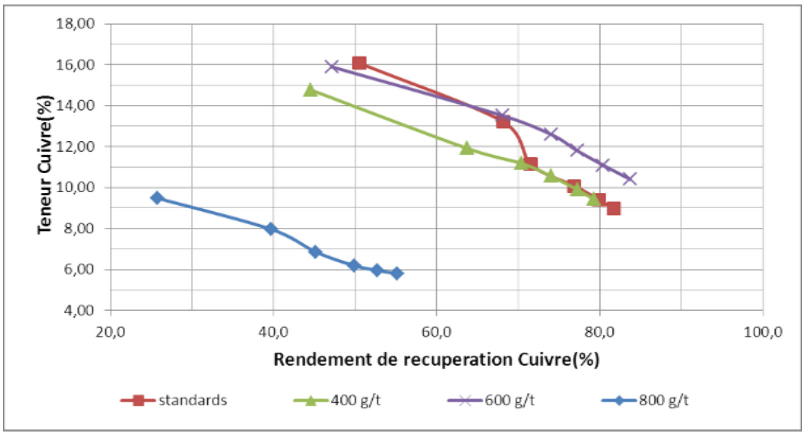
Table 2: Synthesis of the results of Test 11

N° TEST	FRACTION	COPPER		COBALT	
		Assay (%)	**Recovery (%)**	**Assay (%)**	**Recovery (%)**
11	Head Conc	16,08	50,5	0,83	18,30
	Roughing Conc	8,96	81,70	0,76	48,70

2. **Flotation Tests with Citric Acid**

These tests were carried out in summers maintaining optimal doses of NaSH, KAX, Na_2SiO_3 and mixtures, and differ only in the citric acid. The figure below combines the results obtained with citric acid and those of Test 11:

Figure 6: Influence of the dose of citric acid



It is clear from these tests that citric acid alone has a depressive effect on mineral Copper and Cobalt, this translates into a metallurgical performance degradation. However, the dose of 600 g /t yielded the best results. The table below shows the results of the test carried out at 600 g /t of citric acid.

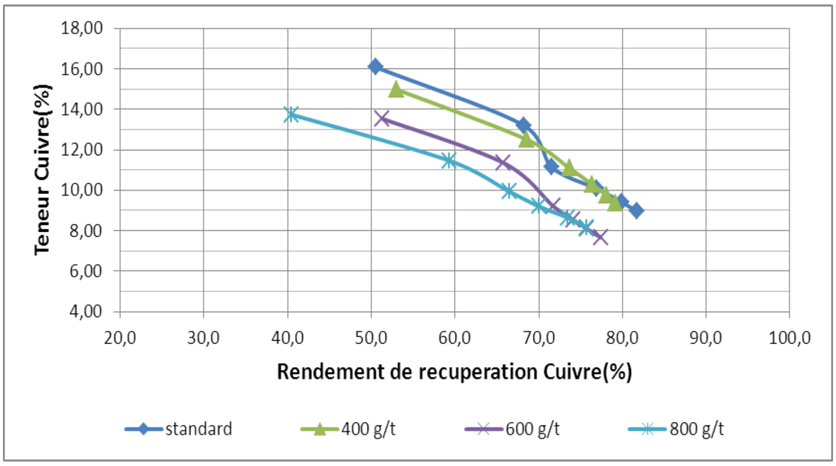
Table 3: Synthesis results of Test No. 17

N° TEST	FRACTION	COPPER		COBALT	
		Assay (%)	**Recovery (%)**	**Assay (%)**	**Recovery (%)**
17	Head Conc	15,89	47,18	0,57	13,11
	Roughing Conc	10,40	83,75	0,62	38,49

3. **Flotation Tests with Ammonium Sulfate**

The results of tests carried out with ammonium sulfate alone and those of the reference test (Test 11) are represented in the following figure:

Figure 7: Influence of the dose of ammonium sulfate



This figure provides information that ammonium sulfate alone does not improve the ability to study ore flotation. There is a depression minerals Copper and Cobalt and 400 g / t given the best metallurgical results. The results obtained at the end of this test are shown in Table below:

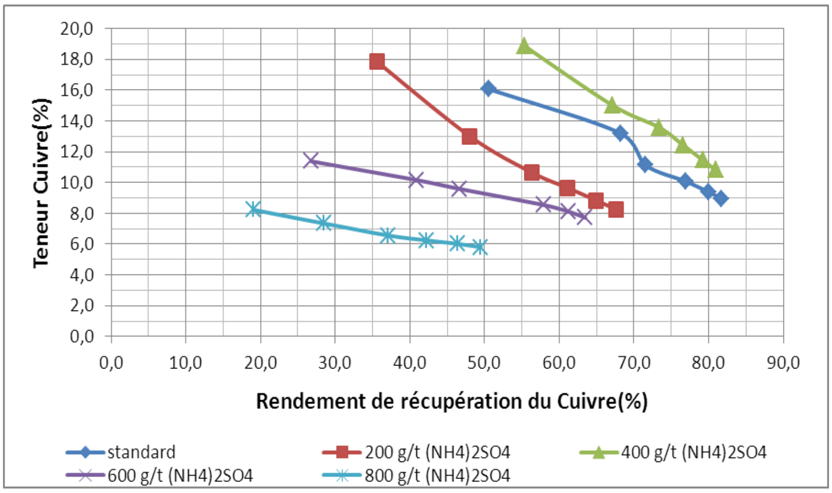
Table 4: Synthesis of the results of Test 20

N° TEST	FRACTION	COPPER		COBALT	
		Assay (%)	**Recovery (%)**	**Assay (%)**	**Recovery (%)**
20	Head Conc	14,98	52,99	0,83	21,77
	Roughing Conc	9,37	79,16	0,80	50,32

4. **Tests With Citric Acid and Ammonium Sulfate**

In order to exploit the synergy of the two reactants, four tests were carried out at 600 g /t of citric acid while varying the dose of ammonium sulphate. The following figure combines the results with those obtained in reference conditions (Test 11).

Figure 8: Influence of the dose of ammonium sulfate at 600 g /t Citric Acid



Metallurgical results are significantly improved to 600 g /t of citric acid and 400 g /t of ammonium sulfate. Performance obtained at the end of these tests are shown in the table below:

Table 5: Synthesis of the results of Test 25

N° TEST	FRACTION	COPPER		COBALT	
		Assay (%)	**Recovery (%)**	**Assay (%)**	**Recovery (%)**
25	Head Conc	18,87	55,34	1,2	21,77
	Roughing Conc	10,81	80,94	1,05	50,32

The graphical representation of tests having given the best metallurgical performance (Tests 11, 17,20 and 25) is given in Figure 9 for Copper and Figure 10 for Cobalt

Figure 9: Metallurgical performances of Tests 11, 17,20 et 25(Copper)

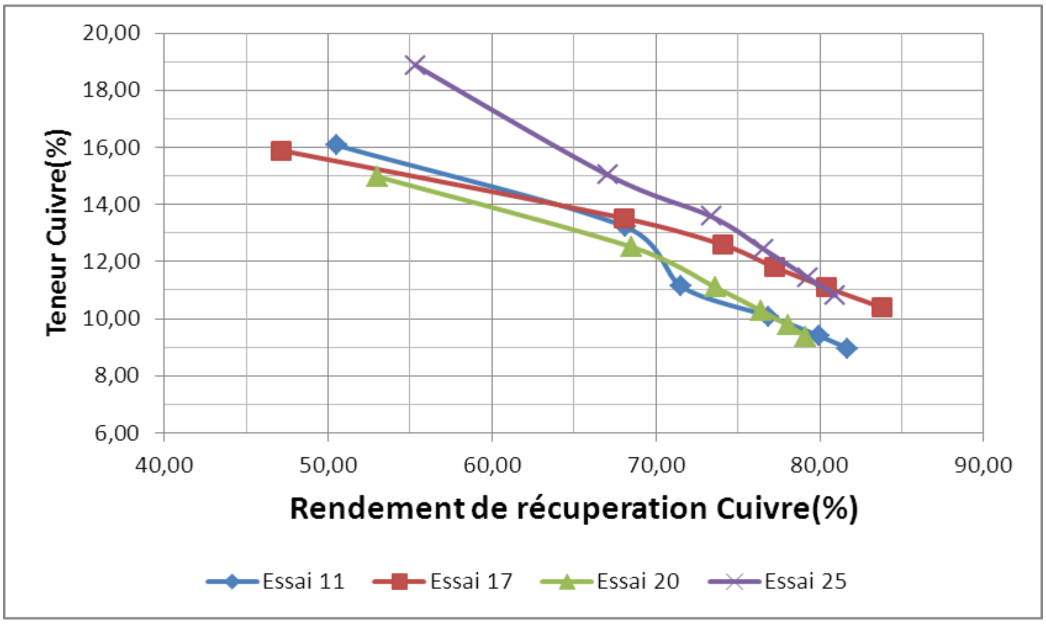


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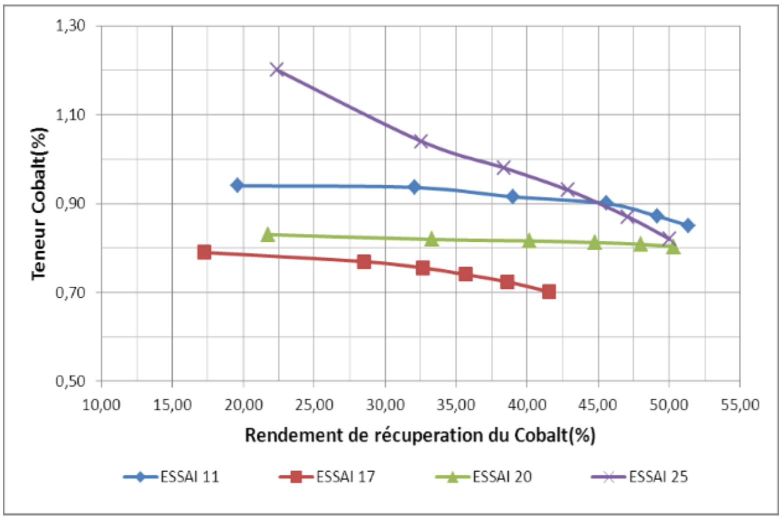
Figure 10: Metallurgical performances of Tests 11, 17,20 et 25(Cobalt)



The test 25 performed with citric acid and ammonium sulphate improves metallurgical performance as well as for Copper and Cobalt. This mixture allows us to have a good selectivity and a great depression of the matrix. The economic evaluation showed that the production of 10,000 tons of ore Kamfundwa requires a partial operation cost $ 140,745 for test 11 and $ 164,265 for test 25. This corresponds to an increase of approximately $ 24,000. This assessment was made taking into account only the cost of reagents.

4. Conclusion

The objectives of this study were to determine the effects of ammonium sulphate and citric acid on the ability to flotation of Kamfundwa ore whose average grade Copper and Cobalt are respectively 2% and 0, 3%. After characterization of the ore sample studied, tests were conducted to optimize flotation mode sulfidisation have determined the optimal doses of sodium hydrosulfide (NaSH), potassium amylxanthate (KAX), silicate sodium (Na_2SiO_3), and the mixture diesel-Rinkalore 10 respectively 3000, 300, 500 and 250 g /t. Under these conditions, the concentrates produced in head and roughing assayed respectively 16.08% and 8.96% copper recovery yields corresponding to 50.5% and 81.7%.

To meet the objectives, flotation tests were carried out in reference conditions, with variation of citric acid and ammonium sulfate. With these, we found a separate regression metallurgical performance depends on a depression which would be exerted both of these reagents on Copper and Cobalt minerals.

Flotation tests were carried out to seek synergy effect with the combination of these two reagents. It appears from these tests that at the dosage rates of 600 g / t citric acid and 400 g /t of ammonium sulfate a significant improvement in metallurgical performance was observed. This recipe mixture allowed to activate the minerals Copper and Cobalt. Thereby produce a head concentrate of 18.87% with a recovery yield of 55% and a roughing concentrate grading 10.8% copper with recovery of order of 81%.

This study was conducted in laboratory tests, so the pilot scale turns out to be necessary before the industrial application of the conclusions at the end of this work.

5. Conflict of interest

Authors do not have any conflict of interest to declare.

6. Acknowledgements

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