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Leaching Characteristics of Upgraded Copper Flotation Tailings

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***Abstract*—**The copper flotation tailings from Konkola Copper mine in Nchanga, Zambia were used in the study. The purpose of this study was to determine the leaching characteristics of the tailings material prior and after the physical beneficiation process is employed. The Knelson gravity concentrator (KC-MD3) was used for the beneficiation process. The copper leaching efficiencies and impurity co-extraction percentages in both the upgraded and the raw feed material were determined at different pH levels and temperature. It was observed that the copper extraction increased with an increase in temperature and a decrease in pH levels. In comparison to the raw feed sample, the upgraded sample reported a maximum copper extraction of 69% which was 9%, higher than raw feed % extractions. The impurity carry over was reduced from 18% to 4 % on the upgraded sample. The reduction in impurity co-extraction was as a result of the removal of the reactive gangue elements during the upgrading process, this minimized the number of side reaction occurring during leaching.

***Keywords*—**Atmospheric leaching, Copper, Iron, Knelson concentrator

I. Introduction

CURRENTLY, there is a drop in the copper ore grades around the world. The reclaiming of tails from old metallurgical extraction processes has been identified as key to the lifespan extensions of mines. Recent advances in the development and improvement of the processing techniques of low-grade copper flotation tailings are done so as to slow down the depletion of high-grade reserves and reduce operational cost [1].

The interest in exploiting the man-made tailings dams is not only getting the minerals back to production, it is also perpetuated by increasing statutory and regulatory scrutiny with regards to the handling of tailings. Sulphide deposits co-exists with oxide patches which are rejected during the flotation process as tailings. The tailings have complex mineralogy; they combine different gangue minerals such as cupriferous micas, calcites, siliceous, feldspar and iron bearing oxide gangue materials. These materials are known for increasing acid consumption which is accompanied by operational cost incline [5], [11], [10] & [8].

At Nchanga, Zambia low grade oxide of (0.4 – 0.6 % Cu) and the high grade of (4-10% Cu) material consisting of chrysocolla, malachite and cupriferous vermiculite were stock piled for years awaiting future processing [8], [9].

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With solvent extraction technology these stock piles can be processed but the drawbacks are impurities such as Fe, Al and Mg carrying over to solvent extraction and electrowining [10]. In most cases tailings materials are fed directly to the leaching circuit without passing through the beneficiation stage, as a result, treating of tailing became a costly exercise because of the high gangue acid consumption which was accompanied by high impurity co-extraction. The presence of the gangue material in the pregnant leach solution results in increased impurity (Fe, Mg and Al) carry over to solvent extraction and electrowinning while decreasing the leaching efficiency. When impurities are carried over to the tank house they negatively affect current efficiency, cathode quality and hikes in energy consumption as a result of co-plating. The organic degrade rate also increases with the presence of impurities in the pregnant leach solution [10].

The knelson centrifugal gravity concentrator technology have been employed in the gold industry to recover both coarse and fine gold from primary, placer deposits, tailings and pre concentrates [7], [6]. This unit was introduced into the mineral processing industry as a batch unit. The knelson concentrator utilizes the combination of fluidization water, centrifugal force and shear induced dispersive forces formed as a result of the slurry upward movement which creates an interstitial tricking effect on the concentrating bed which simulates a percolation effect [4], [6], [7] & [12].

The separation mechanisms are driven by the main forces acting on particles inside the truncated cone shaped bowl which are the centrifugal force and the drag force. The governing principle in the knelson concentrators is the hindered settling mechanism [4], [6] & [7]. In practice, the bowl rotational speed produces a centrifugal force 60 times that of gravity which enables it to separate finer material based on density. In this study, tests were carried out to upgrade the copper assays by separating heavy gangue materials from light copper silicoues materials using Knelson concentrator prior to the leaching stage.

Bench scale leach tests were carried out using both the raw and upgraded feed, at variable leaching conditions to obtaining the leaching characteristics of both feed material and compare. The purpose of this was to validate the anticipated increment in leaching efficiency and a decline impurity levels as the benefits of upgrading prior to the leaching process.

II. Materials

The copper flotation tailings from Nchanga Konkola copper mine were used for this study. The tailings feed materials were sent for XRF analysis to determine the chemical composition and XRD (Fig.1) for qualitative and quantitative analysis. The chemical compositions are indicated by table I.

TABLE I
THE CHEMICAL COMPOSITION OF THE COPPER TAILINGS FEED MATERIAL BEFORE UPGRADING

	Composition (wt %)
SiO_2	58.65
TiO_2	0.6
Al_2O_3	17.77
Fe_2O_3	3.34
MnO	0.14
MgO	2.98
CaO	2.99
K_2O	7.23
SO_3	4.91
CuO	0.61

The material was sent for physical beneficiation using the KC-MD3 laboratory knelson concentrator for upgrading prior to the leaching test. The batch leaching tests were performed using diluted sulphuric acid. Standard glass ware (volumetric flasks for solution preparation, 500ml and 250ml beakers for leaching, watch glasses), 5 ml pipette was used for sampling , Magnetic stirrer hot plate for agitation and temperature control, pH meter with a thermo probe was used for both pH and temperature measurements for all leaching experiments. All leaching experiments were performed inside a fume cupboard. The leaching process constitutes of the following reactions [3], [2] & [1]:

Copper oxide minerals breakdown

$$Cu_2(OH)_2CO_3 + 2H_2SO_4 \rightarrow 2CuSO_4 + CO_2 + 3\,H_2O \qquad (1)$$

Limonite mineral breakdown

$$Fe_2O_3 + 6H^+ \longrightarrow 2Fe^{3+} + 3\,H_2O \qquad (2)$$

Silicate mineral breakdown

$$(H, K)_2(Mg, Fe)2Al_2(SiO_4)_3 + 10H^+ \rightarrow 2K^+ + 2Al^{3+} + 3H_4SiO_4 + (Fe, Mg)^{2+} \qquad (3)$$

$$KAlSi_3O_8 + 4\,H^+ \longrightarrow K^+ + Al^{3+} + 3H_4SiO_4 \qquad (4)$$

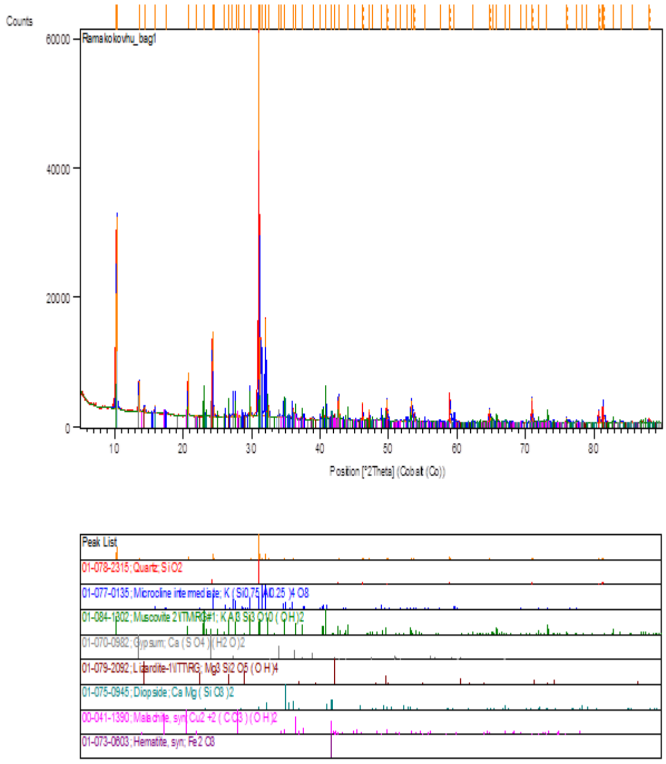

Fig. 1 XRD pattern of raw copper flotation tailings

III. EXPERIMENTAL PROCEDURE

A. Knelson concentrator (KC-MD3)

The Knelson concentrator manual discharge (KC_MD3) was operated at the Knelson Concentrator Africa (Pty)(Ltd) test laboratory. The knelson batch test work process flow is shown in Fig. 2.The KC_MD3 unit is a batch process and the concentration is manually discharged by removing the concentrating cone. The feed slurry containing 35% solids of copper tailings was made up. The feed slurry tank was agitated until the slurry was homogenously mixed. The optimum fluidization flow rate of 4.5 l/min was set using the attached flow meter then the unit was started with the optimum rotational bowl speed of 120 G- Force, set at the control panel box. The slurry was fed from the slurry tank at the feed rate of 0.5 kg /min. The light valuable materials were collected at the bottom outlet pipe of the unit and then filtered using the filter press at the end of the cycle and dried in the oven at T=80°C. At the end of the cycle the unit was stopped and the heavy gangue materials were washed out of the concentrating ring and pressed before drying in the oven at T= 80°C. Both the concentrate and the tailing samples are then sent for XRD analysis and the semi quantitative determination of the samples were done using the Autoquan Rietveld Refinement method. The other samples were taken for ICP-OES digestion analysis to determine the amount of soluble and insoluble copper present in the samples.

B. Batch Atmospheric Leaching

Batch leach tests were carried out in a 500 ml glass vessel with a watch glass lid. For temperature control the glass vessel was put on top of a temperature regulated hot plate inside a fume cupboard.

At the beginning of each test, 300 ml de-ionised water was introduced into the leach vessel and then the water was brought to the desired temperature prior to the introduction of the sample at a mass calculated to yield 25 % solids to liquid ratio.

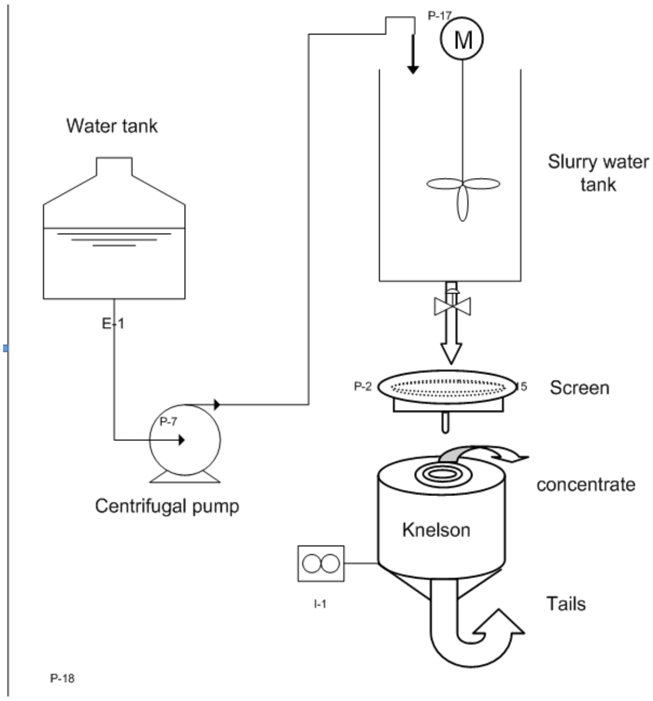

Fig. 2 Knelson concentrator (KC-MD3) test work flow sheet

Agitation was initiated to ensure homogeneity of the mixture while making up the volume to 500 ml using de-ionised water. The leach tests were carried out under absolute atmospheric pressure with the pH controlled by dosing H_2SO_4 using a volume marked burette. The residence time for each leaching cycle was 8hours with 5 ml pipette drawn samples at predetermined intervals with the first sample at 30 minute and the last sample at 480 minutes. The solution samples were analyzed using ICP –OES and the solids residue was analyzed using XRD.

IV. Results And Discussions

Table II indicates the elemental composition of raw and upgraded copper flotation tailings. The qualitative results in table II shows that after the untreated sample was beneficiated using the knelson concentrator (KC-MD3) the Mg content decreased by an average of ~1.9%. The Al content was downgraded by an average of ~2.63% with Fe content lowered by ~ 0.8%. The copper content in the sample was upgraded from 0.61% to ~ 1.02 %.

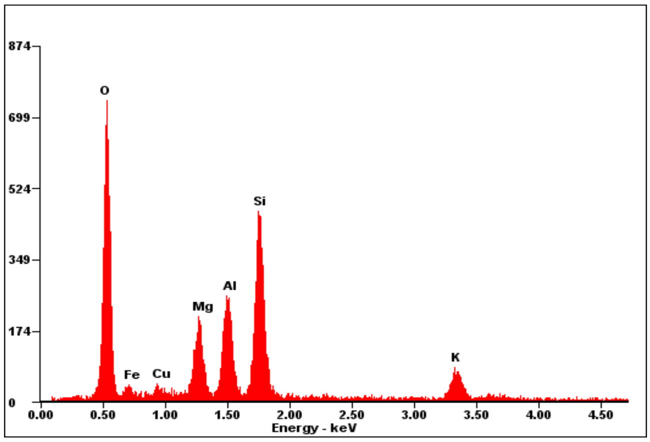

Fig. 3 SEM - EDS spectrum of the Knelson concentrator material at 4.5l/min fluidisation, 120 G- force

TABLE II
Elemental Composition of Raw and Upgraded Feed

Element wt%	O	Mg	Al	Si	K	Fe	Cu
Raw feed	50.16	3.42	9.17	29.70	4.50	2.44	0.61
Upgraded	54.97	1.52	6.54	32.01	4.04	1.64	1.02

The reduction of Al, K, Mg and Iron content from the sample prior leach has a positive outcome on the leaching process. When leaching the silicate mineral breakdown (3), (4) in the presence of sulphuric acid and Al, K, Mg, Fe ions encourage the formation of precipitates such as jarosite, silica and alunite. Alteration of the solids products (vermiculite and kaolinite) also occurs, acid is highly consumed as a result these side reactions and copper extraction is negatively affected. The presence of high Fe content in the feed material may result in Fe co-extraction during leaching which causes problems in the secondary concentration stages. Fig. 4 and 5 shows the copper leaching efficiency of both raw and upgraded copper tailing materials at different pH levels. The data fig 4 and 5 indicates the copper extraction as a function of pH at given time intervals. Lower pH values reported higher copper extraction rates. However the maximum copper extraction of 69% was obtained when leaching the upgraded feed. In comparison to the raw feed the data in fig. 5 indicated an overall increase in the copper extraction percentages of the upgraded feed by an average of 9%.

This is attributed to the fact that during the upgrading process the content of reactive gangue material was reduced, this limited acid consumption by decreasing the number of side reactions occurring during the leaching process. The reduction of these side reactions increased more contact time between the acid and the valuable mineral resulting in high leaching efficiency.

In the presence of reactive gangue material hydrogen ions are consumed by side reactions resulting in an increase in pH which hinders copper dissolution by decreasing Eh [3]. Leaching the flotation tailings directly without the upgrading showed an increased acid consumption accompanied by lower recoveries and the risk of impurity carry over to the purification stages.

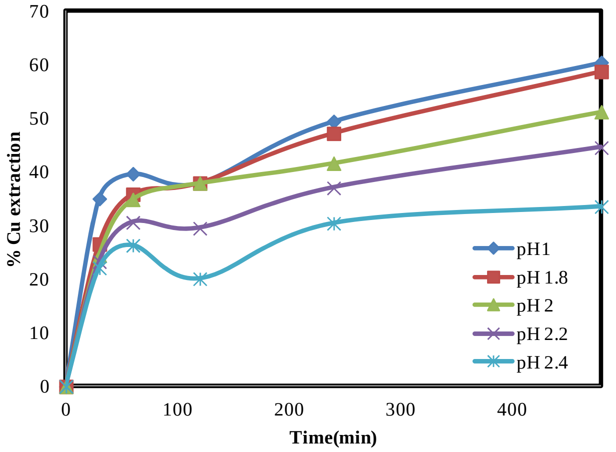

Fig. 4 Leaching efficiency of copper flotation raw feed material at different pH levels. T= 398K, solids feed= 25%, agitation speed =500rpm, PSD = 80% passing 150µm

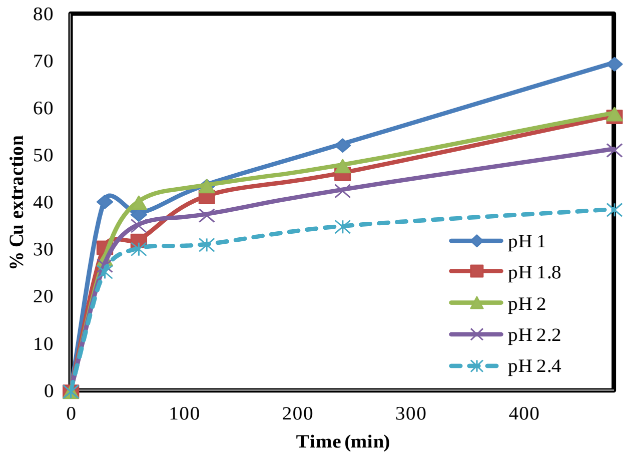

Fig. 5 Leaching efficiency of copper flotation upgraded feed material at different pH levels. T= 398K, solids feed= 25%, agitation speed =500rpm, PSD = 80% passing 150µm

Fig. 6 and 7 indicate the copper and iron extraction during leaching at pH=2 for both raw and upgraded feed material. Fig. 6 and 7 data showed that at given time intervals iron is extracted along with copper (1) to the pregnant leach solution. The raw feed (Fig.6) reported maximum iron co- extraction of 18% Fe while the upgraded feed (Fig.7) reported a minimum of 4% Fe. Iron forms part of the silicate (3), (4) and limonite (2) deposit therefore without the upgrading the feed material iron will leach out along with the copper, resulting in iron ions reporting to the PLS.

The presence of iron ions in PLS solution causes problems in solvent extraction and electro winning which are the purification stages used for further copper processing.

After the upgrading the feed material the amount of iron oxide is reduced along with lizardite and diopside, therefore the side reactions occurrence is limited during leaching. At similar conditions the data indicates an increase in copper extraction of the upgraded material to 59% Cu compared to 51% of the raw feed.

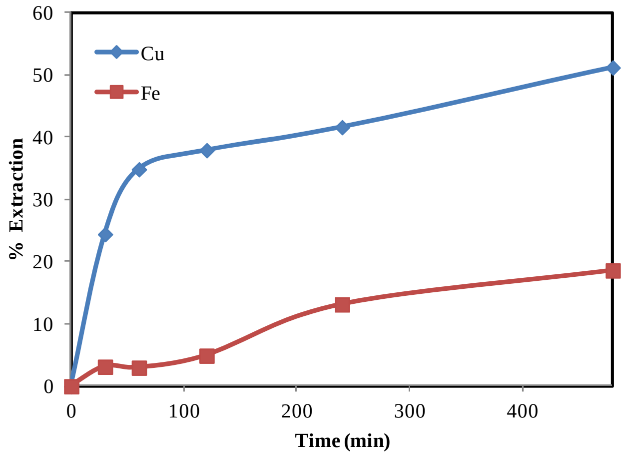

Fig. 6 Leaching efficiency of Fe and Cu in sulphuric acid solution. Material = raw feed, pH = 2. T= 398K, solids feed = 25%, agitation speed = 500rpm, PSD = 80% passing 150µm

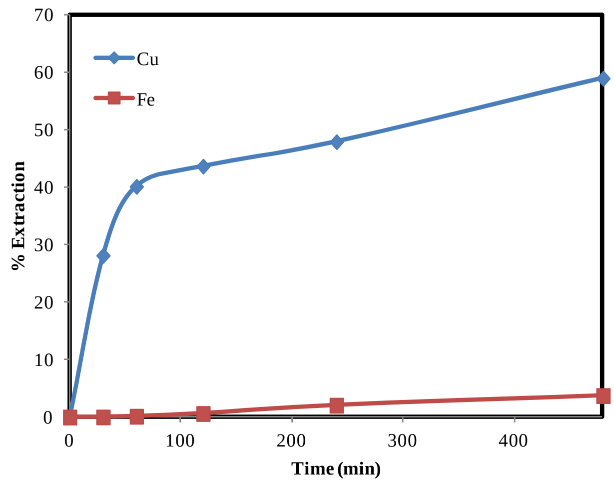

Fig. 7 Leaching efficiency of Fe and Cu in sulphuric acid solution Material = Upgraded feed, pH = 2. T= 398K, solids feed= 25%, agitation speed =500rpm, PSD = 80% passing 150µm

Fig. 8 and 9 indicate the characteristics of both the upgraded and raw feed material during leaching at three different temperature readings. Leaching rate is highly dependent on temperature. The results (Fig.8 and 9) indicate a similar trend for both upgraded and raw feed material indicating an increase in copper extraction along with an increase in temperature. The upgraded material reported a maximum of 84 % copper extraction at T= 418K. In overall the upgraded feed material had the highest copper recoveries for all experiments conducted at three different temperatures. Fig 8 and 9 shows that when temperature increases the leaching efficiency also increased, however in Fig. 9 the copper extraction efficiency reported a maximum of 84% at T= 418K, which is 9% higher than the extraction efficiency in Fig. 8 at similar leaching conditions. The data (Fig.8 and 9) showed that upgrading prior leaching minimizes Fe co-extraction which enhanced the leaching efficiency of copper.

More work still needs to be done to determine the economics of upgrading process along with further investigation on the impurities eliminated prior leaching.

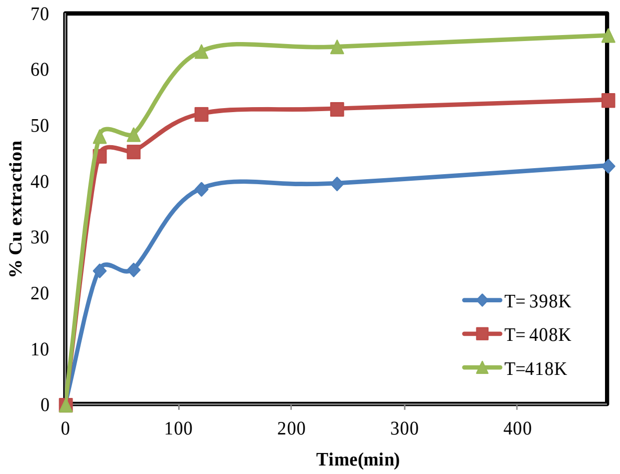

Fig. 8 Effect of temperature on copper extraction. Material = Raw feed, pH = 2, solids feed= 25%, agitation speed=500rpm, PSD=80%passing150μm

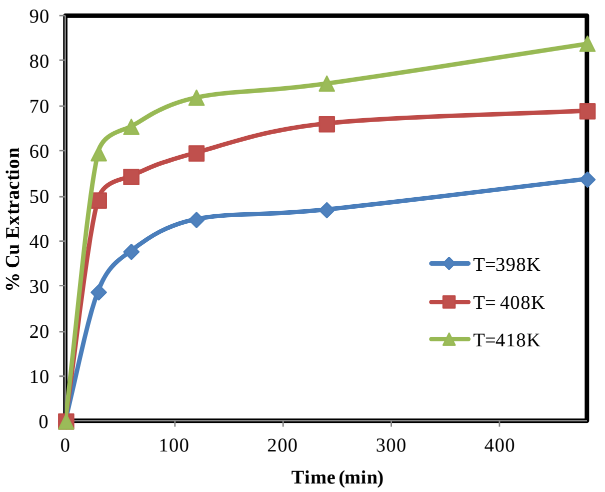

Fig. 9 Effect of temperature on copper extraction. Material = Upgrade feed, pH = 2, solids feed= 25%, agitation speed =500rpm, PSD = 80% passing 150µm

V. Conclusion

In conclusion the Knelson concentrator upgraded the copper flotation tailing material by decreasing the reactive gangue content found along with the silicate mineral deposit (Al, K, Mg, Fe). After the upgrading process, leaching of the upgraded material increased the overall copper extraction at different pH levels and temperatures. The copper extraction was increased by an average of 9% at different pH levels. The iron co-extraction was decreased from 18% to 4% after the material was upgraded. The copper extraction increased to 84% at T=418K when comparing the raw feed material and the upgraded material at different temperatures. In all experiments conducted the upgraded material proved to have the best copper leaching percentages.

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