Synergistic effects of the Jetti chalcopyrite leach catalyst and biooxidation — A bioreactor example

by Candice Simms, Monserrat Rebolledo and John L. Uhrie

The world's largest source of copper is contained in the hypogene zone of porphyry ore bodies, dominantly present as the mineral chalcopyrite ($CuFeS_2$) (Schlesinger et al., 2011). The conventional method to produce copper from chalcopyrite involves bulk mining, fine grinding, flotation, dewatering and, finally, smelting and electrorefining.

A lesser but still significant percentage of the world's copper is produced from the oxide and supergene zones of copper porphyry ore bodies (ICSG, 2022). Copper from these minerals is economically recovered using the proven industrial hydrometallurgical process of heap leaching. Heap leaching involves using bulk mining methods, but instead of using conventional milling and smelting, these ores are stacked into large stockpiles or heaps (with or without crushing) and irrigated with an acid-ferric sulfate solution to leach copper into solution. The now-aqueous copper is then concentrated and recovered using conventional solvent extraction-electrowinning (SX-EW) techniques.

Table 1

Chemical assays of ore sample (percent).

	Cu	Fe
Head	0.08	2.4

Table 2

Copper-sequential leach results of ore sample (percent).

	CuT	CuAS[a]	CuCN[b]	CuRes[c]
Head (−1/4" crushed)	0.088	0.002	0.005	0.081
Normalized to head assay (percent)		2.27	5.68	92.0

CuT: Total copper measured by the sequential leach analysis
CuAS[a]: H_2SO_4 acid soluble
CuCN[b]: NaCN soluble after acid leach
CuRes[c]: Residual copper

Chalcopyrite leaching is slowed due to the presence of an iron-depleted, copper-rich layer that rapidly forms on the mineral surface under typical bioleaching conditions. This surface passivation layer is a p-type semiconductor, which while in contact with an n-type semiconductor of unleached chalcopyrite forms an electrical diode (Ren et al., 2022). Diodes are one-way electrical gates that will, in turn, effectively halt leaching reactions.

Jetti Resources has invested nearly 10 years and millions of dollars into developing a catalyst that allows the recovery of copper from chalcopyrite ores. This patented technology requires little to no environmental permitting, is fully compatible with existing heap leach SX-EW processing, has very low capital intensity, is relatively inexpensive, and is stable under acidic conditions. The Jetti catalyst acts on the chalcopyrite surface and overcomes the passivation layer, allowing economic hydrometallurgical recovery of copper from low-grade chalcopyrite dominant ores.

Experiments

A series of bioleach reactors were operated at the SGS Burnaby laboratories using inoculum and mine site raffinate as lixiviant. A general description of the analytical procedure is summarized below.

Materials. A chalcopyrite dominant ore sample from a "typical" copper porphyry deposit was used for the test work. The sample copper grade is below mill-cutoff and contains 0.08 percent copper (Cu) and 2.4 percent iron (Fe), as determined by multielement analysis with inductively coupled plasma-atomic emission spectroscopy (ICP-AES) and shown in Table 1.

The copper deportment as determined by copper-sequential assay was 2.3 percent acid-soluble copper, 5.7 percent cyanide-soluble copper and 92 percent residual copper, which often relates to the presence of refractory chalcopyrite. This is further summarized in Table 2.

The inoculum consists of a wild culture of iron and sulfur oxidizing acidophilic bacteria grown on MKM salts and ferrous iron. This inoculum is considered as the ideal lixiviant for reactor test work. The composition is shown in Table 3.

Mine raffinate received from the site was used for reactor test work. The raffinate composition is shown in Table 4.

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Experimental procedure

A series of mechanically agitated batch reactors were operated with 76 g of ground ore (P100, 0.106 mm) at 2.5 percent pulp density, ambient temperature and pH 2.1. Lixiviants used were bacterial inoculum, treated raffinate, and treated raffinate with supplemental iron (2 g/L Fe^{3+}). One control and one catalyzed reactor were run for each lixiviant. The tests were agitated at 550 rpm and operated for 76 days.

At designated sampling intervals, measurements of the solution weight, specific gravity, pH and oxidation-reduction potential (ORP) were recorded. The leachates were submitted for multielement analysis by ICP-AES to determine the chemical composition.

Upon termination of the tests, the leach slurry was filtered to collect the pregnant leach solution (PLS). The residue was washed with adjusted deionized water at pH 2, air-dried, and submitted for chemical analysis.

Results and discussion

Bacterial sequencing. To investigate the microbial activity in the mine site raffinate, samples of the raffinate, SX-treated raffinate and inoculum were sent to a third-party laboratory to conduct bacterial cell count and 16S RNA sequencing.

Table 3

Composition of ferrous medium.

Species	Concentration (g/L)
H_2SO_4	1
$FeSO_4 \cdot 7H_2O$	15
$(NH_4)_2SO_4$	0.4
$MgSO_4$	0.4
K_2HPO_4	0.1

Table 4

Chemical assays of mine raffinate (g/L).

	Al	Cu	Fe	Mg	Cl
Raffinate	3.0	0.03	0.3	5.8	5.4

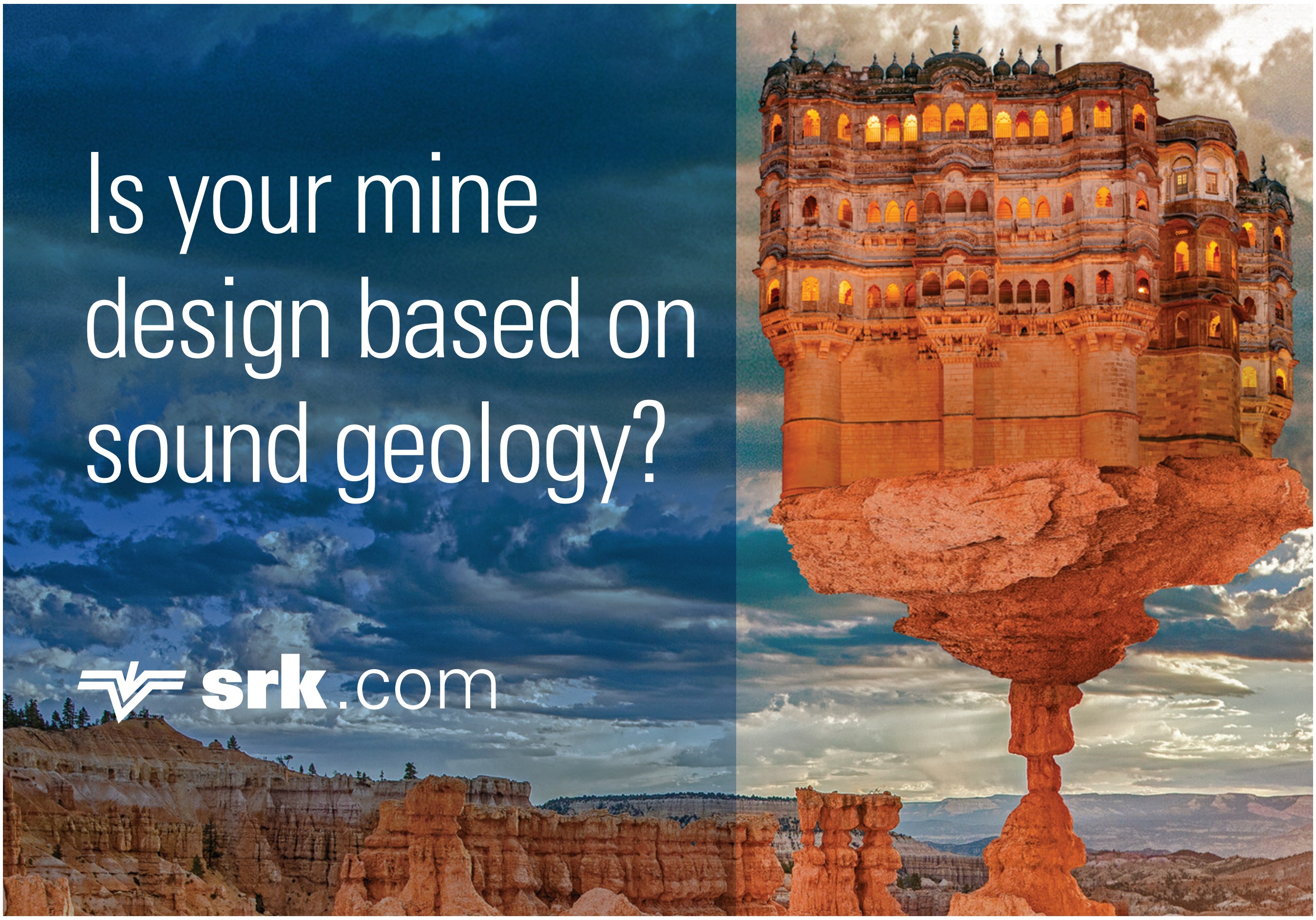

Figure 1

Microbial cell count for as-received mine raffinate, treated mine raffinate and inoculum.

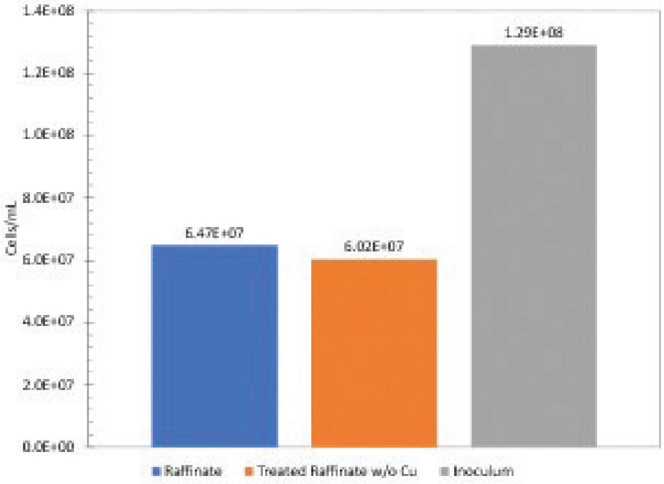

Table 6

ANOVA test summary.

Source	Sum of squares	df	Mean square	F-value	p-value
Model	2,406.1	4	601.5	2,970.5	0.014
A-Catalyst	2,020.2	1	2,020.2	9,976.3	0.006
B-Fe	23.5	1	23.5	116.2	0.06
C-Lixiviant	189.1	1	189.1	933.6	0.021
AC	132.7	1	132.7	655.2	0.025
Error	0.20	1	0.20		
Total	2,406.3	5			

Figure 2

Distribution of microbial genus for mine raffinate, treated mine raffinate, and inoculum.

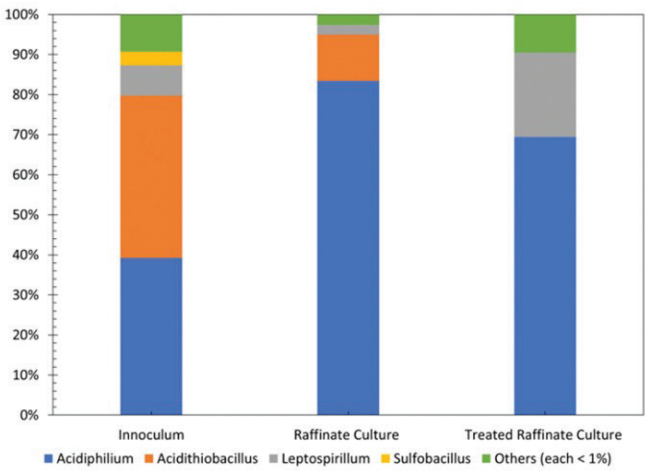

Table 5

Results of microbial monitoring.

Test ID	Cells/mL
Raffinate	6.5E+07
Treated raffinate	6.0E+07
Inoculum	1.3E+08

The raffinate samples had approximately one order of magnitude lower cell concentrations than the inoculum. This is expected because of the 5.4 g/L of chlorine (Cl) present in the raffinate, which is known to harm bacteria. The cell counts of each lixiviant are summarized in Table 5 and Fig. 1.

Due to the limited quantity of bacteria present within the raffinate sample, the bacterial population was enhanced by culturing the samples before 16S sequencing.

Examination of the 16S RNA sequencing data allows for a more thorough understanding of the bacteria consortia present within each sample. The most abundant bacterial genus in each sample is shown in Fig. 2. The inoculum sample has the most diverse population of bacteria present. The most abundant microbe in the raffinate and treated raffinate samples was *Acidiphilium sp*. Further, *Sulfobacillus sp.* was not present in either of the raffinate samples, while *Acidithiobacillus sp*. was not present in the treated raffinate sample. The lack of a diverse bacteria consortia can have a negative impact on the efficiency of the leaching as the oxidant is not regenerated within the system.

Reactor tests. For the tests operated with inoculum, after 78 days of leaching, 79 percent copper extraction was obtained for the catalyzed reactor test compared to 30 percent observed in the control test, an increase of 2.6 times as shown in Fig. 3. The overall extraction was lower in the tests with mine raffinate (51 percent in the catalyzed compared to 26 percent in the control); however, the uplift factor was still significant (1.9 times), as shown in Fig. 4.

Due to the significant difference in initial ferric concentrations between the tests using inoculum (2 g/L) compared to the tests using synthetic raffinate (0.3 g /L), additional tests were run using the treated raffinate with supplemental iron (2 g/L) to ensure sufficient oxidant availability.

Tests with ferric supplemented raffinate performed similarly to tests using the original treated mine site raffinate, indicating that the amount of initial oxidant present did not affect copper leach extraction. Results for these tests yielded copper extractions of 56 percent in the presence of Jetti's technology compared to 22 percent in the control, as shown in Fig. 5. The final copper extraction in the control and catalyzed tests are within ±5 percent of the synthetic raffinate tests without supplemental iron and can be considered normal variation. This conclusion is validated further with statistical analysis in the following section.

ANOVA test. An ANOVA test was carried out to interpret the statistical effects of each factor on the response: that is, copper extraction in reactors. The factors tested were catalyst (A), initial iron concentration (B) and lixiviant (C). Factor C was included as a categorical factor with input −1 (inoculum) or +1 (synthetic raffinate). The ANOVA test results are summarized in Table 6.

Catalyst (A), lixiviant (C) and the interaction between these two factors (AC) all have a statistically significant effect ($p < 0.05$) on the copper extraction. Based on this model, iron does not contribute to copper extraction, which further validates the observations made in the previous section.

The F-values indicate that the presence of catalyst had the largest impact on copper extraction. This is followed next by lixiviant and the interaction of the two factors. Normalizing the coefficients in the model shows that the presence of catalyst accounts for a 25 percent increase in response of the model, while synthetic raffinate contributes to a 9 percent decrease in response compared to inoculum. Finally, there is a minimal effect on the response (6 percent) from the combined interaction between the lixiviant and catalyst.

Conclusion

Jetti's catalytic technology works synergistically with biooxidation to leach chalcopyrite that would otherwise be unleachable.

Under optimal conditions, the Jetti catalyst can provide a copper extraction 2.6 times higher in bioreactors compared to tests under noncatalyzed conditions. In reactor tests using suboptimal commercial raffinate, the presence of catalyst increased copper extraction by 1.9 times compared to the control. ■

References

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Figure 3

Effect of catalyst addition on reactor tests operated with inoculum.

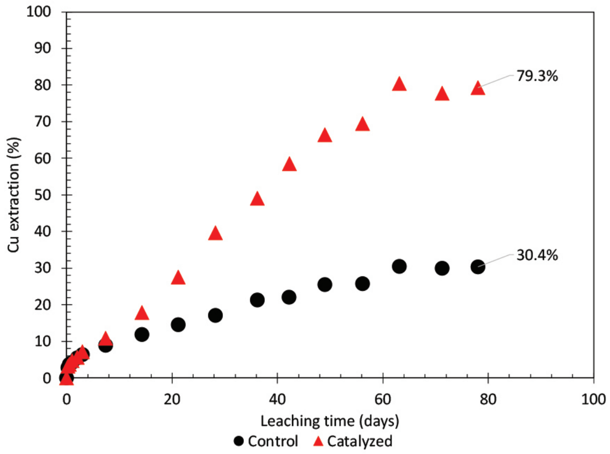

Figure 4

Effect of catalyst addition on reactor tests operated with treated raffinate.

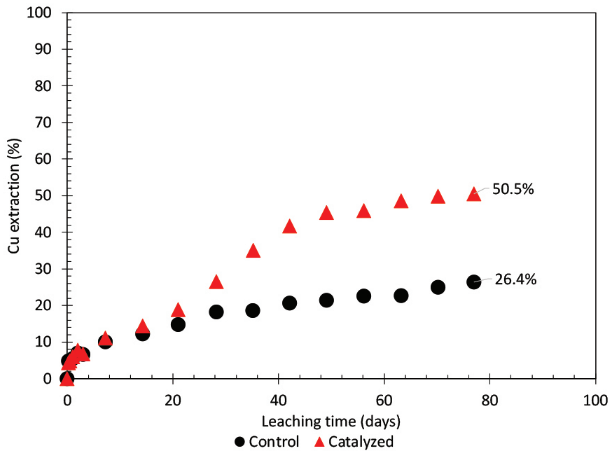

Figure 5

Effect of catalyst addition on reactor tests operated with treated raffinate with added iron.