Leach Cycle Reduction in Percolation Leaching of a Zambian Copper Oxide Ore by the Use of an Optimized Acid-in-Agglomeration Dosage

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The effect of acid dosage to ore agglomeration in the leaching of a copper oxide ore was investigated in 1 m column leach tests at 24, 48 and 71 kg H_2SO_4/t. The primary objective was to see whether the initial copper leaching kinetics could be enhanced to such an extent by the addition of an optimized amount of 98% sulphuric acid in the agglomeration process that, in the subsequent leach, the overall cycle would be reduced with respect to duration and solution volumes.

The results of the column leach tests showed that the lowest acid-in-agglomeration dosage of 24 kg H_2SO_4/t limited the rate of copper dissolution and that the optimum dosage to maximize copper recovery was between 24 and 48 kg H_2SO_4/t, with higher dosage having no benefit. The irrigation ratio, *i.e.*, the applied solution volume to mass of ore in m^3/t, required to achieve the same copper recovery was significantly reduced at the acid addition of 48 kg H_2SO_4/t compared with the lower acid addition of 24 kg H_2SO_4/t. The percentage reductions in the required irrigation ratio was 44 %, 40 %, 37 % and 27 % at respective copper dissolutions of 80 %, 85 %, 90 % and 95 %.

INTRODUCTION

Agglomeration is the process by which fine particles in an ore are effectively reduced by binding them to coarser particles by means of chemical binding agents and a rolling, tumbling action. In heap leaching of crushed ore, this is an important pre-treatment step which aims to prevent segregation of fine and coarse ore particles during heap construction or stacking (Johanson, 1978), in which larger rocks tend to roll to the bottom of the heap while fines predominate in the upper part of the heap (Bartlett, 1998). Under irrigation, migration of the fines can reduce heap permeability by hindering, or even blocking, solution flow in some parts of the heap to cause preferential flow or channelling in other parts (Chamberlin, 1981). This can result in low metal recoveries and long leaching periods (McClelland *et al.*, 1983).

Heap leaching of copper oxide ores usually incorporates the use of sulphuric acid (H_2SO_4) and water to bind fines to larger ore particles during the agglomeration process. In addition, the use of concentrated sulphuric acid could also aid in copper mineral leaching at high sulphuric acid concentration during the agglomeration/curing stage. Furthermore, copper mineral liberation could also be improved by enhanced acid–gangue reaction during this stage. Thus, a sufficiently high acid-in-agglomeration dosage could result in a faster rate of copper dissolution during the early stages of leaching as well as improved extents of overall copper dissolution.

This paper presents the results of an investigation where the effect of acid dosage to ore agglomeration in the leaching of a copper oxide ore from Zambia was investigated in 1 m column leach tests. The primary objective was to see whether the initial copper leaching kinetics could be enhanced to such an extent with the addition of an optimized amount of 98% sulphuric acid in the agglomeration process that, in the subsequent leach, the overall cycle would be reduced with respect to duration and solution volumes.

EXPERIMENTAL

Three 1 m column leach tests, as part of a larger metallurgical program, were conducted at three different acid-in-agglomeration dosages on a 100 % passing 25 mm copper oxide sample. Figure 1 shows operational 1 m columns.

Figure 1. 1 m Column set-up.

The columns were operated in open circuit with an irrigation solution acid concentration of 7 g/L H_2SO_4, an irrigation rate of 6 L/m^2.h and at 25 °C. The applied acid-in-agglomeration dosages were 24, 48 and 71 kg H_2SO_4/t. The experimental test matrix is shown in Table I.

Solid head and residue samples (after digestion) were analyzed by inductive coupled plasma optical emission spectroscopy (ICP-OES) for aluminium, calcium, copper, cobalt, chromium, iron, lead, magnesium, manganese, nickel, silicon, titanium, vanadium and zinc. Carbonate was determined by combustion (LECO).

Daily copper and iron solution samples were assayed by atomic absorption spectroscopy (AAS). Compounded solution samples were also analyzed by ICP-OES for aluminium, arsenic, calcium, copper, cobalt, chromium, iron, lithium, magnesium, manganese, molybdenum, nickel, lead, silicon, sulphate, titanium, vanadium and zinc.

Daily sulphuric acid and ferrous titrations were done by established methods.

Table I. 1 m Column leach tests.

Conditions	Units	Test ID		
		C1	C2	C3
Crush size	mm	–25	–25	–25
Leach duration	days	162	162	162
Temperature	°C	25	25	25
Acid-in-irrigation	g/L	7	7	7
Irrigation rate	L/m².h	6	6	6
Acid-in-agglomeration[1]	kg/t	24	48	71
Curing duration[2]	days	x	x	x
Dry SG loaded		1.30	1.28	1.32
Moisture	% w/w	11	11	11

1) Agglomeration was performed in a rotary drum mixer using acidified water (7 g/L) and 98% concentrated sulphuric acid.
2) The curing duration was the same for all three tests.

RESULTS

Head Sample Characterization

A bulk run-of-mine (ROM) ore sample of approximately 360 kg was crushed to 100 % passing 25 mm, blended and then split into 30 kg batches. Three randomly selected 30 kg batches were each screened on the following sieve sizes: 25 mm, 16 mm, 13.2 mm, 12.5 mm, 9.5 mm, 6.7 mm, 4.75 mm, 3.35 mm, 2.36 mm, 1.7 mm, 1.18 mm, 850 µm, 600 µm, 425 µm, 300 µm, 212 µm, 150 µm, 106 µm, 75 µm, 53 µm and 38 µm in order to establish a weighted average particle size distribution for the whole sample (see Figure 2).

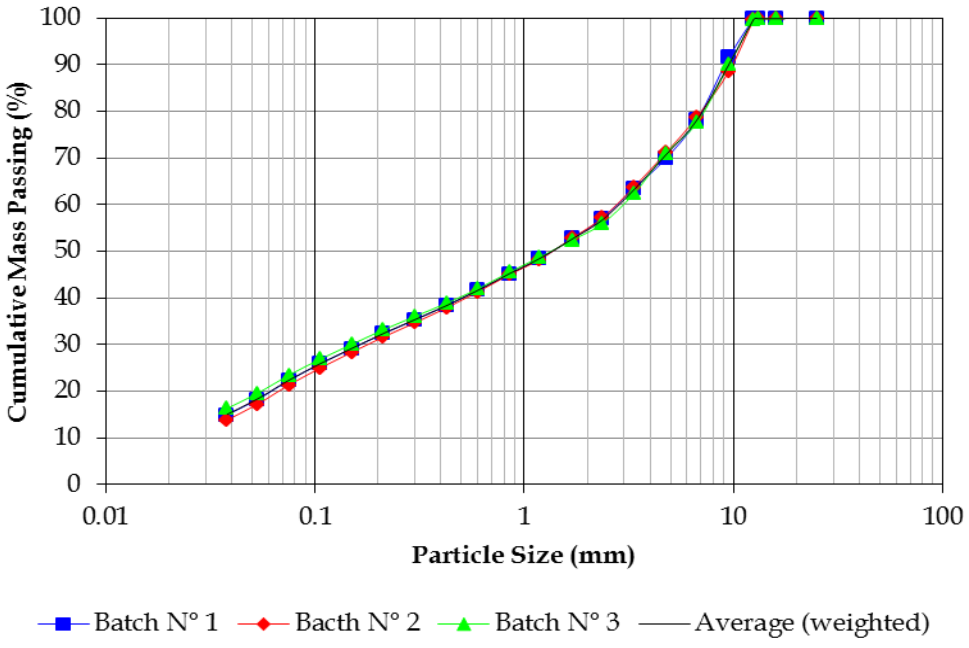

Figure 2. Particle size distribution of the head sample.

The narrow grouping of the particle size distributions for the three selected 30 kg batches confirms that the blending and splitting were done satisfactorily. The average particle size distribution shows a P_{80} (80 % passing) of 7 mm with 49 % passing 1.18 mm and 30 % passing 150 µm.

The screened ore fractions of one 30 kg batch were combined into four size classes, namely –25+6.7 mm, –6.7+3.35 mm, –3.35+1.18 mm and –1.18 mm. Thereafter, each size class was crushed to –1.7 mm and rotary split into sub-samples. From these, a split from each size class was submitted for mineralogical analysis. Another –1.7 mm sub-sample from each of the four size classes was pulverized to –38 µm and further divided by rotary splitting for use in chemical analysis.

Table II presents the chemical assays of the more important constituents of the head sample for each of the individual size classes. From these and the corresponding ore weight fractions, the overall constituent content was calculated.

Table II. Chemical analysis of the head sample.

Size class (mm)	Ore (% w/w)	Cu		Co		Fe		CO_3	
		(%)[1]	(%)[2]	(%)[1]	(%)[2]	(%)[1]	(%)[2]	(%)[1]	(%)[2]
-25+6.7	21.8	3.38	22.3	0.26	14.5	3.48	19.1	6.37	36.4
-6.7+3.35	15.0	3.47	15.8	0.30	11.9	3.86	14.5	4.75	18.7
-3.35+1.18	14.8	4.24	19.1	0.38	14.6	4.60	17.2	3.93	15.3
-1.18	48.4	2.91	42.8	0.47	59.0	4.04	49.2	2.33	29.6
Total	100	3.29	100	0.38	100	3.98	100	3.81	100

1) Constituent content for the size class
2) Constituent content for the size class as a percentage of the total constituent content

The ore sample contains 3.29 % copper, 0.38 % cobalt, 3.98 % iron and 3.81 % carbonate. Copper occurs as malachite (72 %), chrysocolla (20 %), pseudo-malachite (4 %), chalcocite (4 %) and very little chalcopyrite (< 1 %). Cobalt is present as heterogenite, and carbonate as dolomite and malachite.

Leach Test Results

The copper dissolution profiles are shown in Figures 3 and 4. The profiles were plotted using the recalculated copper head and solution analysis. The recalculated head entails a 100 % copper mass balance (i.e., copper out/copper in) with respect to both solid and solution phases.

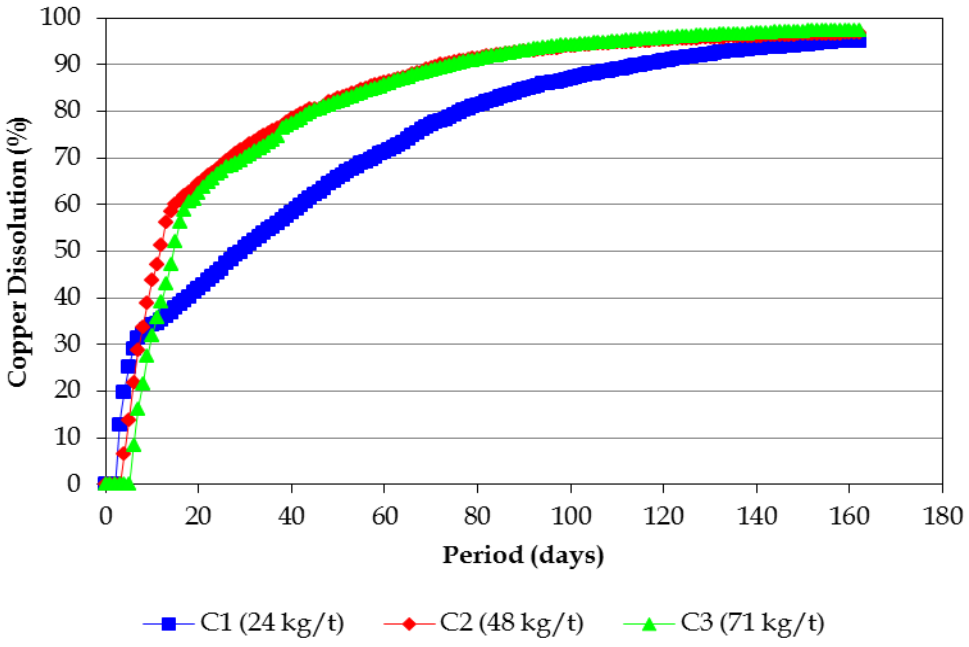

Figure 3. Copper dissolution profiles (time).

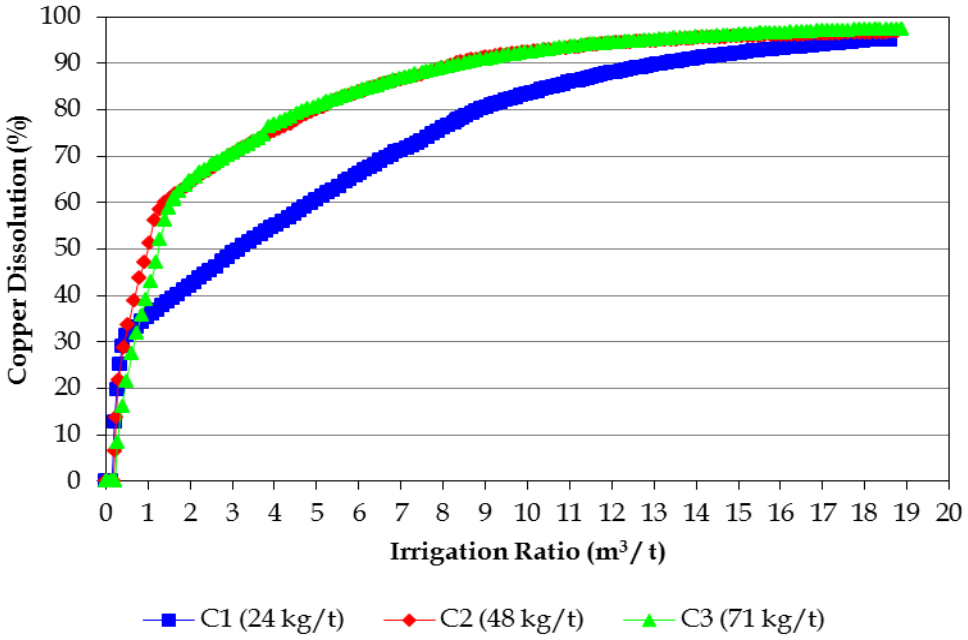

Figure 4. Copper dissolution profiles (volume).

The rate of copper dissolution during the initial stages of leaching improved dramatically when the acid-in-agglomeration dosage was increased from 24 to 48 kg H_2SO_4/t. For example, column C1 achieved 60 % copper dissolution after 42 days of leaching against column C2's 15 days. Or, in terms of solution volume, column C1 required 4.9 m^3/t of irrigation solution to achieve 60 % copper dissolution whereas column C2 only needed 1.4 m^3/t. This seems to suggest that the rate of copper dissolution was limited with respect to the amount of acid used in agglomeration in the case of column C1, *i.e.*, 24 kg H_2SO_4/t.

The copper dissolution profiles for columns C2 and C3 are almost identical. Therefore, an acid-in-agglomeration dosage of 71 kg H_2SO_4/t is clearly excessive since there is no further benefit to be gained to use a dosage higher than 48 kg H_2SO_4/t. The optimum acid-in-agglomeration dosage is between 24 and 48 kg H_2SO_4/t.

Figure 5 depicts net acid consumption vs. copper dissolution profiles.

The net acid consumption is defined as follows:

$$m_{NAC} = m_{FEED} - m_{PLS} - m_{SX} \quad [1]$$

where:

m_{NAC} net acid consumption, in kg H_2SO_4/t dry ore
m_{FEED} acid in the irrigation solution, in kg H_2SO_4/t dry ore
m_{PLS} acid in the pregnant leach solution, in kg H_2SO_4/t dry ore
m_{SX} acid in the raffinate solution after copper solvent extraction, in kg H_2SO_4/t dry ore (1.54 kg H_2SO_4/kg Cu extracted)

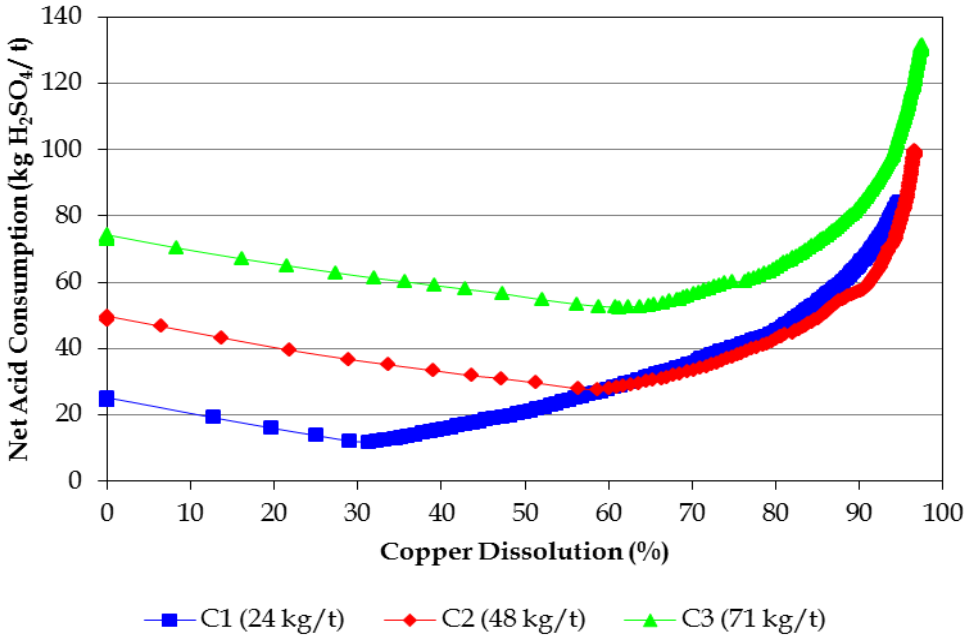

Figure 5. Net acid consumption vs. copper dissolution.

Column C3's net acid consumption is higher than those for columns C1 and C2 over the whole copper dissolution range. This also indicates that an acid-in-agglomeration dosage of 71 kg H_2SO_4/t is excessive.

Column C2's net acid consumption is higher than that for column C1 for copper dissolutions less than 60 %. Therefore, despite the fact that copper dissolutions in this range are achieved faster and with smaller irrigation solution volumes in the case of column C2, the net acid consumption for this column is not optimum in this range. For copper dissolutions above 60%, the net acid consumptions for columns C1 and C2 are very similar despite the fact that the latter's acid-in-agglomeration dosage was twice that of the former.

Tables III, IV and V compare leach duration (time), irrigation ratio (solution volume) and net acid consumption for columns C1, C2 and C3 at overall copper dissolutions of 80 %, 85 %, 90 % and 95 %, respectively. The results show that percentage reductions in leach duration of 44 %, 38 %, 37 % and 28 %, at respective overall copper dissolutions of 80 %, 85 %, 90 % and 95 %, could be achieved if the acid-in-agglomeration dosage is increased from 24 kg H_2SO_4/t (C1) to 48 kg H_2SO_4/t (C2).

Table III. Leach duration.

Copper dissolution (%)	Leach duration (days)		
	C1	C2	C3
80	77	43	45
85	91	56	58
90	115	72	75
95	158	114	109

Table IV. Irrigation ratio.

Copper dissolution (%)	Irrigation ratio (m^3/t dry ore)		
	C1	C2	C3
80	8.9	5.0	4.8
85	10.6	6.4	6.3
90	13.2	8.3	8.5
95	18.2	13.2	12.8

The similar percentage reductions in irrigation ratio (to leach duration) of 44 %, 40 %, 37 % and 27 %, at respective overall copper dissolutions of 80 %, 85 %, 90 % and 95 %, should be obvious.

Table V. Net acid consumption.

Copper dissolution (%)	Net acid consumption (kg H_2SO_4/t dry ore)		
	C1	C2	C3
80	45	43	64
85	54	49	72
90	65	57	84
95	83	79	106

As shown earlier, the net acid consumptions are similar, whether an acid-in-agglomeration dosage of 24 kg H_2SO_4/t (C1) or 48 kg H_2SO_4/t (C2) is used (see Figure 5).

Copper Dissolutions

The solid residues from the 1 m column leaches were treated in the same fashion as the head sample. This allowed, in addition to the extent of overall copper dissolution, also the copper dissolutions for each of the four selected size classes to be calculated. The results are summarized in Table VI.

Table VI. Size class and overall copper dissolutions.

Size class (mm)	Copper dissolution (%)		
	C1	C2	C3
–25+6.7	92.2	95.4	96.0
–6.7+3.35	92.3	95.7	96.9
–3.35+1.18	96.8	97.8	98.2
–1.18	96.9	97.3	98.0
Overall	95.1	96.7	97.4

From the size class copper dissolutions, it can be seen that an increase in acid-in-agglomeration dosage shows more of a positive impact on ore particles of the coarser –25+6.7 mm and –6.7+3.35 mm size classes than the finer –3.35+1.18 mm and –1.18 mm classes. This is somewhat intuitive since it is expected that copper contained in coarser ore particles would be less liberated than copper contained in finer ore particles. Therefore, it is obvious that the potential impact on overall copper dissolution would be very much dependent on the mass distribution of copper with respect to the different ore particle size classes.

Copper Mineral Dissolutions

Tables VII, VIII and IX list size class and overall malachite, chrysocolla, pseudo-malachite and chalcocite dissolutions for each of the three columns. These were calculated from data generated from mineralogical (QEMSCAN) analysis on each of the selected size classes.

Table VII. Size class and overall copper mineral dissolutions (column C1).

Size class (mm)	Mineral dissolution (%)			
	Malachite	Chrysocolla	Pseudo-malachite	Chalcocite
–25+6.7	95.9	92.8	87.6	89.4
–6.7+3.35	97.0	96.1	94.6	91.5
–3.35+1.18	99.5	98.9	98.2	96.6
–1.18	99.8	99.7	99.6	93.7
Overall	98.3	97.2	96.5	92.6

Table VIII. Size class and overall copper mineral dissolutions (column C2).

Size class (mm)	Mineral dissolution (%)			
	Malachite	Chrysocolla	Pseudo-malachite	Chalcocite
–25+6.7	98.7	98.0	100	88.9
–6.7+3.35	99.3	98.3	100	94.8
–3.35+1.18	99.8	99.4	100	93.7
–1.18	99.8	100	100	87.8
Overall	99.4	99.1	100	90.9

Table IX. Size class and overall copper mineral dissolutions (column C3).

Size class (mm)	Mineral dissolution (%)			
	Malachite	Chrysocolla	Pseudo-malachite	Chalcocite
–25+6.7	98.6	97.3	99.2	93.3
–6.7+3.35	99.5	99.0	99.5	97.1
–3.35+1.18	99.9	99.7	99.9	97.4
–1.18	99.9	99.6	99.9	91.1
Overall	99.5	99.0	99.7	94.3

The size class copper mineral dissolutions show the same tendency as observed for the copper dissolutions in that an increase in acid-in-agglomeration dosage has more of a positive effect on the copper minerals in ore particles of the coarser –25+6.7 mm and –6.7+3.35 mm than the finer –3.35+1.18 mm and –1.18 mm size classes during leaching.

CONCLUSIONS

The lowest acid-in-agglomeration dosage of 24 kg H_2SO_4/t limited the rate of copper dissolution.

The optimum acid-in-agglomeration dosage to maximize copper recovery was between 24 kg H_2SO_4/t and 48 kg H_2SO_4/t, with higher acid dosage having no benefit.

The irrigation ratio, *i.e.*, the applied solution volume to mass of ore in m^3/t, required to achieve the same copper recovery was significantly reduced at the acid addition of 48 kg H_2SO_4/t compared with the lower acid addition of 24 kg H_2SO_4/t. The percentage reduction in the required irrigation ratio was 44 %, 40 %, 37 % and 27 % at respective copper dissolutions of 80 %, 85 %, 90 % and 95 %.

The lower irrigation ratio required at an acid-in-agglomeration dosage of 48 kg H_2SO_4/t resulted in the net acid consumption being very similar to the leach with the lower acid-in-agglomeration dosage of 24 kg H_2SO_4/t, for the same dissolutions above 60 % copper dissolution.

An increase in acid-in-agglomeration dosage had more of a positive impact on copper and copper mineral dissolution from ore particles of the coarser –25+6.7 mm and –6.7+3.35 mm size classes than the finer –3.35+1.18 mm and –1.18 mm classes.

Shorter leach durations have obvious advantages to the heap leach process, and smaller irrigation ratios would result in smaller pregnant leach solution volumes, but at higher copper tenors. Apart from smaller ponds, this could also have economic benefits in down-stream processing such as solvent extraction with smaller-sized equipment and more efficient reagent (*e.g.*, organic) consumption.

The results highlight the importance of establishing and using an optimized acid-in-agglomeration dosage when heap leaching copper oxide ores because this parameter has bearing on the leach duration and process volumes.

ACKNOWLEDGEMENTS

The financial and technical support of Mintek is gratefully acknowledged.

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