Investigating the Interplay Between Flotation Chemistry and Ore Mineralogy

A. K. Muhindo, E. M. Mfungo, J. L. Tembo
Mineral Processing Institute, Dar es Salaam, Tanzania

***Abstract*—**Froth flotation remains to date as one of the most used metallurgical processes for concentrating metal-bearing minerals in ores. Oxide ores are relatively less amenable to froth flotation and require a judicious choice of reagents for the recovery of metals to be optimised. Laboratory batch flotation tests were conducted to determine the effect of two types of gasoil-rinkalore mixtures on the flotation response of a copper cobalt oxide ore sample. The head assay conducted on the initial ore sample showed that it contained about 2.90% of Cu, 0.12% of Co.

Upon the flotation test work, the results obtained indicated that the concentrate obtained with use of the mixture gazoil-rinkalore RX yielded 8.24% Cu and 0.22% Co concentrate grades with recoveries of 76.0% Cu and 78.0% Co respectively. But, the concentrate obtained by use of the mixture gazoil-rinkalore RX3 yielded relatively bad results with 5.92% Cu and 0.18% Cu concentrate grades with recoveries of 70.3% Cu and 65.3% Co respectively.

***Keywords*—**Cobalt, copper, froth flotation, Rinkalore RX, Rinkalore RX3, Shangolowe.

I. Introduction

KAMBOVE concentrator is an important business unit of Gecamines that processes both copper and cobalt sulphide and oxide ores. A simplified flowsheet of Kambove concentrator is shown in Fig. 1 (tailing from cleaner bank is not displayed in Fig. 1. for clarity and simplicity reasons). It consisted of 2 stages of rougher flotation, 3 stages of scavenger flotation and a cleaner bank. The oxide ores processed at Kambove concentrator are mainly originating from Shangolowe mine with about 2.90% copper and 0.12% cobalt. Oxide ores do not easily lend themselves to froth flotation. The flotation of such ores is achieved by use of sulphidisation agents (activators) that enhance adsorption
susceptibility of collectors onto the mineral grain surfaces [1][4]. Xanthates are the most common primary collectors used for the flotation of copper-cobalt ores [5]-[7]. They are also often used for flotation of nonferrous metallic minerals where a strong but non selective collector is desired [8]. However, it should be noted that copper cobalt oxide ores do not generally respond successfully to traditional primary collectors. Some

more selective collectors are therefore often added as secondary collectors and are used in synergy with primary collectors to promote the overall flotation response. Rinkalore mixtures are typical example of secondary collectors that can be used along with a xanthate collector for the flotation process of copper and cobalt ores [9], [2]. In this paper, we endeavour to investigate the effect of two types of rinkalore mixtures (RX and RX3) on the floatability of a copper cobalt oxide ore sample.

II. Experimental

A. Description of the Experimental Laboratory Flotation Cells

The experimental laboratory tests were conducted using Denver D12 laboratory flotation machines provided suspended type mechanism. The impeller speed was set at 1350 rpm and the airflow was controlled manually to maintain the froth level.

B. Flotation Reagents

The reagents used in the flotation tests were potassium amylxanthate (KAX) as the primary collector, mixture gazoilrinkalore RX or mixture gazoil-rinkalore RX3 as secondary collectors and G41 as the frother. Two modifiers were also used: sodium sulhydrate (NaSH) as the activator and sodium silicate (Na_2SiO_3) as the dispersant. The flotation reagent compositions and laboratory operating conditions are specified in Table I.

The volume of flotation agents is given by (1):

$$\text{volume of reagent (mL)} = \frac{\text{mass of ore sample kg} \times \text{reagent dose g/t}}{\text{g reagent strength L}} \quad (1)$$

C. Reagent Addition Points

Appropriate reagent addition points were chosen, based on the actual industrial flotation flowsheet of Kambove concentrator, to obtain good metallurgical results. No reagent was added at the pre-flotation of talc, as it is naturally hydrophobic. The reagent doses used with their relative addition points are summarised in Table II. In this table, the following notations are used:

- PC: pre-float concentrate (after talc removal)
- 1RC and 2RC: first and second rougher concentrates
- 1SC, 2SC and 3SC: first, second and third scavenger concentrates
- TC: tailings concentrate

TABLE I

Flotation agent	Composition	Conditioning time	Strength	Total doses

Primary collector				
Potasium amylxanthate (KAX)	100% KAX	1 min	1.2 g/L(1.2%)	400 g/t
Secondary collectors				
Mixture gazoil-rinkalore RX	90% of gasoil and 10% of rinkalore RX	2 min	1.2 g/L(1.2%)	150, 250, 300 and 400 g/t
	A small amount of sodium carb	$_2CO_3$, 30%) was also added to the mixture gazoi	kalore RX in the ratio 10/100	
	(Na	rin	v/v.	, 250, 300 and 400
Mixture gazoil-rinkalore RX3	50% of sodium	ulhydrate and 50% of rinkalore	2 min RX3	2 g/L(2%) 100, 150 g/t
Frother agent				
G41	100% G41	1 min	Concentrated	80 g/t
Modifying agents				
Activator				
Sodium sulhydrate (NaSH)	100% NaSH	1 min	12 g/L(12%)	4000 g/t
Dispersant				
Sodium silicate (Na_2SiO_3)	100% Na_2SiO_3	5 min	one third concentrated	300 g/t

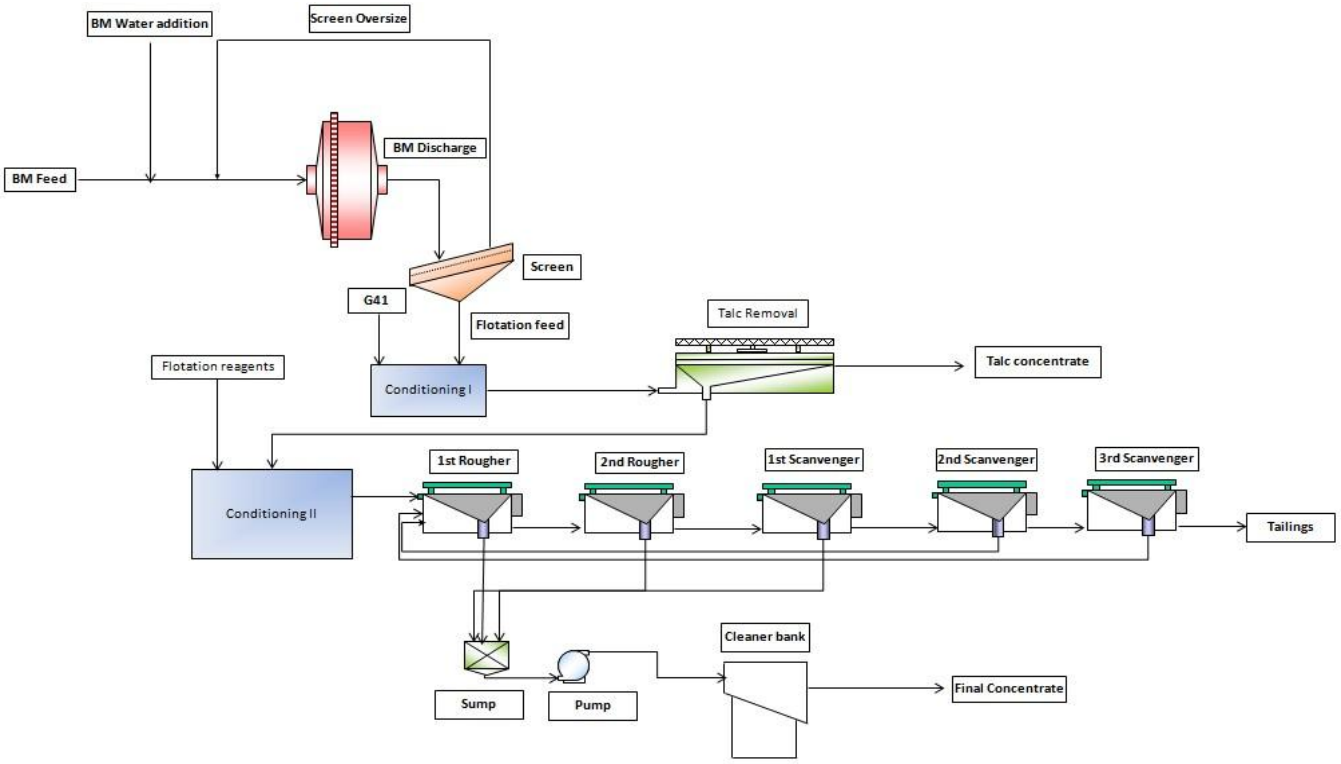

Fig. 1 Simplified flowsheet of Kambove concentrator

TABLE II
FLOTATION REAGENT ADDITION POINTS AND RELATED DOSES

	Flotation tests with the mixture gazoil-rinkalore RX (g/t): 150, 250, 300 and 400 g/t				**Flotation tests with the mixture gazoil-rinkalore RX3 (g/t): 100, 150, 250, 300 and 400 g/t**			
Reagent addition points	Na SiO (g/t)	NaSH (g/t)	KAX (g/t)	G41 (g/t)	Na SiO (g/t)	NaSH (g/t)	KAX (g/t)	G41 (g/t)
PC (talc removale)								
Reagent conditioning								
1RC								
2RC								
1SC								
2SC								
3SC								
TC								
Total Feed (1RC+2RC+1SC+2SC+3SC+TC)								

FLOTATION REAGENT LABORATORY OPERATING CONDITIONS

D. Flotation Test Work

The actual flotation test work was conducted on the pulp obtained after wet grinding, using the D12 Denver flotation machines. The appropriate reagents were step-wise added to the pulp after they were conditioned for specific time. Once the first concentrate (1RC) was collected, additional amount of reagents was added to obtain the second concentrate (2RC). The same procedure was repeated in all the flotation tests, and six separate concentrates were collected at 2 minutes interval during each run. The different concentrates obtained and the tails for each test were carefully removed from the flotation machine. They were weighed in the collection bucket while wet; then pressure filtered, using tared filter paper before being placed on a pan and finally in an oven for drying. The dried samples were then re-weighed, and a representative sample was assayed by AAS for Cu and Co contents determination.

III. Results and Discussions

A. Sample Characterization

The copper cobalt oxide ore sample used in the actual study originated from Shangolowe mine in the Democratic Republic of Congo (DRC). It was obtained from the feed to the secondary ball mill at Kambove concentrator and was labeled under # 4303 at the Gecamines Research Centre in Likasi, DRC.

1. XRF analysis

The chemical analysis of the copper cobalt oxide ore sample was conducted using a ZSX Rigaku Primus II spectrometer. The results showed that the ore sample contained about 2.90% of Cu, 0.12% of Co, 4.30% of Fe,
0.24% of CaO, 1.99% of MgO and 47.80% of SiO_2.

2. XRD analysis

The mineralogy study of the ore sample was conducted using a Rigaku diffractometer, using a CuKα radiation, a scintillation counter detector and a K-beta filter. The scanning angles ranged from 3 to 90° (2theta) at the speed 2.0 deg. per min. Fig. 2 shows the XRD patterns on of the ore sample. The gangue was mainly constituted of quartz, goethite, hematite, talc, iron oxide and dolomite. Valuable minerals accounted were malachite ($CuCO_3.Cu(OH)_2$) and heterogenite ($CoO_3.Co_2O_3.CuO.7H_2O$). About 62% of the total Cu in the ore sample occurred in the form of malachite, the remaining was in the form of heterogenite.

B. Grinding of the Ore Sample

The as-received sample was wet ground down in closed circuit with a 300 µm limiting screen, using a ball mill (mill diameter: 0.183 m, mill length: 0.285 m). The milling parameters were chosen so as to obtain a pulp with a size distribution closer to that obtained in closed-circuit ball milling at Kambale concentrator. Hence, the wet grinding was performed for 5 min 30 sec on 1.20 kg of the ore sample. The solid-liquid ratio considered was about 1, i.e. 50% water to 50% ore sample.

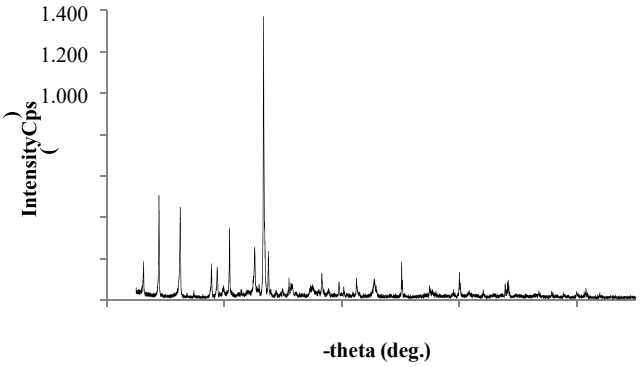

Fig. 2 XRD Spectra of the copper cobalt oxide ore sample

C. Size Fraction Assays of the Copper Cobalt Oxide Ore Sample

A wet sieving was then performed on 119.99 g of the ground ore sample to investigate the particle size distribution and the distribution of Cu and Co in each size fraction. Because slime particles are not well suited to flotation, the ore sample was deslimed. To this end, the -38 µm fraction was placed in a 2000 ml test tube, to which was added water up to the gauge and 10 ml of Na_2SiO_3 (30%). The solution obtained was stirred for 2 minutes and was allowed to decant for about 10 minutes.

About 1.0 g sample was taken from each dried size fraction for the determination of Cu and Co contents by atomic spectrometry analysis (AAS). The results are shown in Table III. It can be seen that about 17.64% of the material occur in the coarse fraction (+106 µm) with a further 11.87% in the - 100 + 75 µm fraction. About 79.74% of Cu and 76.22% of Co were found in the -212 +25 µm. There were also approximately 19.05% of Cu and 23.38% of Co in the -25 µm fraction.

D. Flotation Batch Test Work Results

In this section we present the results obtained upon the flotation test work with two mixtures (gazoil-rinkalore RX and gazoil-rinkalore RX3) along with other flotation reagents.

1. Effect of the Mixture Gazoil-Rinkalore RX on the Floatability of the Oxide Copper Cobalt Ore Sample

The effect of the mixture gazoil-rinkalore RX (150, 250, 300 and 400 g/t) was investigated in order to optimise the floatability of an oxide copper cobalt ore sample. The total doses of the other flotation reagents were kept constant at 300 g/t for Na_2SiO_3, 4000 g/t for NaSH, 400 g/t for KAX and 80 g/t for G41. Figs. 3 and 4 show the cumulative % recovery against cumulative concentrate mass and the cumulative % recovery against the grade curves of Cu and Co. One can see that both the recovery and grade of Cu and Co increased with an increase in the mixture dose from 150 g/t to 250 g/t; but quickly drop beyond. The good floatability of the copper cobalt oxide ore sample was therefore obtained at 250 g/t of the mixture gazoil-rinkalore RX.

TABLE II
I
SIZE-BY-ASSAYS OF THE COPPER COBALT OXIDE ORE SAMPLE

	Feed material			Copper (Cu)				Cobalt (Co)			
Size Fractions	Mass (g)	Mass %	Cumulative mass %	Grade (%)	Mass (g)	Mass %	Cumulative mass %	Grade (%)	Mass (g)	Mass %	Cumulative mass %
+212 µm	2.86	2.39	2.39	1.47	0.04	1.21	1.21	0.08	0.00	1.40	1.40
-212 +150 µm	8.75	7.29	9.67	2.96	0.26	7.43	8.64	0.05	0.01	3.50	4.90
-150 +106 µm	9.55	7.96	17.64	2.74	0.26	7.52	16.15	0.05	0.00	2.80	7.69
-106 +75 µm	14.25	11.87	29.51	2.83	0.40	11.56	27.72	0.03	0.01	3.50	11.19
-75 +53 µm	14.93	12.44	41.95	2.91	0.43	12.45	40.17	0.03	0.01	3.50	14.69
-53 +45 µm	7.47	6.22	48.17	3.01	0.23	6.46	46.63	0.25	0.02	13.29	27.97
-45 +38 µm	3.43	2.86	51.03	2.98	0.10	2.93	49.56	0.25	0.01	6.29	34.27
-38 µm	34.18	28.49	79.52	3.20	1.09	31.39	80.95	0.18	0.06	43.36	77.62
Slimes	24.58	20.48	100.00	2.70	0.66	19.05	100.00	0.13	0.03	22.38	100.00
Total	119.99	100.00		2.90	3.49	100.00		0.12	0.14	100.00	

The first rougher concentrate yielded 18.68% Cu and 0.62% Co with recoveries of 36.1% Cu and 45.7% Co respectively. The tailings yielded 1.25% Cu and 0.03% Co concentrate with estimated recoveries of 24.0% Cu and 22.0% Co respectively. However, the cumulative concentrate mass produced yielded 8.24% Cu and 0.22% Co concentrate with recoveries of 76.0% Cu and 78.0% Co respectively.

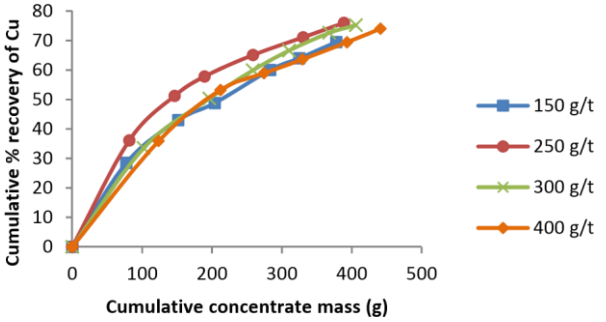

Fig. 3 (a) Cu cumulative % recovery against cumulative concentrate mass (g) and grade (%)

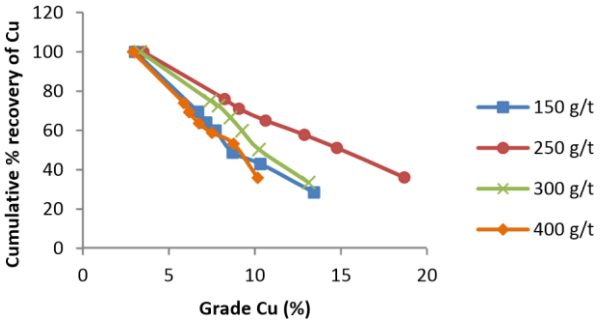

Fig. 3 (b) Cu cumulative % recovery against cumulative concentrate mass (g) and grade (%)

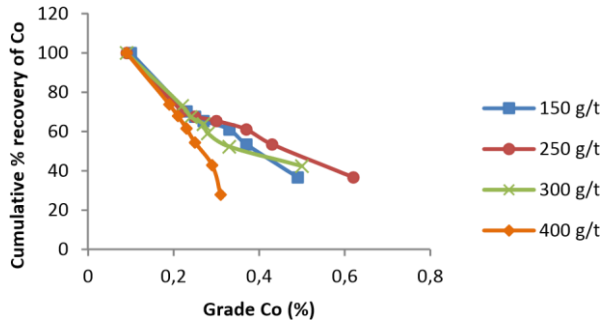

Fig. 4 (a) Co cumulative % recovery against cumulative concentrate mass (g) and grade (%)

Fig. 4 (b) Co cumulative % recovery against cumulative concentrate mass (g) and grade (%)

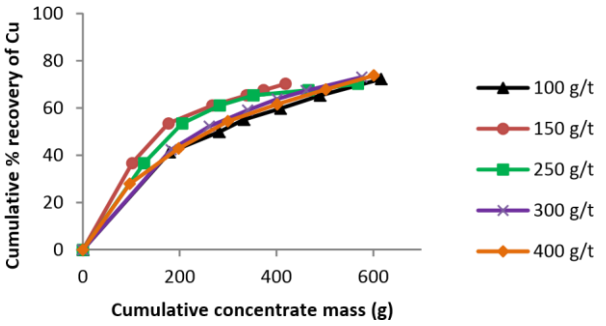

Fig. 5 (a) Cu cumulative % recovery against cumulative concentrate

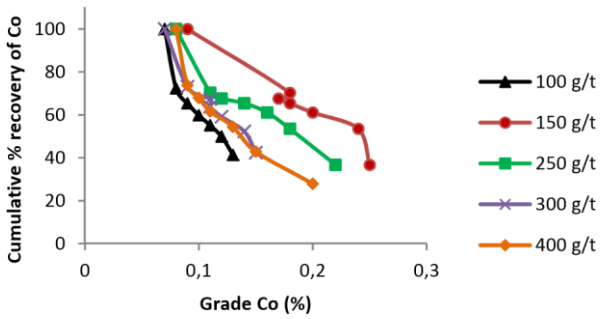

Fig. 6 (b) Co cumulative % recovery against cumulative concentrate mass (g) and grade (%)

mass (g) and grade (%)

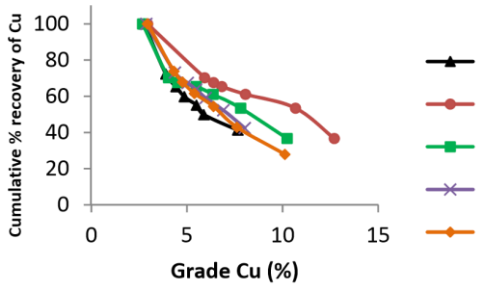

Fig. 5 (b) Cu cumulative % recovery against cumulative concentrate mass (g) and grade (%)

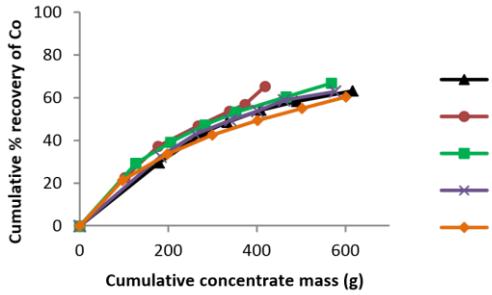

Fig. 6 (a) Co cumulative % recovery against cumulative concentrate mass (g) and grade (%)

100 g

150 g/t

250 g/t

300 g/t

400 g/t

2. Effect of the Mixture Gazoil-Rinkalore RX3 on the Floatability of the Copper Cobalt Oxide Ore Sample

The effect of the misxture gazoil-rinkalore RX3 (100, 150, 250, 300 and 400 g/t) was also investigated in order to optimise the floatability of a copper cobalt oxide ore sample. As previously, the total doses of other flotation reagents were kept constant at 300 g/t for Na_2SiO_3, 4000 g/t for NaSH, 400 g/t for KAX and 80 g/t for G41. The results are presented in Figs. 5 and 6. It can be seen that the optimum floatability of the copper cobalt oxide ore sample was obtained at 150 g/t of the mixture gazoil-rinkalore RX.

The first rougher concentrate obtained yielded 12.70% Cu and 0.25% Co concentrate with recoveries of 36.7% Cu and 22.6% Co respectively. The tailings produced yielded 1.34% Cu and 0.05% Cu concentrate with expected recoveries of 29.7% Cu and 34.7% Co respectively. The cumulative concentrate % recoveries obtained were 70.3% and 65.3% for Cu and Co respectively and the cumulative concentrate grades obtained were 5.92% and 0.18% for Cu and Co respectively.

3. Comparison of the Flotation Performances with the Mixture Gazoil-Rinkalore RX and the Mixture Gazoil-Rinkalore RX3

The optimum results obtained upon the flotation with 250 g/t of the mixture gazoil-rinkalore RX were compared to those obtained with 150 g/t of the mixture gazoil-rinkalore RX3. Fig. 7 shows the flotation performances obtained for Cu with both the mixtures considered in this work. It can be seen that best % recovery and grade obtained for Cu with use of the mixture gazoil-rinkalore RX were slightly at just about 0.5% of % recovery and 4% grade higher than those obtained with the use of the mixture gazoil-rinkalore RX3.

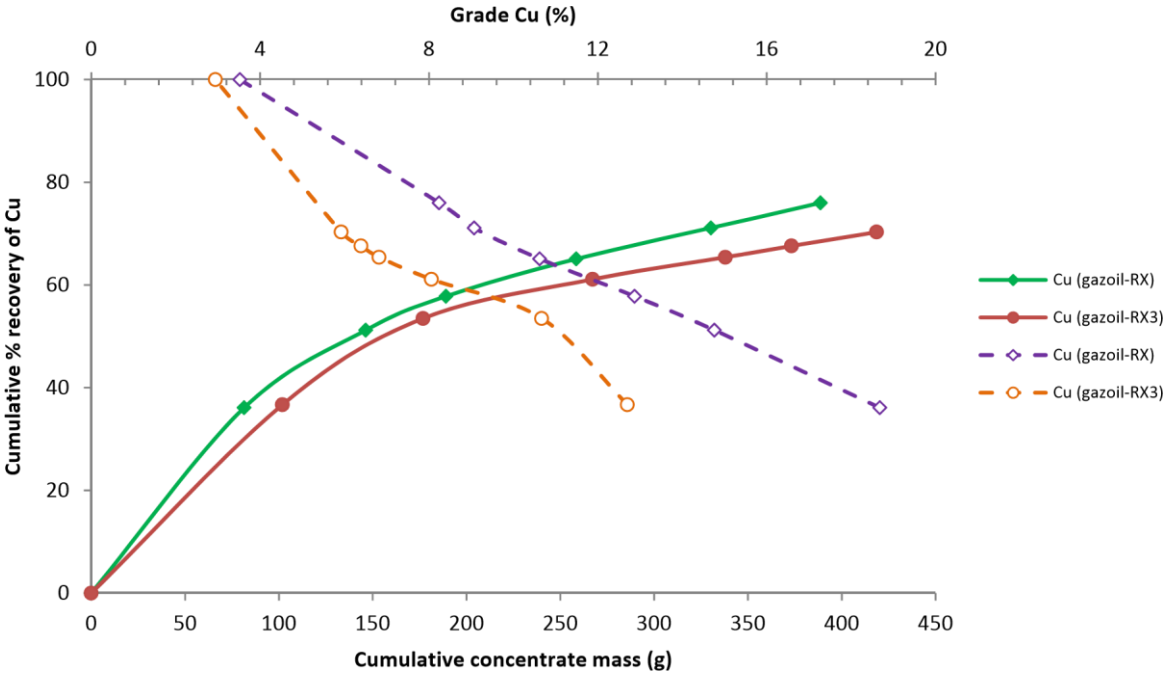

Fig. 7 Comparison between Cu recoveries and grades obtained with the mixture gazoil-rinkalore RX and the mixture gazoil-rinkalore RX3

Similar results were also obtained for Co as shown in Fig. 8. The difference in the results obtained with use of the two types of mixtures was noticeable. The Co % recovery and grade obtained by use of the mixture gazoil-rinkalore RX were at about 17% of % recovery and 0.2% higher to that obtained by use of the mixture gazoil-rinkalore RX3.

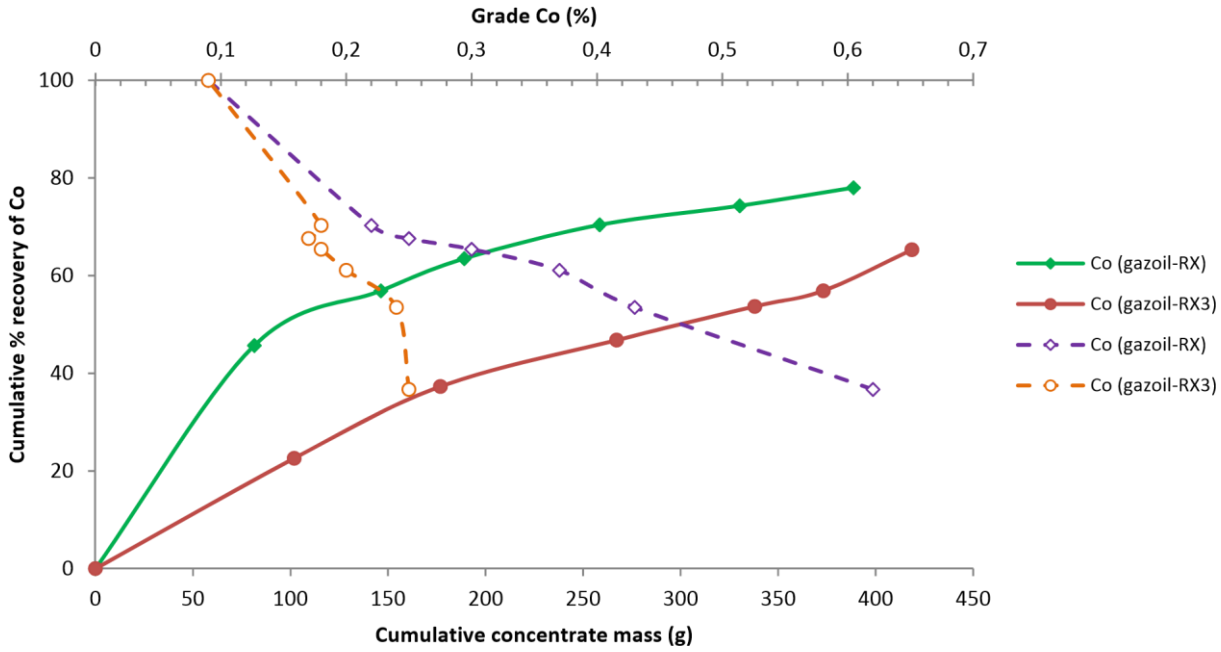

Fig. 8 Comparison between Co recoveries and grades obtained with the mixture gazoil-rinkalore RX and the mixture gazoil-rinkalore RX3

The low recoveries and grades obtained with the use of the mixture rinkalore RX3 could be explained in that this mixture

contained already 50% of sodium sulhydrate (NaSH), which was also used as the activator. It is then believed that the excess of NaSH destroyed partially the superficial sulphides formed during flotation and therefore hindered an efficient collection of the minerals in the froth phase. It is also believe that the excess of NaSH increased substantially the pH, which would lead obviously to bad flotation response.

IV. Conclusion

Flotation tests were conducted with the use of two types of rinkalore mixtures, along with other flotation reagents. The results indicated that the copper cobalt oxide ore sample had a good flotation response with the use of the mixture rinkalore RX as compared to the flotation test results obtained with the use of the mixture rinkalore RX3. However, the Cu and Co recoveries obtained with both types of mixtures were relatively low. In order to improve these results, further tests should be required to optimize the pH and reagent addition points.

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