

REPROCESSING OF OLD REFRACTORY TAILINGS-A CASE STUDY OF A ZAMBIAN MINE

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ABSTRACT

A Zambian Mine, Mines Refractory Copper ores from Open Pits and Underground Mines and treats the same through concentrators at floatation recovery less than 15% Total Copper. Tailings from the concentrator are treated at the Tailings Leach Plant with recoveries of about 35% Total Copper. Overall Total Copper recovery is 50%. Final tailings are deposited at the Tailings Dam, and over the years, an estimated 500 million tons has been deposited. Over 1,000 Samples were collected across the Tailings Dam to determine feasibility of retreatment and the optimal processing route.

Feed characterization showed 0.61% Total Copper, with over 52% cupriferous mica (refractory copper), 30% sulphides (chalcocite and chalcopyrite), and 19% Malachite and Pseudo-malachite. The material was subjected to Ambient Temperature Leaching and Elevated Temperature Leaching.

Results showed average Total Copper recoveries of 34.6%-Ambient Temperature Leaching, and 70.8%-Elevated Temperature Leaching; with Elevated Temperature Leaching giving the highest recovery. Optimization was undertaken at elevated temperature. Optimum parameters are: Residence Time-2hours, Slurry Density 1300kg/m³, pH 1.8, and Temperature 70°C. Acid Consumption was 23kg/T material treated for Ambient Temperature Leaching and 58kg/T for Elevated Temperature Leaching.

The scope of implementation covers the following: establishing a new Tailings Storage facility, construction of hydro sluicing facilities for the Tailings Dam, construction of 16km pipeline to transport slurry, and construction of a slurry pump station. Capex is estimated at \$40million. Reprocessing of refractory tailings is commercially feasible through both Ambient Temperature Leaching and Elevated Temperature Leaching. At LME \$8500/T, NPVs over 10years are \$154 million and \$358 million, for Ambient and Elevated Temperature leaching respectively. Elevated Temperature Leaching is the optimum tailings reprocessing route.

Keywords: Total Copper, Refractory Ores, Floatation, Ambient Temperature, Elevated Temperature, Leaching

INTRODUCTION

A Zambian Mine, Mines Refractory Copper ores from Open Pits and Underground Mines and treats the same through concentrators at floatation recovery less than 15% Total Copper. Tailings from the concentrator are treated at the Tailings Leach Plant with recoveries of about 35% Total Copper. Overall Total Copper recovery is 50%. Final tailings are deposited at the Tailings Dam, and over the years, an estimated 500 million tons has been deposited. The said Mine has been evaluating sources of Ore as its Ore sources are getting depleted. The Tailing Disposal Dam was investigated, and results presented in this paper.

OBJECTIVES

The work had the following objectives:

- Estimate Copper content of the material stored at the Tailings Dam.
- Establish the most viable Copper recovery options for the Tailings Dam material considering Ambient and Elevated Temperature Leaching.
- Determine optimum parameters for processing Tailing Dam material.

METHODOLOGY

Sampling

A point zero was Identified and labelled on the dam perimeter eastern side where a 2 kg sample was collected 10-50 cm below the surface. Coordinates were recorded for the point and the sample bag labelled. From point zero 50 m towards the inside of the Dam, the next sampling point was recorded, sample taken and coordinate taken. 800 samples were collected in a similar manner along the peripherals of the Dam.

Chemical and Mineralogical Analysis of TAILINGS DAM Feed Sample

Samples were drawn from each of the samples and subjected to chemical analysis using the Atomic Absorption Spectrometer (AAS). A number of samples were Composited and subjected to Mineralogical Analysis using Microscopic Identification and Quantification of Main Copper/Cobalt Sulphide and Oxide Minerals.

Sulphuric Acid Leaching Tests

Leaching tests were carried out as per procedure outlined below. The following five critical parameters were varied during initial test works; residence time, slurry density, pH, particle size distribution (PSD) and Temperature. One parameter was varied during each set of tests whilst maintaining the others constant during trials as shown in table below. A second confirmatory test was conducted at each level of the varied parameter.

Table 1: Leaching Test Parameters

S/N	Variable Parameters	Constant Parameters
1	Time, hours: 0.5, 1, 1.5, 2	Density, pH, PSD, Temperature*
2	Density: 1100, 1200, 1250, 1300, 1400	Time, pH, PSD, Temperature*
3	pH: 1.5, 1.8, 2.0, 2.5	Density, Time, PSD, Temperature*
4	% PSD, -75mic: 60, 70, 80 90 100	Density, Time, pH, Temperature*
5	Temperature, °C: 40, 50, 60, 70	Density, Time, pH, PSD*

*Fixed parameters: Slurry density=1250gpl, Time=2hrs, pH=1.8, PSD= as sampled (61.29% -75microns), Temperature=RTP (22-26°C)

Leach test procedure

The procedure followed in performing the leach tests is outlined below:

- 500g predetermined weight of Tailings dry sample and volume of domestic water were added to the leach vessel to achieve the required slurry densities of 1100, 1200, 1250, 1300 & 1400 gpl.
- A Heidolph mechanical stirrer was then placed in the leach vessel with enough clearance at the bottom to allow for efficient mixing.
- A burette containing Sulphuric acid was then mounted above the vessel for acid addition and a HANNA HI 9125 pH/ORP meter securely placed in the leach vessel and immersed about 4 cm into the slurry.
- The stirrer was then started and pH monitored until it stabilized, then the initial reading noted.
- Acid addition as well as the timer were started.
- For elevated temperature leaching, the leach vessel containing the respective slurry sample was heated to the required temperature (40-70° C) using a hot plate with a thermostat.
- After a set time duration of leaching, the leached slurry was filtered using a vacuum pump and a conical flask. The filtrate was retained for analysis of solution copper while a small representative portion of the leach residue was returned for chemical analysis.
- After establishing optimum test conditions in the first composite sample, subsequent tests were carried out on established test conditions.

RESULTS AND DISCUSSION

Chemical and Mineralogical Analysis

Chemical and Mineralogical analysis results are shown in tables below. Total Copper ranged from 0.49% to 0.75%, and 0.11% to 0.41% Acid Soluble Copper. Averages were as follows: 0.61% Total Copper, 0.31% Acid Soluble Copper and 0.022% Total Cobalt.

Table 2: Chemical Analysis

Description	%TCu	%ASCu	%AICu	%TCo	%ASCo	GAC kg/T
Average	0.61	0.31	0.28	0.022	0.005	22.07
Min	0.49	0.11		0.019	0.002	7.93
Max	0.75	0.41		0.035	0.007	37.80

Mineralogical composition was as shown in table below.

Table 3: Mineralogical Analysis Results

Mineral	Feed TAILINGS DAM			% Of TCu
	Wt.%	%TCu	%ASCu	
Chalcopyrite	0.016	0.050	-	8.2%
Bornite	-	-	-	
Chalcocite	0.166	0.133	0.002	21.8%
Covellite	0.051	0.034	-	5.6%
Pyrite	0.139	-	-	
Malachite	0.12	0.069	0.069	11.3%
Pseudo malachite	0.089	0.049	0.049	8.0%
Cupriferous Micas	8.000	0.320	0.080	52.5%
Gangue	91.419	-	-	
TOTAL	100	0.610	0.200	

Chemical and Mineralogical analysis indicated that Tailings Dam material is composed of oxide and sulphide copper Minerals, cupriferous micas (52% of the total copper), pyrite as well as gangue Minerals. The sulphide Minerals included chalcopyrite, chalcocite and covellite, oxide Minerals included malachite and pseudo malachite. All the samples analyzed had similar composition with cupriferous micas accounting

for over 40% of the contained copper Mineral. Milton Simukoko et al 2022, showed that copper ores predominantly micaceous can be processed using elevated temperature leaching.

Residence time Optimization

Figure 1 below shows variation of leach efficiency with leaching residence time.

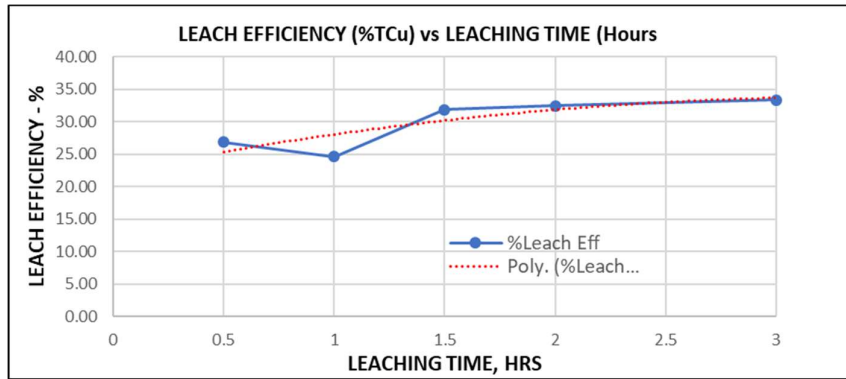


Figure 1: Leaching efficiency vs Residence time

Figure 1 shows that leach efficiency flattens at 2 hours, with Total Copper recovery 32.5%. Therefore 2 hours is the optimum residence time.

The settling rate for the leached slurry at all residence times was 2.66 cm/min, this value was above the minimum tailings leach plant requirement of 2.53 cm/min.

Slurry Density Optimization

Figure 2 below shows variation of leach efficiency with Slurry Density.

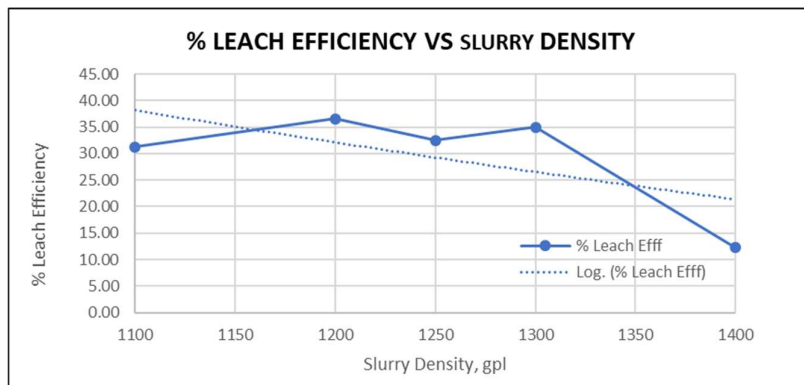


Figure 2: Leaching efficiency vs Slurry density

Figure 2 shows that highest leach efficiency of 36.55% was achieved at 1200 gpl and there was minimal reduction at 1300gpl with leach efficiency at 34.93%. There was a significant reduction in leach efficiency though from 34.93% at 1300 gpl to 16.42% at 1400 gpl. This was indicative of reduced interaction between acid (leachant) and solids. Density between 1200gpl and 1300gpl is acceptable.

The settling rate for the leached slurry at all residence times was 2.54 cm/min, this value was above the minimum tailings leach plant requirement of 2.53 cm/min.

pH Optimization

Variation of leach efficiency with pH is shown below.

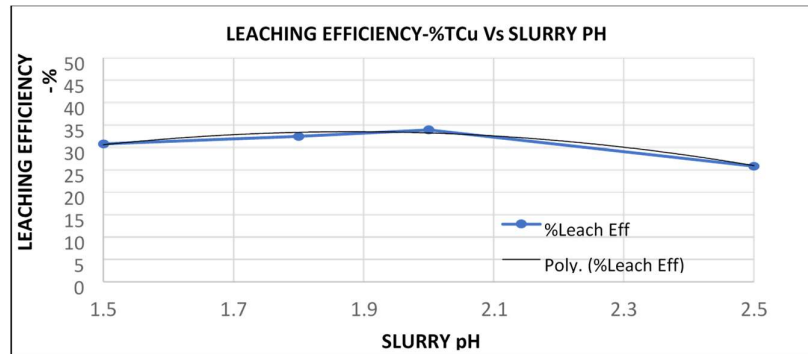


Figure 3: Leaching efficiency vs slurry pH

Figure 3 indicates that the optimum leaching pH is 2.0, with Total Copper leach efficiency at 33.94%.

The settling rate for the leached slurry for all trials was 2.66 cm/min, this value was above the minimum tailings leach plant requirement of 2.53 cm/min.

Particle size distribution optimization

Variation of Leach Efficiency with Particle Size Distribution is shown below.

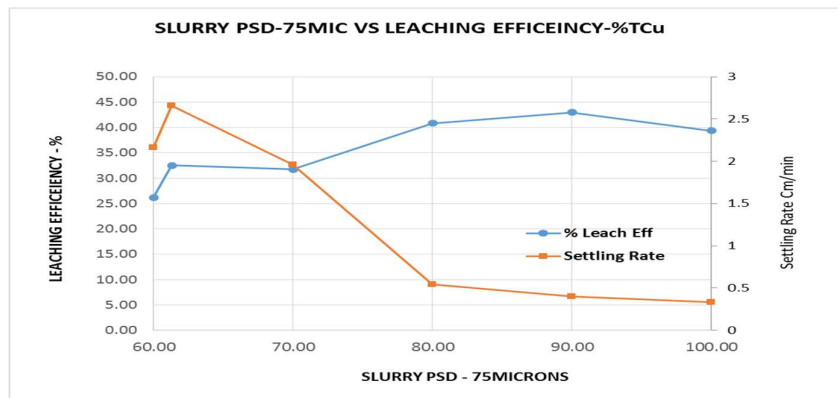


Figure 4: Leaching efficiency vs slurry particle size PSD

Figure 4 shows that milling Tailings Dam material to reduce particle size improved total copper leach Efficiency with maximum leach Efficiency of 42.96% obtained at 90% passing 75 microns compared with 33% at 61% Passing 75 microns. However, there is significant reduction in settling rates.

The settling rate for the received sample (61.29% PSD) was 2.66 cm/min, this value was above the minimum tailings leach plant requirement of 2.53 cm/min. From 70% passing 75 microns to 100% passing 75 microns, settling rates are below allowable minimum of 2.53 cm/min. it is therefore better to leach the material as is. Several dosages of flocculants were tried with minimal settling rate improvement. For a new leaching plant design however, regrind should be considered.

Slurry Temperature Optimization

Variation of leach efficiency with temperature is shown in figure 5 below.

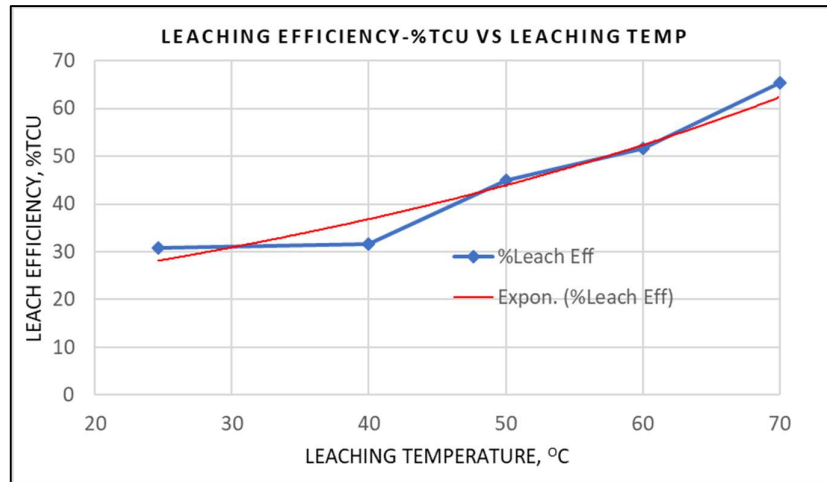


Figure 5: Leaching efficiency vs leaching temperature

Figure 5 shows that maximum leach efficiency was obtained at 70°C and higher copper recoveries can be attainable at temperatures higher than 70°C. However, this would require changes in materials of construction and design of leaching vessels and piping for the investigated Mine. For the Mine investigated 70°C is the maximum allowable temperature.

The settling rate for the leached slurry in the as sampled condition (61.29% PSD), 70°C was 2.66 cm/min, this value was above the minimum tailings leach plant requirement of 2.53 cm/min.

Optimizing Residence time at Elevated Temperature Leaching

Figure 6 below shows variation of leach efficiency with residence time at Elevated Temperature.

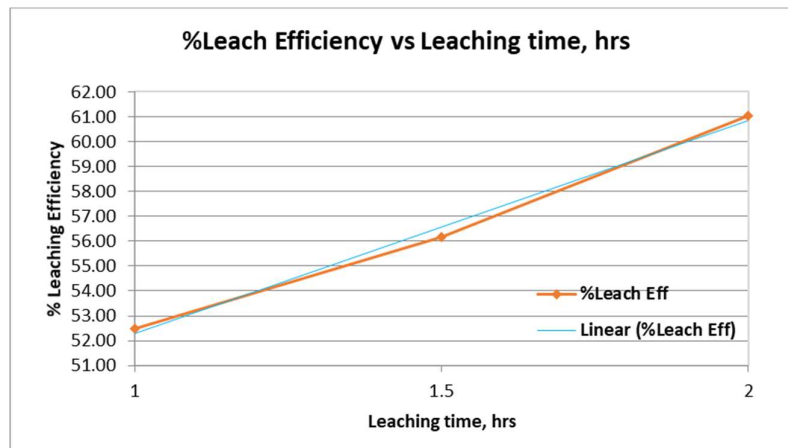


Figure 6: Leaching efficiency verses leaching time

Maximum leach efficiency was obtained at 2 hours. ENFI 2018 showed that 2.5 hrs. is the optimum residence time at Elevated Temperature Leaching.

Optimizing pH at Elevated Temperature Leaching

Figure below shows variation of leach efficiency with pH at Elevated Temperature.

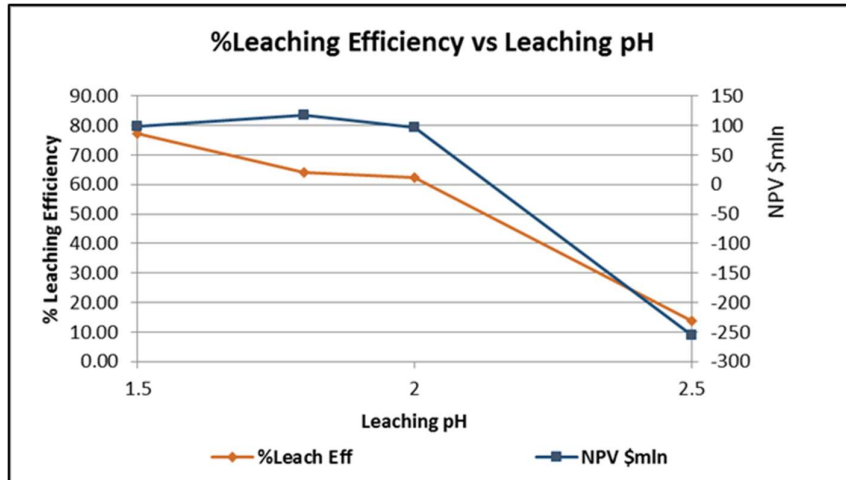


Figure 7: Leaching efficiency versus leaching pH

Figure 7 shows maximum leach efficiency at pH 1.5, with acid consumption at 77.10 Kg/ton, and 77.34% TCu recovery. However, the 10-year NPV at this pH is \$99 million. Maximum 10-year NPV was obtained at pH 1.8. Therefore, pH 1.8 gave maximum value thus is the optimum pH.

Confirmatory test works

After establishing optimum parameters, all test work were carried out at the established parameters. A summary of results is shown below.

Table 4: Results Summary

Description	ETL				Ambient Temp Leach			
	TCu Leach Eff %	ASCu Leach Eff %	TCo Leach Eff%	Acid Consumption Kg/T	TCu Leach Eff %	ASCu Leach Eff %	TCo Leach Eff%	Acid Consumption Kg/T
Average	70.84	86.43	75.29	58.89	34.64	81.18	18.54	22.65
Min	58.43	50.72	32.72	45.18	18.27	46.95	1.22	8.71
Max	78.70	97.21	97.21	89.66	53.87	94.24	47.78	36.24

Elevated Temperature leaching Total Copper Leach efficiency averaged 70.84% with minimum 58.43% and maximum 78.70%. Ambient Temperature leaching on the other hand, Total Copper leach efficiency averaged 34.64% with minimum 18.27% and maximum 53.87%.

Cobalt Leach efficiency averaged 75.29% for Elevated Temperature leaching and 18.54 for Ambient Temperature Leaching.

Acid Consumption average 58.89 kg/T material treated for Elevated Temperature leaching. ambient temperature acid consumption averaged 22.65 kg/T. Under Elevated Temperature Leaching conditions, TCo leach efficiency averaged 75.29%. This will eventually lead to cobalt accumulation in the circuit and precipitation of Copper and Cobalt (Mwansa Mibenge et al 2019) should be considered.

FINANCIAL EVALUATIONS

Summary of financial evaluation are shown in table below.

Table 5: Financial Evaluations Summary

SN	Description	UOM	ETL	Ambient Temp Leach	ETL	Ambient Temp Leach
1	LME	\$/t	8,500	8,500	6500	6500
2	Treatment Rate	Tpd	15,000	15,000	15,000	15,000
3	Days per year	Days	360	360	360	360
4	Annual Treatment Rate	Tpa	5,400,000	5,400,000	5,400,000	5,400,000
5	TCu Grade	%	0.61%	0.61%	0.61%	0.61%
6	TCu Leach Efficiency	%	70.8%	34.6%	70.8%	34.6%
7	TCu Recovery	%	63.8%	31.2%	63.8%	31.2%
8	Annual Copper Production	Tpa	19,951	9,756	19,951	9,756
9	Acid Consumption	kg/T	59	23	59	23
10	Total Opex	\$mIn	91	45	91	45
11	Capex	\$mIn	(40.00)	(40.00)	(40)	(40)
12	Annual EBIDTA	\$mIn	72	35	33	15
13	10year NPV @13%	\$mIn	358	154	141	48
14	Payback Period	Months	7	14	15	31

At treatment rates of 15,000 tons per day dry solids based on the balance tonnage requirement from the current Life of Mine, Elevated Temperature Leaching (ETL) annual production is 19,951 tpa while Ambient Temperature Leaching produces 9,756 tpa. 10-year Net Present Value at LME \$8,500/t and 13% discount rate is \$358 million for ETL and \$154 million for Normal Leach. Payback period is 7 months for ETL and 14 months for normal leach.

At LME \$6,500/t ETL NPV is \$141 million and normal leach is \$48 million. Payback period is 15 months for ETL and 31 months for Normal Leach.

Capex: Capex includes laying pipeline from the Tailings Dam to the Leaching Plant (16km), setting up reclamation facilities-hydro sluicing and pump chamber, and all contingency work. \$20million is meant for setting up a new tailings storage facility.

Cobalt Recovery Option: In the financial evaluation, cobalt recovery has not been factored. From the leach efficiency of 75%, cobalt will continue accumulating in raffinate that at some point there be need to recover cobalt using the precipitation route. This presents a significant upside to current financials.

IMPLICATION ON THE FLOW SHEET

Final tailing after Acid Soluble copper recovery is neutralized and disposed-off to the Tailing Dam, which was the subject of this work. It has been shown that this material is a potential resource. This has implications below.

Alternative disposal Site (Tailings Storage Facility)

An alternative tailings storage facility should be identified and developed with full environmental considerations.

Elevated Temperature Leaching

Elevated temperature leaching gives better value for the Project and consideration should be given to implementing the same project. This will change Life of Mine and make other Ores viable.

CONCLUSION AND RECOMMENDATIONS

The following conclusions have been drawn:

- The Tailing Dam Copper grades averaged 0.61%, 0.31% Total and Acid Soluble Copper respectively and 0.022% Total Cobalt.
- Both Ambient and Elevated Temperature Leaching can be used as treatment options for Tailings Dam material, with the more viable option being elevated temperature leaching (10-year NPV LME \$8,500/t \$358 million).
- Results obtained from leach tests done on material sampled from Tailings Dam indicated the following parameters as optimum: Residence Time 2-2.5 hours, pH 1.8-2, Density 1200-1300gpl (or Kg/M³), Temperature 70°C. Acid Consumption was 23kg/T material treated for Ambient Temperature Leaching and 58kg/T for Elevated Temperature Leaching

The following recommendations have been made:

- Establish and Alternative Tailings Storage Facility to replace the current one immediately.
- Geological drilling and sampling should be undertaken to define the resource along with metallurgical test work from representative geological samples.
- With Geological drilling results, consider Elevated Temperature Leaching Implementation

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