

# Recovery of Copper Metal through Reprocessing of Residues from a Hydrometallurgical Plant

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**ABSTRACT**— *The Chemical of Africa (CHEMAF) is a hydrometallurgical plant operated in Katanga since 2001. It produces copper metal using a process comprising the sulphuric acid leaching of copper-cobalt oxide ores under reducing conditions ( $\text{Na}_2\text{S}_2\text{O}_5$  or  $\text{SO}_2$ ) followed by the leach liquor purification by solvent extraction (SX) and electrowinning of copper. The leach liquor is recovered during the thickening of pulps from the leaching section and the scavenging of residues by washing in the counter-current decanters (CCD). The process residues were anciently dumped near the plant. With the increase in the run of mine (ROM) ores sulphide minerals content related to changes in the Kalukuluku deposit mineralogy and considering that the storage of residues may result in toxic pollutants release to the environment, their reprocessing is gaining the ground as the best option. The present research aims at recovering copper metal from residues (2.01% Cu and 0.32% Co) through their reprocessing based on the sulphuric acid leaching prior to the recovery of copper metal through cementation with iron shavings. The results from the experiments have showed that the leaching of copper ( $\approx 90\%$ ) and cobalt (86%) was successful when conducted during 90 minutes at  $75^\circ\text{C}$  using 150 g of residues subjected to stirring (500 rpm) in 1 L of  $\text{H}_2\text{SO}_4$  (30 g/L) in the presence of  $\text{Na}_2\text{S}_2\text{O}_5$  (330 mV). Consequently, one recovers satisfactorily copper metal (2.5 g of solids assaying 93% Cu recovered at 86%) when 1 g of iron shavings was stirred (400 rpm) during 60 minutes at constant speed and at the room temperature in 250 mL of the metalliferous solution (10.84 g/L Cu and 1.73 g/L Co) prepared by the leaching of residues.*

**Keywords**— Hydrometallurgical processing residues, Pollutants release, Reprocessing, Copper metal recovery

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## 1. INTRODUCTION

The export of copper and associated metals produced in the Katanga province by the mineral industry constitutes one of the most important sources of the financial godsend needed by the DR Congo government to conduct its various regalia missions. However, the production of metals intended for export is acknowledged a great source of the pollution which threatens the environment and endangers the human health and wildlife owing to the generation of huge volumes of wastewaters and solid wastes [1]. Indeed, one estimates at more than 400 million tonnes the amount of solid wastes generated by the mineralurgical and metallurgical processes implicated in the production of copper metal [2]. Moreover, the mine wastes and tailings from the processing and beneficiation of copper ores were stored since many decades in the vicinity of different cities without the environment safeguarding policies in the majority of the cases [3-5]. These solid wastes are undergoing erosion by winds and weathering by rainfalls ultimately resulting in the release of toxic pollutants to the environment mainly as airborne particles and as the dissolved matters contained in the surface waters. The concerned pollutants are reputed harmful to the human health and wildlife [6, 7].

Residues from the hydrometallurgical processing of copper-cobalt oxide ores are made of the insoluble components consisting of siliceous matters, clayey materials, sulphide minerals as well as the unrecovered valuable metals. The concerned residues can be used as the secondary and cost-saving raw materials for the minerals processing industry [5, 8]. With the increase in the ROM ores sulphide minerals content arising in the majority of copper deposits mined in

Katanga due to changes in mineralogy with the height, the reprocessing of residues from hydrometallurgical processes is presently looked at as an interesting option considering the environment issues and costs associated to their storage.

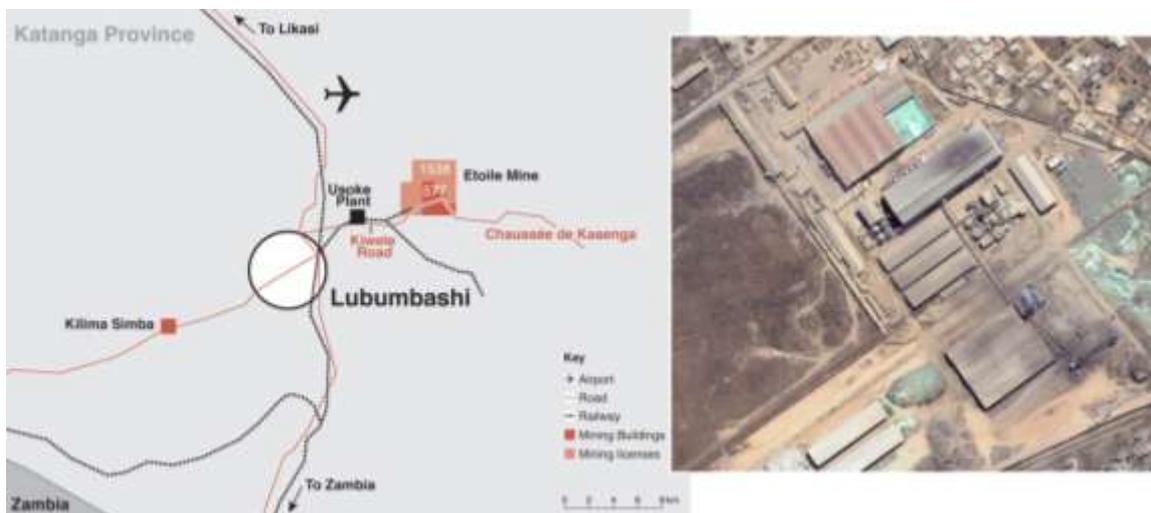
The *CHEMAF* technical service is interested in the reprocessing of residues from the hydrometallurgical processing of copper-cobalt ores and especially the process wastes that were anciently dumped in the vicinity of the *Tshiamilemba* camp belonging to the Congolese National railway Company (SNCC). The reprocessing of the concerned process residues could both enhance the environment safeguarding and back the company wastes management policy presently oriented toward the recycling of process wastes in the hydrometallurgical plant considering their contents in recoverable metals and bearing in mind their industrial value as the low-cost secondary raw materials. The reprocessing of wastes from hydrometallurgical plants is presently looked at as a palliative to the process dysfunctions arising due to the increased presence of sulphide minerals in the ROM ores used as feed resulting in the valuable metals retention in the leaching residues [9]. It is imposing itself as the transitory solution prior to the hydrometallurgical process overhauling to adapt to variations in the feed mineralogy related to the increasing presence of sulphide minerals in the ROM ores.

The present research work aims at recovering copper metal through the reprocessing of residues from the *CHEMAF* hydrometallurgical plant and especially those anciently dumped in the vicinity of the *Tshiamilemba* camp. The suggested processing route comprises the sulphuric acid leaching of residues under the reducing conditions ( $\text{Na}_2\text{S}_2\text{O}_5$ ) followed by the precipitation of copper ions by cementation with iron shavings. To achieve the research objective, the leaching and cementation tests were conducted while varying the following parameters: the sulphuric acid concentration, time and temperature followed by the amount of iron shavings added to the leach liquor subjected to stirring at constant speed and during a given period of time.

## 2. MATERIAL AND METHODS

### *Plan location and process description*

The *CHEMAF* is a mining company owned by a private investor. It is acknowledged to be the first mining company to restart the production of copper in Katanga after the vertiginous drop in the country output of copper following the collapse of the Kamoto underground mine in 1990. Its hydrometallurgical plant is located at the site of *Usoke* [10] found in the City of Lubumbashi (Figure 1) at approximately 8 km from the Kalukuluku mine commonly named “*Etoile*” [11].



**Figure 1:** Location of the CHEMAF hydrometallurgical plant

Designed with the handling capacity of 1200 tonnes per day of copper-cobalt oxide ores, The *CHEMAF* hydrometallurgical plant, operated in Katanga since 2001, produces monthly 90 tonnes of copper cathodes grading 99.99% and 5 tonnes of hydroxides of cobalt upgraded at 28% using the process described at Figure 2.

In 2011, the *CHEMAF* hydrometallurgical plant has produced 20,191 tonnes of the Class A graded copper cathodes and 2155 tonnes of cobalt hydroxides [12]. The ROM ores (3.5% Cu and 1.5% Co) from the *Kalukuluku* mine are comminuted by crushing and wet grinding to produce 70-75 passing 150  $\mu\text{m}$  followed by the comminuted matter classification using cyclones. The underflow is returned back to regrinding whereas the pulp with the specific gravity of 1400 – 1450 g/L or the cyclones overflow is directed to preleaching using 70% of the raffinate coming from the plant

copper SX section. Subsequently, the pre-leached matter is subjected to leaching during 4 hours using sulphuric acid (pH range: 1.5 – 1.7 and the solids content at 20-22%) in the presence of sodium metabisulphite (with redox potential kept at 350 – 370 mV) to enhance dissolution of trivalent cobalt contained in heterogenite present in the ROM ores.

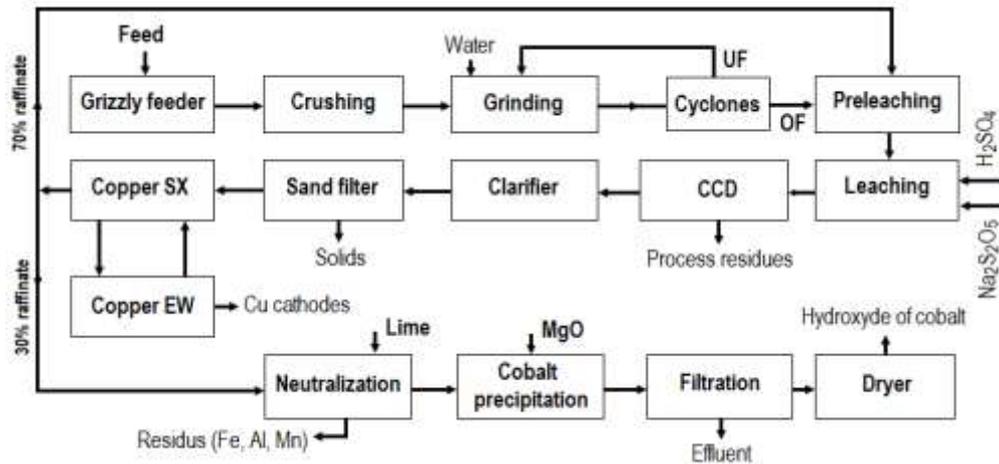


Figure 2: CHEMAF hydrometallurgical plant simplified flowsheet

The pulp given by the ROM ores comminution and leaching is subjected to thickening in view the high grade pregnant leach solution (5 - 10 g/L Cu at a recovery of 95-97%) separation as the thickener overflow whereas the underflow, consisting of the leaching residues (process residues), is subjected to scavenging achieved by a washing in CCDs using the effluent from the cobalt precipitate filtration section in mixture with process water from the tailings pond. The scavenged residues are subjected to neutralization by lime before being dumped as process residues. The recovered leach liquor is subjected to clarification and filtration followed by copper SX using LIX984N diluted in kerosene prior to EW to produce cathode (99.99% Cu). As for the remaining 30% of the raffinate from the plant (Figure 2) Copper SX section, it is subjected to purification in view to remove iron, aluminium and manganese (IAM) through precipitation at pH 3.5-4. The precipitating agent consists of the pulp of limestone (with the solids content kept at 20%) in combination with air dabbling followed by the precipitate thickening and disposal as process waste. The overflow from the precipitate thickening is directed to the plant section reserved to precipitation of cobalt as hydroxide (28% Co) using lime. The obtained precipitate of cobalt is subjected to vacuum filtration for lowering the water content at 30-35% and constitutes the process secondary end-product. As for the cobalt precipitate thickener overflow, it consists of process water which is partially returned back to the plant copper SX purification section based on the IAM removal. It is mixed with limestone to prepare the alkaline pulp used during the precipitating of impurities.

### Samples chemical, mineralogical characteristics and grindability

The samples used in the present research consist of the leaching residues anciently dumped in the vicinity of Thiamilemba camp (Figure 3). They consist of matters with particles passing 45 µm and the chemical composition given in Table 1.

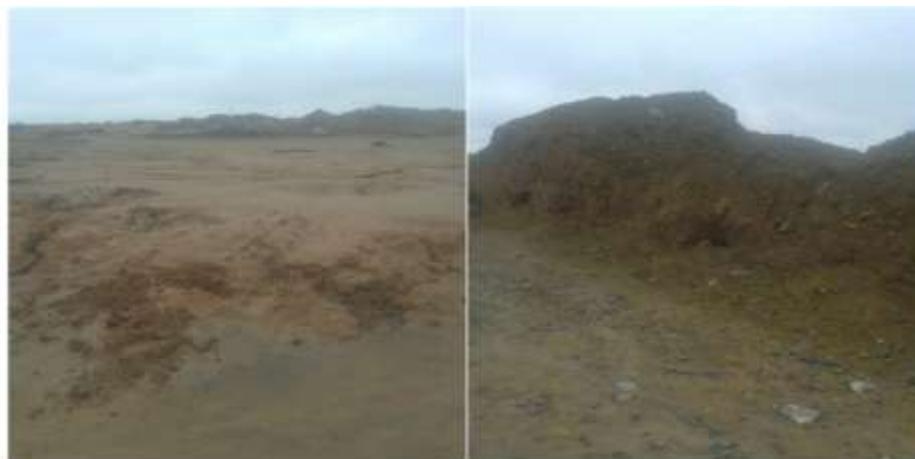
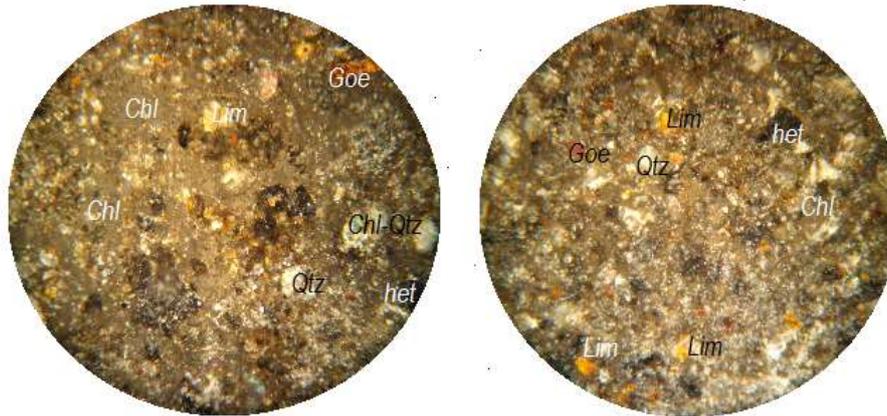


Figure 3: CHEMAF hydrometallurgical plant process residues storage sites

**Table 1:** Contents of the majors chemical elements in the process residues

Element	Copper	Cobalt	Iron	Manganese
Content (%)	2.01	0.32	4.30	0.06

Copper and cobalt are present in the process residues both as sulphides and oxides namely chalcopyrite ( $\text{CuFeS}_2$ ), chalcosite ( $\text{Cu}_2\text{S}$ ) and carollite ( $\text{CuCo}_2\text{S}_4$ ) and in the form of chrysocolla ( $\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$ , malachite [ $\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$ ] as well as black oxide minerals recalling the presence of heterogenite (Figure 3). As for the gangue minerals, they consist of pyrite ( $\text{FeS}_2$ ), chlorites [ $\text{Mg}_6\text{Si}_4\text{O}_{10}(\text{OH})_{10}$ ], hematite ( $\text{Fe}_2\text{O}_3$ ) and limonite [ $\text{FeO}(\text{OH}) \cdot x\text{H}_2\text{O}$ ] together with the siliceous ( $\text{SiO}_2$ ) and clayey matters (Figure 4).

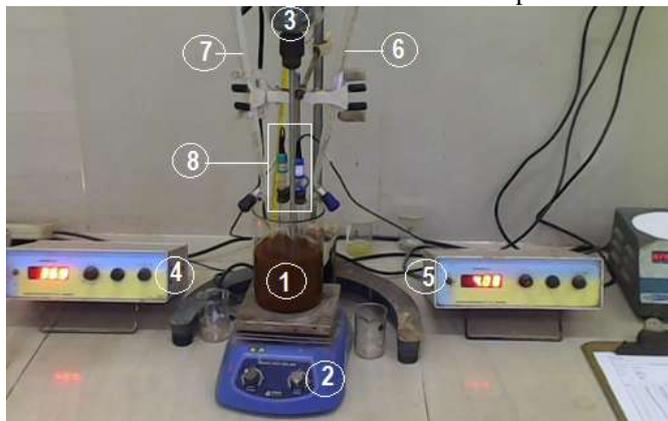


**Goe:**Goethite; **Lim:**Limonite; **Qtz:**Quartz, **het:**heterogenite (black minerals)

**Figure 4:** Images from the ligh microscopy analysis of residues

### **Hydrometallurgical residues leaching tests**

The leaching tests of residues from the hydrometallurgical processing of copper-cobalt oxide ores were conducted after the pulps preparation and while varying the following parameters: the sulphuric acid concentration, the leaching time and temperature as well as the amount of sodium metabisulphite added to the pulps mechanically stirred in view the enhanced dissolution trivalent cobalt contained in grains of heterogenite. These tests were conducted with aim to determine the leaching conditions leading to the greatest dissolution of copper and cobalt contained in the process residues. The leaching of residues was conducted with the online measurement and adjustment of the pulp pH and redox potential achieved via the continuous addition of sulphuric acid and sodium metabisulphite (Figure 5).



1. Beaker for the sulphuric acid leaching of residues
2. Heating plate for temperature variation
3. Mechanical agitator for the pulp stirring
4. Potentiometer
5. pH-meter
6. Burette of sulphuric acid
7. Burette of sodium metabisulphite
8. Probes for the online measurement of pH and redox potential

**Figure 5:** Experimental device for the sulphuric acid leaching of residues

### ***Influence of the sulphuric acid concentration on solubilisation of copper and cobalt***

The leaching tests of residues, from the hydrometallurgical processing of copper-cobalt oxide ores achieved at the CHEMAF, were conducted using 1000 mL of a sulphuric acid solution prepared while varying the concentration (20 - 35 g/L). 150 g residues were added to the sulphuric acid solution placed in 2000 mL beaker and the obtained mixture was mechanically stirred (500 rpm) during 91 minutes at room temperature. The pulps prepared during the leaching tests were subjected to vacuum filtration to recover the leach liquors. Each cake given by the pulps filtration was subjected to washing using 450 mL of the distilled water and the obtained waters added to the leach liquors. Afterwards, the washed cakes were dried at 105°C in Memmert Steam room, weighted, homogenized and sampled by quartering to obtain a 1 g sample that was later subjected to leaching with *aqua regia* (5 mL concentrated nitric acid and 15 mL concentrated hydrochloric acid) to ascertain that copper and cobalt were totally dissolved. The leach liquors given by the leaching tests of residues were diluted 125 times prior to analysis of copper and cobalt by the emission spectroscopy using a *Spectro Ciros Vision* apparatus. As for the solutions from the cakes attack by *aqua regia*, they were diluted 5000 times and assayed for copper and cobalt.

### ***Influence of the leaching time on solubilisation of copper and cobalt***

The leaching tests of residues were conducted while varying time and the sulphuric acid concentration kept at 30 g/L using the same experimentation procedure. The obtained leach liquors and cakes samples were subjected to the same preparation procedure before being assayed for copper and cobalt. The concerned tests aimed at determining the influence of time on the dissolution of copper and cobalt contained in the studied residues.

### ***Influence of the leaching temperature on solubilisation of copper and cobalt***

Concerning the influence of this parameter on the dissolution of copper and cobalt, it was studied through achievement of the leaching tests of residues through the heating in order to induce the pulp temperature variation (30 – 90°C). 150 g of residues from the hydrometallurgical processing of copper-cobalt oxide ores were mechanically stirred during 90 minutes in 1000 mL of the sulphuric acid solution with the concentration kept at 30 g/L.

### ***Influence of sodium metabisulphite on solubilisation of cobalt***

Considering that the dissolution of trivalent cobalt contained in heterogenite cannot take place in the absence of a reducing agent, the leaching tests of residues were conducted during 90 minutes with the temperature kept at 75°C. Thus, 150 g of residues were mechanically stirred in 1000 mL of the sulphuric acid solution (30 g/L) while varying the concentration of sodium metabisulphite (1- 2.5 g) added to the pulp.

### ***Recovery copper ions by cementation with iron***

The leaching tests of residues have given a metalliferous solution of copper and cobalt. Concerning the recovery of copper ions, it was conducted by cementation with iron shavings. A know amount of iron shavings (from 1 to 2.5 g) was added to 250 mL of metalliferous solution placed in a 500 mL beaker and mechanically stirred (400 rpm) at room temperature during 60 minutes. At the reaction cementation completion, the stirring was stopped to allow the precipitate of copper settling prior to dehydration conducted by filtration and drying at 105°C in a Memmert steam room. The dried matter was homogenized and sampled by quartering to constitute a 1 g sample that was ultimately attacked by 15 mL of concentrated nitric acid. The obtained solution was diluted with distilled water 125 times before being assayed for copper.

## **3. RESULTS AND DISCUSSION**

The results presented in this section of the present research are in relationship with the leaching tests of residues from the hydrometallurgical processing of copper-cobalt oxide ores from the deposit of *Kalukuluku*. It is important bearing in mind that the concerned tests aimed at determining the leaching conditions enabling the enhanced dissolution of copper and cobalt as well as the highest recovery of copper metal from the leach liquor by cementation with iron shavings.

### ***Dissolution of copper and cobalt under the influence of the sulphuric acid concentration***

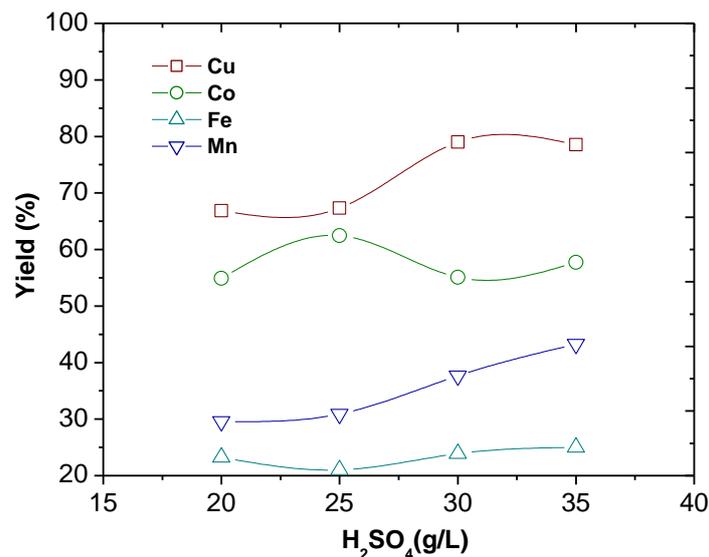
The sulphuric acid concentration variation during the leaching tests of residues from the hydrometallurgical processing of copper-cobalt oxide ores conducted at the CHEMAF has given the results consigned in Table 2. As can be seen from the concerned results, the amounts of copper and cobalt dissolved during the leaching tests of residues is

growing with the sulphuric acid concentration. Indeed, the dissolution yield of copper is increased by 12% when the sulphuric acid concentration is varied from 20 to 30 g/L showing explicitly the increased dissolution of the bearing minerals contained in the residues subject to leaching. One can assume that an increase in the sulphuric acid concentration is magnifying the leaching agent power of towards minerals present in the studied residues and particularly, those containing copper.

**Table 2:** Concentration and yield of copper and cobalt versus the sulphuric acid concentration

H <sub>2</sub> SO <sub>4</sub> (g/L)	Concentration (g/L)		Yield (%)	
	Cu	Co	Cu	Co
20	8.06	1.05	66.85	54.90
25	8.12	1,20	67.33	62.45
<b>30</b>	<b>9.53</b>	<b>1.06</b>	<b>79.02</b>	<b>55.09</b>
35	9.47	1.11	78.53	57.73

As a result, the leach liquor content of copper was raised from 8.06 to 9.53 g/L. As for cobalt, its content in the leach liquor was increased from 1.05 to 1.20 g/L when the initial sulphuric acid concentration is raised by 5 g/L. the dissolution yield of copper was practically raised at 67.3%. The obtained results are supporting the fact the increase in the sulphuric acid concentration is enhancing the dissolution of the bearing minerals of copper and cobalt contained in the residues subjected to leaching. As for the decrease in the dissolution yields of copper and cobalt observed beyond the sulphuric acid concentration of 25 and 30 g/L respectively, it could be attributed to the exaggerated dissolution of the gangue minerals. This statement is supported by the increase in the yields of iron and manganese arising when more sulphuric acid is used and particularly, beyond 25 g/L (Figure 6).



**Figure 6:** Yields of the dissolved metals versus the sulphuric acid concentration

The obtained leach liquor characteristics with respect to copper (9.53 g/L recovered at 79%) do not comply with the industrial requirements (up to 10% at the recovery of 95-97%). However, the leach liquor content of copper surpasses that of the leach liquor (3.18 g/L recovered at 95.1%) prepared by Kalenga [13] who recently conducted a research aiming at recovering copper and cobalt through the reprocessing of residues (1.42% Cu et 0.14% Co) from the hydrometallurgical plant of Shituru located at 150 km from the CHEMAF and operated by the “Gecamines” acknowledged the biggest state-owned mining company in the country.

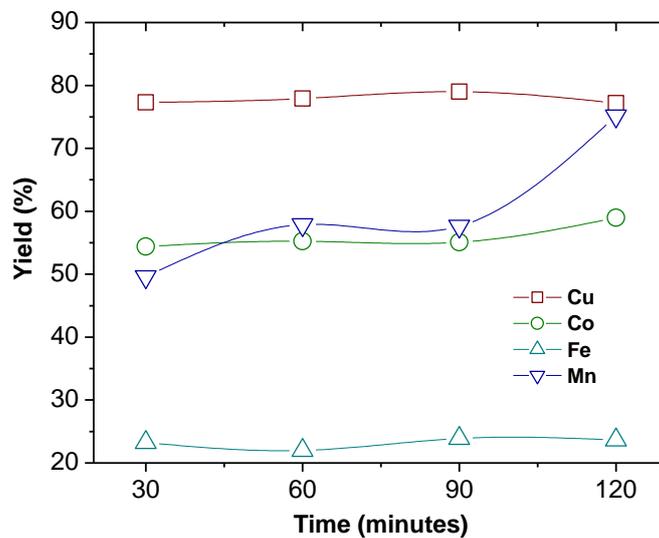
#### **Dissolution of copper and cobalt versus time**

When the leaching tests of residues are conducted while varying time, one obtains the results given in Table 3.

**Table 3:** Concentrations and yields of copper and cobalt versus the leaching time

Time (minutes)	Concentration (g/L)		Yield (%)	
	Cu	Co	Cu	Co
30	9.32	1.04	77.30	54.38
60	9.40	1.06	77.93	55.24
<b>90</b>	<b>9.53</b>	<b>1.05</b>	<b>79.02</b>	<b>55.09</b>
120	9.31	1.13	77.18	58.98

It is obvious that the concentrations and yields of copper and cobalt have slightly changed in spite of the leaching time variation. However, it is obvious that more copper (79%) and cobalt (55%) were dissolved after 90 and 120 minutes respectively during the sulphuric acid leaching of residues with the concentration kept at 30 g/L. As a result, one obtains the leach liquor with the highest concentrations of copper (9.53 g/L) and cobalt (1.13 g/L). Based on what precedes, it can be stated that a prolonged contact between the leaching agent and the studied residues or the lengthening of the reactional time is bring to an enhanced dissolution of the bearing minerals of copper and cobalt. However, one can clearly observe a decrease in the yield and the leach liquor content of copper beyond 90 minutes. This phenomenon could be attributed to the increasing dissolution of minerals from the gangue conducting inevitably the leach liquor pollution by (Figure 7) manganese (75%) followed by that of iron (24%).



**Figure 7:** Yields of the solubilized metals versus the leaching time

Compared to 180 minutes obtained during a similar research conducted by Kalenga [13], it can be assumed that the leaching of residues from the CHEMAF requires less time (90 minutes). This difference of behavior showed by these two types of residues from the hydrometallurgical processing of oxide ores of copper may reside in their chemical and mineralogical compositions, the particles size distribution (100% passing 45  $\mu\text{m}$  vs 80% passing 75  $\mu\text{m}$ ) and the leaching conditions ( $\text{Na}_2\text{S}_2\text{O}_5$  as the reducing agent of Co (III) vs Fe(III) as oxidiser of sulphides). It may result from the storage conditions of residues which obviously have governed the wathering process undergone by the Cu-Co bearing minerals.

### ***Dissolution of copper and cobalt versus temperature***

The leaching tests of residues with the temperature variation (25 – 90°C) have given the results consigned in Table 4.

**Table 4:** Concentrate and yield of copper and cobalt versus the leaching temperature

Temperature (°C)	Concentration (g/L)		Yield (%)	
	Cu	Co	Cu	Co
25	9.53	1.06	79.02	55.09
50	9.83	1.34	81.49	69.88
<b>75</b>	<b>10.22</b>	<b>1.33</b>	<b>84.71</b>	<b>69.60</b>
90	10.87	1.45	90.17	75.42

The dissolution of copper and cobalt is significantly improved when the leaching temperature is raised from 25 up to 90°C. Indeed, one finds in the leach liquor copper and cobalt to concentrations as higher as 10.87 g/L and 1.45 g/L respectively. When compared to the values obtained at 25°C, one can note that the leach liquor contents of the valuable metals have undergone an increase of about 14% and 37% respectively for copper and cobalt with the yields of 90.2 and 75.4%. The increased dissolution of copper and cobalt induced by the raise in the leaching temperature is explicitly showing its great influence on the dissolution kinetics of minerals contained in the residues when kept in contact with the sulphuric acid or the leaching agent. It can be stated that the enhanced dissolution of the bearing minerals of copper and cobalt results from the combined effects of the reaction medium energetic mixing and the raise in temperature acting against the diffusion which is a process commonly acknowledged through literature to slowdown the leaching velocity. This phenomenon is associated with the formation of thin layers consisting of the reacted matters on the surface of the solid particles subjected to the sulphuric acid leaching. The concerned layers are acting as screens that prevent or hinder the direct reaction between the solid matter and the leaching agent. However, it is important noticing that using the leaching temperature as higher as 90°C will undoubtedly become an operation consuming more energy and reagents and ultimately a costly enterprise. Furthermore, the use of a higher temperature will result in evaporation of water requesting to continuously adjust the leaching solution level in the reactor through addition of fresh water. Consequently, an online measurement and the regulation of the acidity and redox potential have been implemented during the experiment conducted at 90°C in order to maintain the solid matters subjected to leaching under the same reactional conditions. That is why; 75°C was retained as the optimal temperature for the remaining leaching tests of residues from the hydrometallurgical processing of copper-cobalt oxide ores implemented at the *CHEMAF*. This temperature is not far from that chosen by Kalenga [13] who conducted at 80°C the leaching of residues dumped at the site of Panda 2.

### ***Influence of sodium metabisulphite on the dissolution of cobalt***

The leaching tests of residues conducted under the optimal conditions (90 minutes and 75°C) and in the presence of sodium metabisulphite led to the results given in Table 6.

**Table 6:** Concentration and yield of copper and cobalt in the presence of sodium metabisulphite

Na <sub>2</sub> S <sub>2</sub> O <sub>5</sub> (g/L)	Pulp redox potential (mV)	Concentration (g/L)		Yield (%)	
		Cu	Co	Cu	Co
1.0	390	9.39	1.6	77.84	84.28
1.5	360	9.7	1.62	79.26	84.63
<b>2.0</b>	<b>330</b>	<b>10.84</b>	<b>1.73</b>	<b>89.73</b>	<b>85.80</b>
2.5	300	10.21	1.45	84.71	75.49

The leach liquor cobalt content is significantly increased under the reducing conditions created by the presence of sodium metabisulphite. This reagent is acknowledged to enhance the dissolution of heterogenite through its reducing action on trivalent cobalt. Even with the lowest concentration of sodium metabisulphite of 1 g/L corresponding to a redox potential of 390 mV, nearly 84% of cobalt and 78% of copper were dissolved during the leaching tests of residues. The highest dissolutions of copper (90%) and cobalt (86%) are achieved in the presence of 2 g/L of sodium metabisulphite corresponding to a redox potential of 330 mV. Under these reducing conditions, one obtains a metalliferous of solution containing 10.84 g/L of copper and 1.65 g/L of cobalt. Beyond 330 mV, the leach liquor contents of copper and cobalt decrease as they may undergo reduction and precipitation as metals under the strongest reducing conditions.

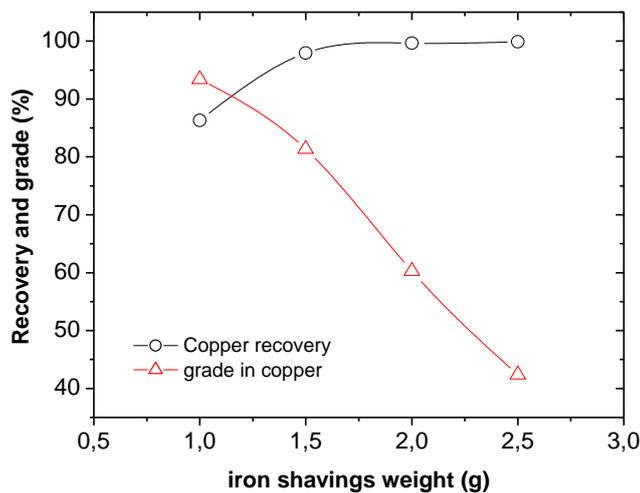
### ***Recovery of copper metal by cementation with iron shavings***

The metalliferous solution (10.84 g/L Cu and 1.73 g/L Co) given by the sulphuric acid leaching of residues was reacted with different amounts of iron shavings in order to precipitation copper ions. The precipitate grade and recovery in copper versus the amount of iron shavings are given in Table 5.

**Table 5:** Recovery and precipitate grade in copper versus the amount of iron shavings

Amount of iron shavings (g)	1	1.5	2	2.5
Metalliferous solution volume (mL)	250	250	250	250
Copper content in the metalliferous solution (g/L)	10,84	10,84	10,84	10,84
Copper weight in the metalliferous solution (g)	2,71	2,71	2,71	2,71
Filtrate volume (mL)	245	245	244	235
Copper content in the filtrate (g/L)	1.52	0.23	0.04	0.01
Copper weigh in the filtrate (g)	0.372	0.056	0.010	0.002
Precipitated copper (g)	2,338	2,654	2,700	2,708
Recovered copper (%)	<b>86,27</b>	97,93	99,63	99,93
Precipitate grade in copper (%)	<b>93.40</b>	81.34	60.27	42.38
Precipitate weight (g)	<b>2.50</b>	3.26	4.33	6.39

As can be seen from the results shown in Table 5, the amount of copper ions precipitated increases with that of iron shavings added to the metalliferous solution. Indeed, the addition of 1 g of iron shavings to the metalliferous solution has enabled to recover about 86% of copper ions in a precipitate with the highest grade (93%). Almost all copper ions initially present in the metalliferous solution were recovered (99.9%) in a precipitate presenting the lowest grade in copper (42%) when 2.5 g of iron shavings were added to the metalliferous solution subjected to stirring. Based on what precedes, it can be stated that the recovery of copper and the precipitate grade vary contrariwise versus the amount of iron shavings added to the metalliferous solution (figure 9).



**Figure 9:** Recovery and grade of copper in the precipitate versus the amount of iron shavings

The observed phenomenon is explicitly showing the fact that the recovery of more copper results in the precipitate grade decrease presumably due to the entrainment of impurities contained in the metalliferous solution apart from iron and other minor impurities brought by the shavings. That is why; 1 g was retained as the optimal amount of iron shavings because it has enabled to precipitate 2.5 g of matter grading 93% Cu recovered at 86% from the *CHEMAF* hydrometallurgical plant process residues.

#### 4. CONCLUSION

The present research was conducted with the aim to recover copper metal through the reprocessing of residues (2.01% Cu and 0.32% Co) from the *CHEMAF* hydrometallurgical plant. It was focused specifically on the determination of the leaching conditions that can enable enhancing the dissolution of copper and cobalt and the amount of iron shavings leading to a precipitate with the highest grade in copper. Based on the results from the experiments, the following conditions can be selected as optimal: 150 g of residues, 1000 mL of the sulphuric acid solution with the concentrate kept at 30 g/L, the mechanical stirring (500 rpm) during 90 minutes and at 75°C and in the presence of sodium metabisulphite (330 mV).

Under the aforementioned conditions, one obtains a metalliferous solution containing 10.84 g/L Cu and 1.73 g/L Co with the dissolution yield of 90 and 86% respectively. As for the recovery of copper metal from the obtained metalliferous solution, the following operating conditions were retained as optimal: 250 mL of the leaching solution, 1 g of iron shaving and a mechanical stirring (400 rpm) at room temperature during 60 minutes. As a result, one recovers 86% of copper contained in the metalliferous solution in the form of a precipitate weighting 2.5 g and grading 93%.

We suggest in the days to come to focus the research on the leach liquor purification by solvent extraction in view to envisage electrowinning of copper and the recovery of cobalt by precipitation with magnesia.

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## 6. REFERENCES

- [1] SNC-Lavalin International. “Étude sur la restauration des mines de cuivre et de cobalt en République Démocratique du Congo”, Rapport Préliminaire M-6708 (603082), Montréal (2003):1-216.
- [2] Andrews C., Bocoum B., Tshimena D. “Democratic Republic of Congo, Growth with Governance in the Mining Sector”, The World Bank Report No.43402-ZR, May 2008, Oil/Gas, Mining and Chemicals Department, AFCC2, Africa Region (2008):1–140.
- [3] Kalenga N.M., Frenay J., Mukendi K., De Donato P., Kaniki T.A. “Inventory of Sites of Production, Storage and Disposal of Mineral Wastes in Katanga and Assessment of Environmental Impacts”, A report of a scientific cooperation project 2005 No. 6312PS508 achieved by the University Of Lubumbashi (UNILU), the Liege (ULg) and the National Polytechnic Institute of Lorraine (INPL) funded by the French speaking countries Academic Agency (FAA), (2006): 1–216.
- [4] Kitobo W.S. “Dépollution et valorisation des rejets miniers du Katanga; Cas de tailings de l’ancien concentrateur de Kipushi”, Thèse de Doctorat en Sciences de l’Ingénieur, Faculté des Science Appliquées, Université de Liège, (2009): 17-87.
- [5] Lutandula M.S. and Banza M. “Recovery of cobalt and copper through reprocessing of tailings from flotation of oxidized ores”, *Journal of Environmental Chemical Engineering* (2013):1085–1090.
- [6] Lutandula M.S. and Kashala, N.G. “Zinc oxide production through reprocessing of the electric arc furnace flue dusts”, *Journal of Environmental Chemical Engineering* 1(2013): 600–603.
- [7] Shengo L.M., Mutiti C.W.N, Nonda A.K. and Mukadi A.T. “Assessment of health risks related to the intake of cabbages grown at sites contaminated by heavy metals”, *Journal of Chemical, Biological and Physical Sciences*, Section D: Environmental Sciences, Aug.2014 – Oct. 2014, Vol. 4, N°4; (2014):3798-3808.
- [8] Journal Officiel de la République Démocratique du Congo. “Décret no. 038/2003 du 26 mars 2003 portant Règlement minier”, Kinshasa (2003):1–179.
- [9] Kambau, G.N. “Determination of the leaching conditions enabling the processing of the mixed ores of copper from the deposit of Kalukuluku in view to use them as feed at the *CHEMAF* hydrometallurgical plant”, An interim report of a project research initiated by the Technical Service and conducted in collaboration of the Inorganic Chemistry Unit/Chemical Department, Faculty of Sciences, University of Lubumbashi (2016):1-35.
- [10] Mthembu – Salter G. “Indian Mining Companies in the Democratic Republic of Congo”, Emerging Powers and Global Challenges Programme, funded by the Swedish International Development Cooperation Agency and the Danish International Development Agency, facilitated through the Danish Embassy in Pretoria, SAIIA Policy Briefing 35(2011):1-4.
- [11] Verlinden P and Cuypers L. “Union Minière du Haut Katanga 1906-1956, Cinquantième Anniversaire de sa création”, VROMATS S.A. Printing House, Meersmans, Brussels (1956): 89-131.
- [12] Yager, T.R. “The Mineral Industry of Congo (Kinshasa)”, U.S. Geological Survey Minerals Yearbook - 2010, U.S. Department of the Interior (2010):11.1-11.9.
- [13] Kalenga, K.T. “Recovery of copper and cobalt through the reprocessing of residues from the hydrometallurgical plant of Shituru, The case of process residues dumped at the site of Panda 2 in the City of Likasi, An interim report of a project research initiated by the Metallurgical Research Division/Gécamines and conducted by the Chemical and Metallurgical Unit, Higher School of Applied techniques of Lubumbashi (2015):1-65.