



GeoBiotics, LLC
12345 West Alameda Parkway, Suite 310
Lakewood, Colorado 80228 USA
1-303-277-0300
1-303-277-1772 Fax

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Thermophilic Bioleaching of Chalcopyrite Concentrates with GEOCOAT® Process

Todd J. Harvey
GeoBiotics, LLC
tharvey@geobiotics.com

Nick Holder, Tracey Stanek
Lakefield Research Africa (PTY) Ltd
nholder@lakefield.com,
tstanek@lakefield.com

ABSTRACT

The extraction of copper from chalcopyrite has for centuries been limited to pyrometallurgical methods. Smelting of chalcopyrite is an efficient process but costly both in terms of capital investment, operating costs and environmental compliance. Biological extraction appeared as an appealing alternative. Unfortunately, traditional mesophilic biological extraction methods have met with little success. The chalcopyrite quickly becomes passivated and unacceptable copper extractions are achieved. It was not until the adoption of thermophilic systems that the biological leaching of chalcopyrite became a reality. Several questions remain as to the applicability of the thermophilic system for chalcopyrite; can the system operate auto-thermally; can reasonable extraction rates be achieved; is the process sensitive to mineralogy or grade; and can the precious metals be recovered?

GeoBiotics, LLC has embarked on an extensive program to develop the GEOCOAT® bioleaching system to chalcopyrite ores. This program encompasses mathematical heap modeling, laboratory amenability and column tests, and large-scale field trials. The GEOCOAT® process involves the coating of concentrates onto a suitable substrate, usually barren rock, then stacking the coated material in a conventional heap fashion. The heap is irrigated with acidic solutions containing iron and nutrients while low pressure ambient air is applied at the heap base.

To date, copper extractions in excess of 97% have been achieved in approximately 140 days. Satisfactory gold extraction from the biooxidation test residue by cyanidation was also achieved. Mathematical modeling indicates that obtaining thermophilic temperatures within the GEOCOAT® heap is not be a problem and that even low grade concentrates should maintain auto-thermality. Development is continuing focusing on the heap design parameters and additional copper concentrates including enargite. Plans are now underway for the first large scale field test in the fall of 2002.

1.0 INTRODUCTION

Pyrometallurgy currently accounts for more than half of all non-ferrous metal production and nearly 95% of all metals produced⁽¹⁾, although iron and steel account for a large portion of this. There are approximately twenty important non-ferrous metals with a combined production of 100 million tonnes per year. Pyrometallurgy predates history, copper production by this method was first recorded in 8000 B.C. and still today just under 90% of the world's cathode copper is produced using this method⁽²⁾.

Pyrometallurgy has clearly predominated in the past and still predominates today for the treatment of "clean" concentrates. The reasons for this are relatively straightforward; the process is fairly simple, reaction rates are faster and the precious metals are recovered easily. However, problems arise in the development of a metallurgically and environmentally acceptable method for treatment of complex sulphides. Not only is classical pyrometallurgy inflexible when it comes to treating complex sulphides efficiently, but also suffers from other inherent disadvantages such as:



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- High capital investments
- High operating costs
- Large volumes of waste gases containing SO₂ requiring fixation/purification,
- Dusts containing Pb, As, Sb, Cu, Zn, Hg, Bi, Se,
- Fugitive gases in the work environment, and
- Large volumes of solid waste products.

It was not until the advent of hydrometallurgical methods in the 1950's that a viable alternative to pyrometallurgy was envisioned and not until the late 1970's when materials of construction advancements allowed for the first commercial pressure hydrometallurgy operation to commence⁽³⁾. Bioleaching also began in the early 1950's although it could be debated that the use of bacteria was accidental as a result of the inadvertent colonization of endemic species surrounding copper dump leaches. It was not until much later that commercial dump leaching employing bacteria was begun, Table 1⁽⁴⁾.

Plant/Location	Size (tpd)	Operator	Ore Grade (% Cu)	Years In Operation
Lo Aguirre, Chile	16,000	Sociedad Minera Pudahuel	1.5	1980-Present
Mt. Leyshon, Australia	1,370	Normandy Poseidon	0.15	1992-1995
Cerro Colorado, Chile	16,000	Rio Algom	1.4	1993-Present
Girrilambone, Australia	2,000	Straits Resources	~3	1993-Present
Ivan, Chile	1,500	Glamis Gold	2.1	1994-Present
Quebrada Blanca, Chile	17,300	Cominco	1.3	1994-Present
Andacollo, Chile	16,000	Dayton Mining	1.0	1996-Present
Dos Amigos, Chile	3,000	Cemin	2.5	1996-Present
Cerro Verde, Peru	32,000	Cyprus-AMAX	0.7	1996-Present
Zaldivar, Chile	~20,000	Placer Dome	1.4	1998-Present
S&K Copper, Myanmar	15,000	Myanmar Government, Ivanhoe Copper	1.25	1998-Present

Dump leaching has several key advantages that make it useful for low grade oxide and secondary sulphide copper ores; the capital and operating costs are relatively low and the process is relatively simple. Unfortunately, dump leaching also suffers from two major drawbacks that prevent it from being economical for treating higher grade ores; long extraction times and moderate metal recoveries. Additionally, the principal primary copper sulphide, chalcopyrite, does not respond well to the mesophilic conditions found in most dump leaches.

Traditional mesophilic biological extraction methods for chalcopyrite extraction have met with little success. The chalcopyrite quickly becomes passivated and unacceptable copper extractions are achieved. It was not until the adoption of thermophilic systems that the biological leaching of chalcopyrite became a reality. There are several stirred tank processes currently being put forward for the biological extraction of copper from chalcopyrite including the BIOCOP® Process, the Mintec/Bactech Process and the HIOX® Process. Each of these systems uses elevated temperatures in the moderate or thermophilic ranges to maintain bacterial populations suitable for chalcopyrite extraction. Although these processes have many advantages over conventional pyrometallurgy such as:

- the ability to produce copper locally at the mine site thus reducing transport costs and smelter charges,
- better environmental compliance, and
- the ability to produce copper at a lower cost, they are still capital intensive.

For stirred tank systems, as a result of the nature of thermophilic bacteria and the operating environment, the capital and operating costs are increased as a result of:

- corrosion: the materials of construction must be stainless steel or better,
- low shear resistance of the bacteria: the tank sizes are large as a result of low pulp densities,



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- high air demand: higher temperatures reduce the dissolved oxygen levels,

The GEOCOAT[®] process melds the advantages of stirred tank systems with the simplicity of conventional heap leaching. The GEOCOAT[®] process involves the coating of concentrates onto a suitable substrate, usually barren rock, then stacking the coated material in a conventional heap fashion. The heap is irrigated with acidic solutions containing iron and nutrients while low pressure ambient air is applied at the heap base.

The GEOCOAT[®] system has several advantages over convention pressure hydrometallurgical processes as well as stirred tank bioleaching:

- Lower capital and operating costs,
 - the heap uses conventional plastic liners and irrigation systems,
 - the lower resistance across the heap means air supply can be low pressure,
 - nutrient loads are recycled,
 - the heap is a natural insulator so target operating temperatures are easily maintained,
 - solutions can be recycled to enhance the PLS grade,
 - simple operation means lower staffing and training levels,
 - smaller operations can afford the system,
- Reduced cutoff grade as a result of lower operating costs,
- Enhanced global metal recovery,
 - Lowered cutoff grades,
 - less dependency on grade means the ability to treat lower grade concentrates and enhance the flotation recovery,
 - ability to utilize low grade material as support rock,
- Inherently safe due to the low pressure environment.

GeoBiotics, LLC has embarked on an extensive commercialization process for the GEOCOAT[®] process for chalcopyrite leaching. This program encompasses mathematical heap modeling, laboratory amenability and column tests, and large-scale field trials. This paper documents the work that has been completed to-date including laboratory tests conducted at Lakefield Research Africa (PTY) Ltd. modeling compiled by the University of British Columbia and the ongoing investigation into heap parameters and effects of concentrate mineralogy including enargite.

2.0 THE GEOCOAT[®] PROCESS

The GEOCOAT[®] process incorporates elements of two successful and commercially proven technologies: heap leaching and biooxidation. Copper-bearing sulfide minerals are concentrated by flotation and thickened. The resulting slurry is thinly coated onto crushed, screened support rock, stacked on a lined pad, and allowed to biooxidize. Coating is accomplished by spraying the concentrate slurry onto the support rock as it discharges from the end of a stacking conveyor onto the biooxidation heap as shown in Figure 1. The coating solids density is highly dependent on the slurry viscosity and densities of 50-65% have been successfully coated at scale.

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Figure 1
Coating Operation

The hydrophobic nature of the concentrate assists in the formation of a coating on the support rock. No binding agents are required. The concentrate naturally adheres to the support rock and does not wash out of the heap during solution application or during heavy rainstorms. A 30mm event was recorded over a half hour at a pilot heap test without consequence.

The support rock is relatively uniformly sized, in the range of 6 to 25 centimeters in diameter and the concentrate coating is relatively thin, less than one millimeter in thickness. The weight ratio of support rock to concentrate is in the range of 5:1 to 10:1. Figure 2 illustrates the concentrate coated support rock from a pilot test.

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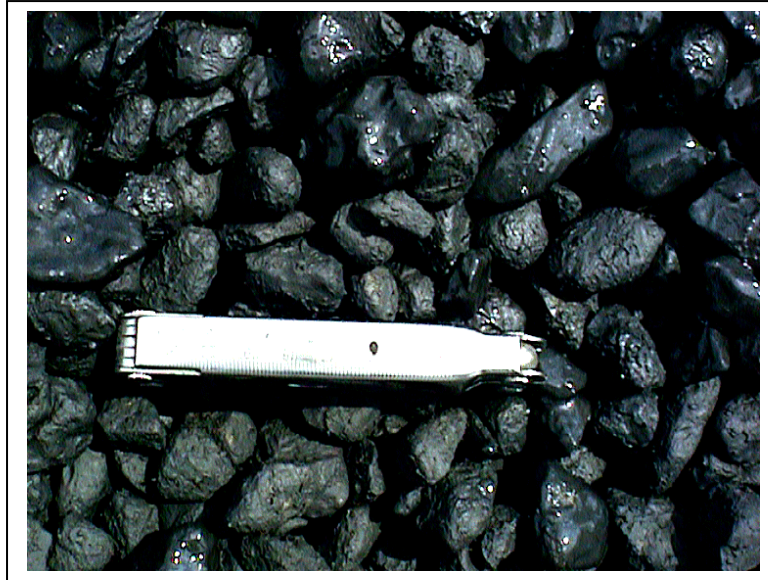


Figure 2
Concentrate Coated Support Rock

Depending on the desired temperature of operation, the heap is inoculated with naturally occurring sulphide-oxidizing bacteria, such as the moderate thermophiles; *Acidothiobacillus caldus* (DSMZ strain 8584), *Sulfobacillus thermosulfidooxidans* (DSMZ strain 9293 and 11920), and the extreme thermophiles; *Acidianus brierleyi* (DSMZ strains 1651 and 6334), *Acidianus infernus*, (DSMZ strain 3191) *Metallosphaera sedula* (ATCC strain 33909) *Sulfolobus acidocaldarius* (ATCC strain 49426) *Sulfolobus shibatae* (DSMZ strain 5389) and *Sulfolobus metallicus* (DSMZ strain 6482).

Nutrients are added to the heap via recirculating solutions. As biooxidation progresses, the sulphides in the concentrate are oxidized and the solubilized copper, iron, arsenic and sulphate are carried from the heap by the recirculating solution. A portion of the solution stream is bled from the circuit for purification and metal recovery.

The relatively uniform size of the support rock leads to large interstitial spaces within the heap and subsequently a low resistance to air and liquid flows. Sufficient air for biooxidation and heat removal is supplied to the heap by low-pressure blowers through a system of perforated pipes laid in the drain rock below the base of the heap.

After biooxidation additional lifts may be placed on the pad or the coated rock may be unloaded from the pad and the oxidized concentrate removed by trommeling or wet screening if precious metal recovery is warranted. The concentrate residue would be neutralized and then subjected to conventional recovery methods. The support can be recycled or, in the case of low-grade sulphide ore, a portion can be bled out for disposal and replaced with fresh copper bearing ore. Figure 3 presents a schematic representation of the process.

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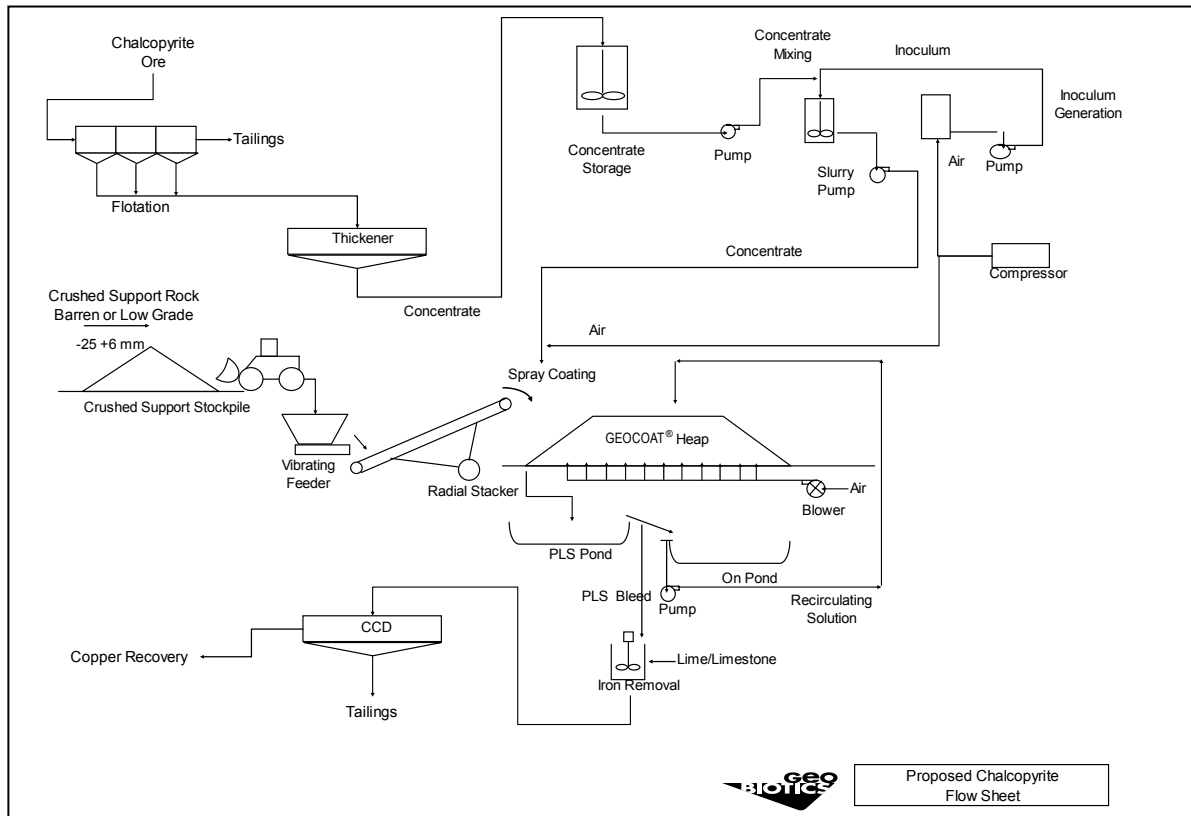


Figure 3
GEOCOAT® Flow Sheet

3.0 GEOCOAT® HEAT BALANCE

Jochen Petersen and David Dixon of the Biohydrometallurgy Research Group at the University of British Columbia were retained to perform a detailed heat balance analysis of the GEOCOAT® system using chalcopyrite samples obtained from a copper mine in Australia⁽⁵⁾ (Concentrate A). This group has performed bioheap leach heat balance analysis in the past for such projects as Cominco's Quebrada Blanca and Newcrest Mining's Telfer Mine among others^(6,7).

The test concentrate was leached in a series of mini-columns under controlled temperature conditions. All columns were operated under nearly identical conditions for variable periods of time before recovering the leached concentrate for chemical analysis. The primary objectives investigated were:

- the determination of the characteristics of thermophilic chalcopyrite heap leaching under GEOCOAT® conditions, and
- the determination of the time-dependent heat generation behaviour of the concentrate under GEOCOAT® leach conditions and the development of a heat model of a full-scale heap.

3.1 Materials and Procedure

Concentrate A was comprised primarily of chalcopyrite with minimal acid soluble copper and pyrite. Table 2 shows the chemical and estimated mineralogical composition of the concentrate.

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Table 2 Chemical and Mineralogical Analysis	
Element/Mineral	Composition (%)
Cu	26.8
Fe	27.5
S ²⁻	28.6
SO ₄	0.3
CuFeS ₂	74.3
FeS ₂	6.5
Acid soluble Cu	1.5
Acid soluble Fe	2.1

The material was finely ground to a size of 80% passing 40um with a mean diameter of 15um. The bacteria employed were supplied by GeoBiotics and included:

- Mesophiles: containing strains of *Leptospirillum*, *Thiobacillus ferrooxidans* and *thiooxidans*, cultured at 30°C
- Moderate Thermophiles: containing strains of *Sulfolobus*, *Acidianus* and *Thiobacillus*, cultured at 48°C
- Extreme Thermophiles: containing strains of *Acidianus*, *Metallosphaera* and *Sulfolobus*, cultured at 68°C.

The GEOCOAT[®] column leach experiments were conducted in 8 small columns immersed in a constant temperature water bath operated between 30 and 80°C ± 1°C as shown in Figure 4. The concentrate was slurried with water to form a thick paste and coated onto granite pebble support in the size range 5 to 10 mm by tumbling in a pail. Each column was loaded with 2.8 kg support rock coated with approximately 320 g concentrate to a bed height of 30 cm.

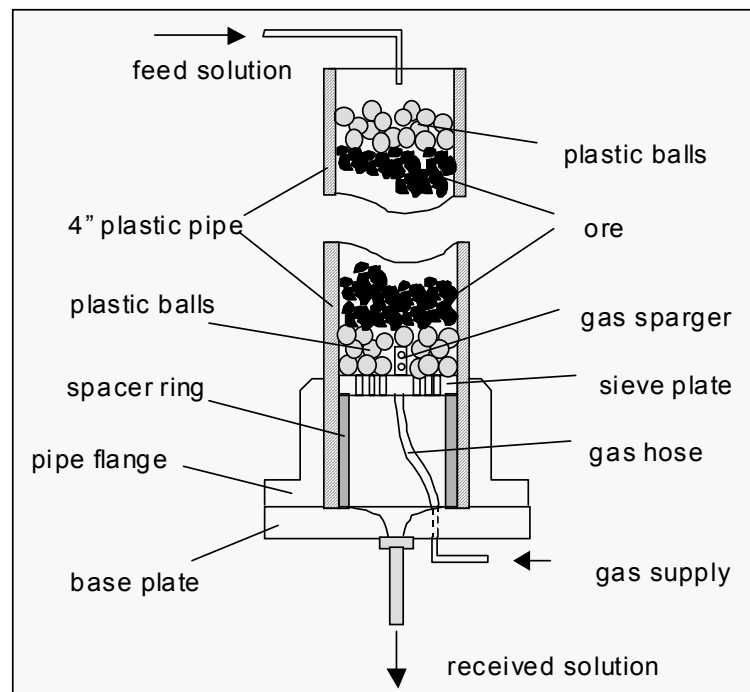


Figure 4
Heat Balance Apparatus⁽⁵⁾

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Solution was fed to the top of the column from the feed container at a rate of approximately 5 L/m²hr, and collected at the base in a separate container. Air, enriched with 1% CO₂, was blown into the base of the column at a rate of approximately 2 m³/m²hr.

Effluent solution was sampled twice weekly and then combined with the residual feed solution. After 4 weeks, one liter of collected solution was discarded on a weekly basis in order to maintain dissolved copper levels below 6 g/L. Removed solution and evaporation losses were made up with distilled water to a total constant circulation volume of 4 L. The feed pH was adjusted to pH 1.3 with concentrates sulphuric acid.

The columns were rinsed with acid for the first 2 days, and then inoculated with mesophile bacteria. The temperature in all experiments was raised from 30°C at the beginning to 72°C within 16 days. Figure 5 indicates the temperature profile and the points at which bacteria were introduced into the columns. Columns C7 and C8, which were started later, operated at 72°C throughout and were inoculated with extreme thermophiles only. All columns were re-inoculated with fresh bacteria every 2-3 weeks as a precaution.

The test columns were dismantled after 1, 2, 3, 5, 6, 8, 13 and 15 weeks. The residue concentrate was recovered, dried, weighed and analyzed.

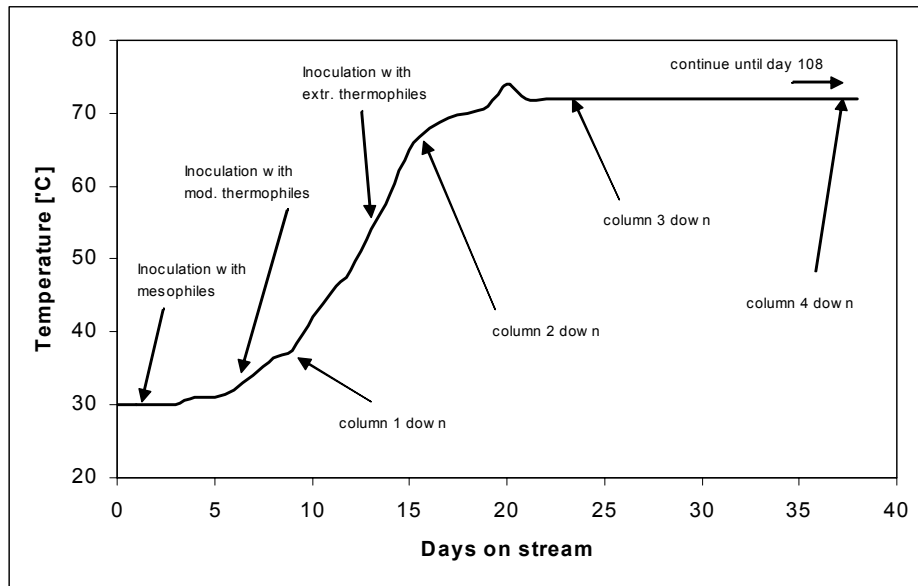


Figure 5
Temperature Ramping Profile⁽⁵⁾

3.2 Results

The detailed results of the heat balance modeling are beyond the scope of this paper and have been published by Dixon and Peterson previously. A summary of the significant results is presented here along with pertinent graphical representation:

- Figure 6 shows the biooxidation results for copper, iron and sulphide sulphur for the individual columns. Chalcopyrite leaching with thermophile bacteria proceeds at a more or less linear rate to 90-95% extraction within 100 days. Further extraction to at least 98% appears possible. Fe is oxidized at rates similar to Cu, but substantial jarosite precipitation occurs towards the end of a

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run, accounting for as much as 15% of all Fe oxidized.

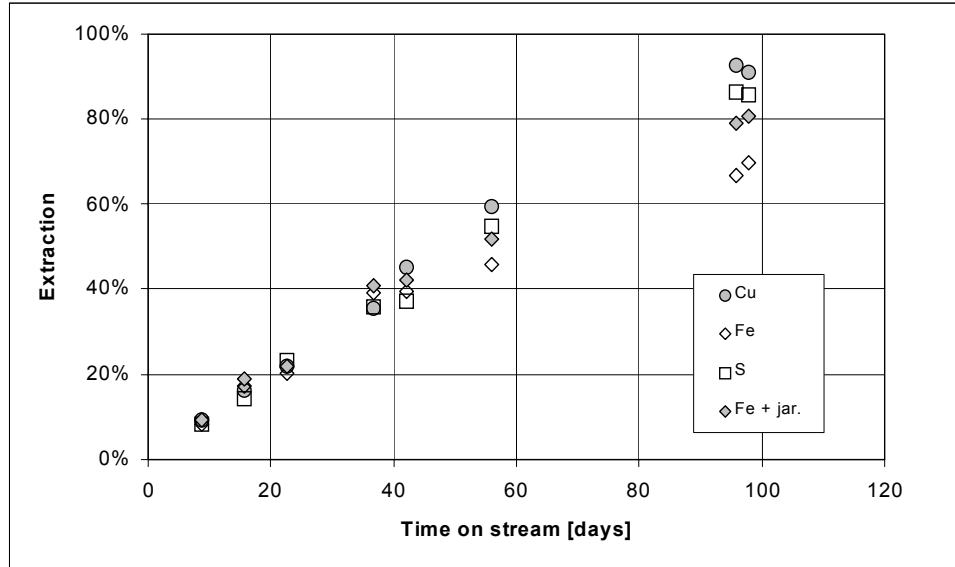


Figure 6
Biooxidation Based on Tails Assays for Cu, Fe and Sulphide Sulphur and Corrected Fe Biooxidation Based on Precipitated Jarosite⁽⁵⁾

- A substantial portion of sulphide oxidized to elemental sulphur during the heat-up (mesophilic) phase of the experiment as shown in Figure 7. During the thermophilic phase all sulphide is oxidized to sulphate. The initially accumulated elemental sulphur is also oxidized.

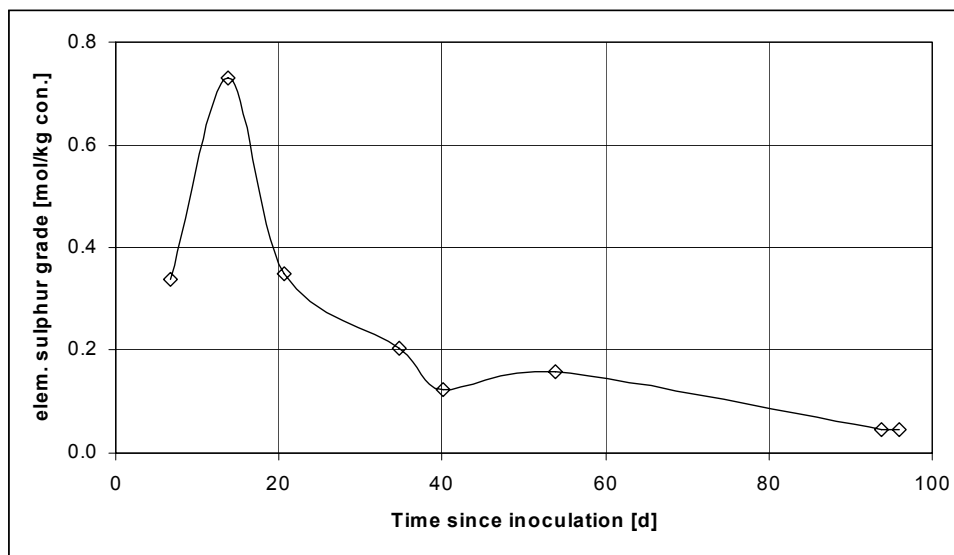


Figure 7
Elemental Sulphur Concentration in the Concentrate⁽⁵⁾

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- High solution potentials are found during the heat-up (mesophilic) phase, but the thermophiles leach mostly at low potentials. Only towards the end of leaching do solution potentials slowly begin to increase. Bacterial counts indicate rapid initial growth of mesophiles which are supplanted by the more moderate growth of thermophiles. Except during the initial heat-up phase the reaction proceeds under more or less acid neutral conditions.
- Heat generation calculated on the basis of tails assays proceeds at a constant rate of around 140 W/m³ after a linear initial start-up. All columns showed very consistent trends as shown in Figure 8.

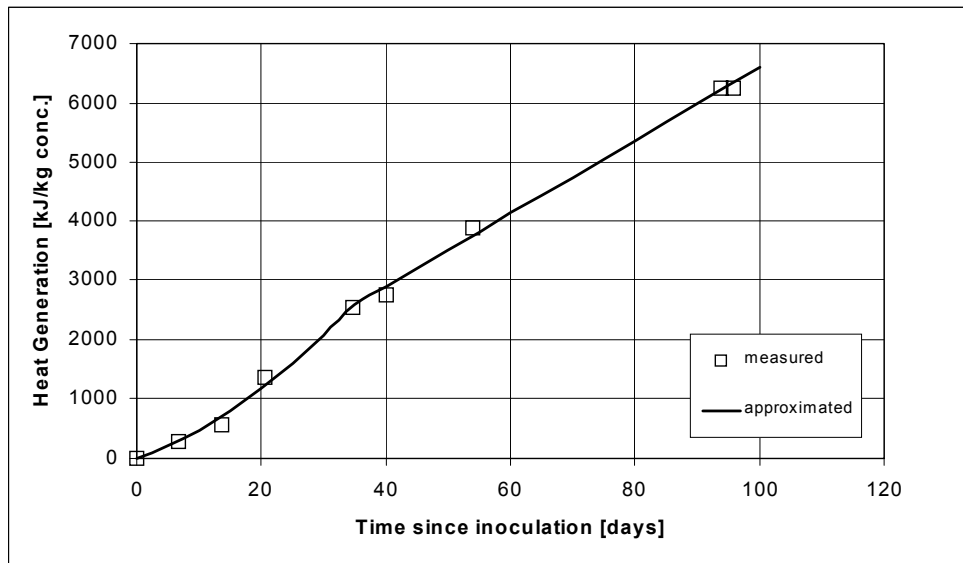


Figure 8
Measured and Approximated Heat Generation⁽⁵⁾

- Figure 9 shows the full-scale heap modeled based on the biooxidation results. The data suggest that a heap with a 1 m drainage layer and 5 m active leach zone will achieve average temperatures between 65 and 75 °C within 2-3 weeks at irrigation rates between 5 and 10 L/m²-hr and aeration rates between 2 and 4 kg/m²-hr. Heaps with active zones between 3 and 7 m are feasible. A lower bed is probably better suited for a high temperature leach scenario, in order to avoid build-up of excessive peak temperatures and to improve controllability of the operation as shown in Figure 10.

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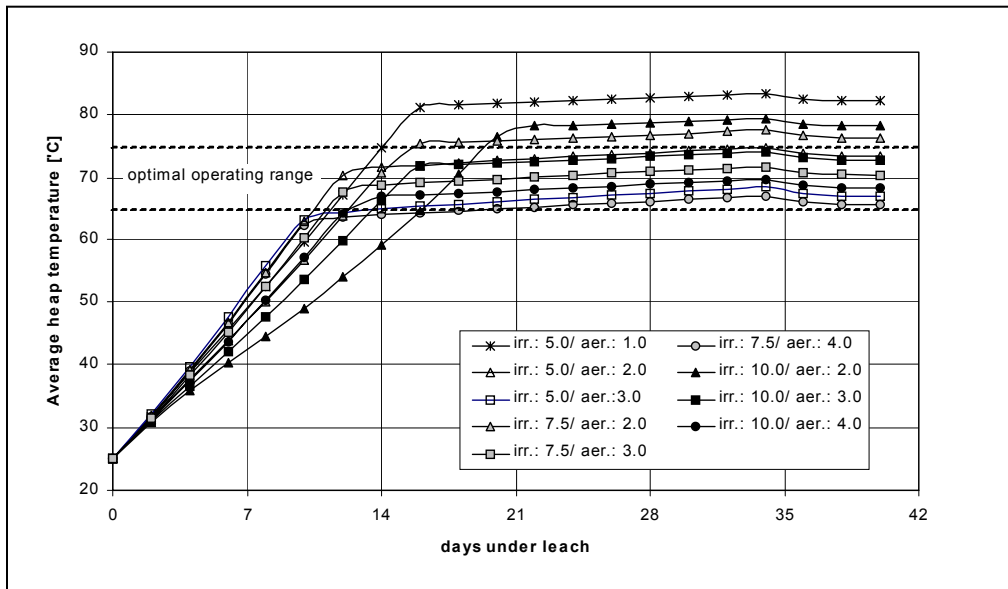


Figure 9
Average Heap Temperature vs. Time Modeled for a Variety of
Irrigation Rates (in L/m²-hr) and Aeration Rates (in kg/m²-hr)⁽⁵⁾

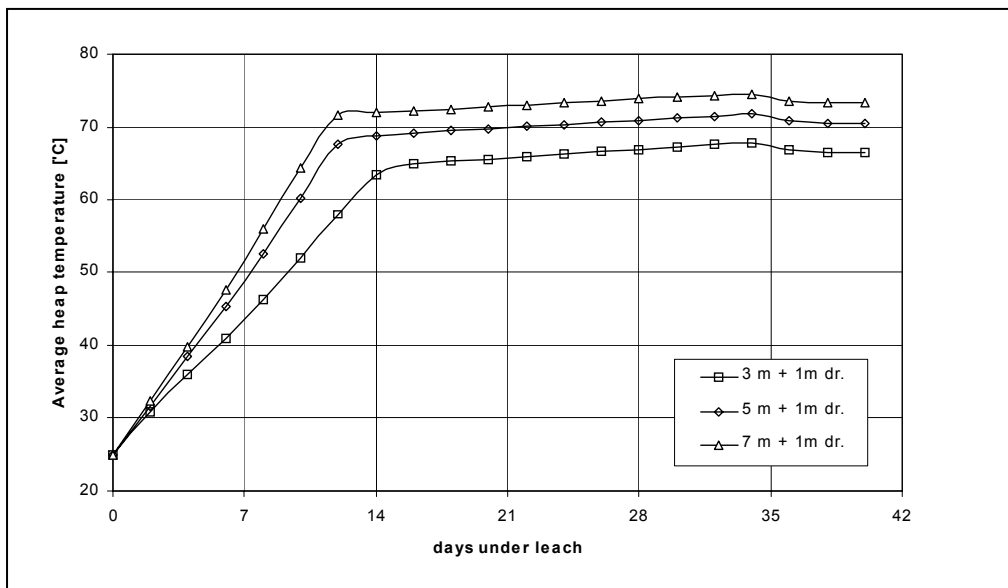


Figure 10
Average Heap Temperature for Various Heap Heights
(Base Case Conditions Of 7.5 L/M²-Hr Irrigation And 3.0 Kg/M²-Hr Aeration)⁽⁵⁾

The results of this modeling have been used to design the full scale column tests currently being conducted by Lakefield Research Africa and discussed below. All of the full height columns (6m) are currently ramped from ambient temperature (30°C) to operating temperature (70°C) over a period of 14 to



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21 days. A suite of mixed inoculum is employed that consists of mesophiles, moderate and extreme thermophiles. Further modeling is scheduled to examine the influence of mineralogy such as the use of enargite and the inclusion of pyrite.

4.0 GEOCOAT® COPPER DEVELOPMENT PROGRAM

GeoBiotics, LLC has embarked on an extensive development program to adapt the GEOCOAT® biooxidation technology for the extraction of copper from sulphide concentrates and low grade sulphide ores. The physical parameters surrounding the application of GEOCOAT® for biooxidation have already been proven in large scale field tests, this includes, coating, aeration, irrigation and concentrate residue recovery^(8,9,10). Additionally, the biooxidation parameters have been defined for gold bearing refractory sulphides at scale. Currently a test program is being conducted to provide the foundation for expanding the GEOCOAT® process to copper sulphides.

4.1 Laboratory Test Program

The laboratory program has been developed to provide insight into the mechanisms involved in the bioleaching of various copper sulphide minerals with the aim of maximizing the leach reaction rate and metal extractions. Investigations include complete mineralogical examination of both feed and residue samples, stirred tank biooxidation amenability testing, large scale column testing, preliminary downstream metal recovery and precious metal extraction. Additionally, adaptation of the specific inoculums is being conducted along with microbiological investigations.

Amenability tests are conducted in heated stirred reactors ranging in size from 10 liters to 40 liters. Aeration is supplied by cleaned compressed air. These reactors are capable of operating over a wide range of temperatures from 30°C to 80°C. A series of heated 6m high by 144m diameter columns have been set up to facilitate the column testing. These columns are equipped with zone heating to ensure uniform temperatures. Low pressure humidified air is applied to the base of the column at rates in excess of stoichiometric. Additionally, carbon dioxide is introduced to the air stream at a volumetric concentration of 1%.

Acid solutions are applied to the top of the heap via a peristaltic pump, the effluent solutions are collect separately at the heap base. Effluent solutions are generally recycled however, solution is removed on a periodic basis to maintain the desired PLS profile. The column is fitted with sampling ports that allow for both solid and liquid sample removal. At the termination of the biooxidation cycle the column is acid/water rinsed, allowed to drain and then emptied. The concentrate residue is removed from the support rock by simple wet screening and the concentrate allowed to dry. All weights and volumes are recorded and all samples are assayed for the appropriate elements. Figure 11 shows the column setup at Lakefield Research Africa (PTY) Ltd.

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Figure 11
Typical Large Scale Column Setup

The development program has been structured in a semi-factorial method using results from initial tests to dictate the subsequent test set. There are many variables surrounding the biooxidation of copper sulphides and this method of test design allows for quick optimization. The general program has been laid out in an effort to determine the influences of the following:

- Mineralogy
 - a variety of copper sulphide concentrates are being tested including two primary chalcopyrite concentrates, an enargite gold concentrate and a mixed copper sulphide gold concentrate,
 - the addition of pyrite is also being examined in an attempt to quantify galvanic effects and the ability to treat lower grade concentrates.
- Inoculum/Temperature
 - a mixed inoculum has been adapted for the various temperature regime under investigation including mesophiles, moderate and extreme thermophiles.
 - a series of tests are being conducted that will determine the extent of copper extraction at each of the 3 temperature regimes for each concentrate type.



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- Particle Size
 - a series of grind sizes are being tested to determine the rate controlling step in the leaching reactions.
- Oxygen Diffusion
 - a variety of oxygen concentrations are being applied to the tests ranging from 21% to 100% O₂.
- Chloride Addition
 - a test is being conducted to determine the influence of chlorides on the copper extraction and bacterial populations.
- Heap Height
 - tests are being conducted at a variety of simulated heap heights to determine the role of height on vertical variations in solution chemistry
- Coating Ratio
 - a variety of coating ratios is being tested to maximize the copper extracted per square meter of heap pad.
- Solution Chemistry
 - solutions compositions are varied through recycle and discard or S/X to achieve the desired PLS concentrations,
 - locked-cycle testing is being conducted to model full scale heap operation.

4.2 Preliminary Results

Currently the copper development program is ongoing and as such only preliminary results are available. At present one column has completed its biooxidation while five others are in process along with three stirred tank amenability tests. A total of 20 columns are planned.

As mentioned, a series of concentrates are under investigation. The first four columns focused on Concentrate A and the remaining two were initiated on Concentrate B. Table 3 shows the chemical and estimated mineralogical composition of these concentrates.

Element/Mineral	Composition (%)	
	A	B
Cu	26.1	25.8
Fe	29.7	31.9
S ²⁻	29.0	35.1
SO ₄	0.98	0.5
Au (g/t)	12.0	4.5
CO ₃ ²⁻	0.5	0.05
CuFeS ₂	75.4	74.5
FeS ₂	14.5	19.8
Acid soluble Cu	1.5	N/A
Acid soluble Fe	2.1	N/A

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The primary copper carrying sulphide in both of these concentrates is chalcopyrite. A difference does exist in the amount of iron sulphide present. Mineralogical investigations of Concentrate A indicate that much of the iron sulphide (63%) may actually occur as pyrrhotite. The visible gold occurs as relatively large grains with some telluride present. Detailed mineralogy on Concentrate B is still pending.

4.2.1 Copper Extraction

Figure 12 shows the course of metal extraction during the biooxidation of Concentrate A. This particular column was initiated at 70°C with an preliminary acid rinse until the pH was below 2 followed by inoculation with an adapted mixed thermophile culture. As indicated there is an initial lag phase of approximately two weeks before any significant chalcopyrite biooxidation occurs. The biooxidation then progresses rapidly over the next 70 days at a rate of 1.14% copper extracted per day. The rate then decreases as the sulphides are consumed. The overall rate for the test was 0.70% per day including the lag period. After 140 days a total copper extraction of 97.5% was achieved based on solution assays. This extraction was confirmed by analysis of the solid residues which indicated a total extraction of 94.0%.

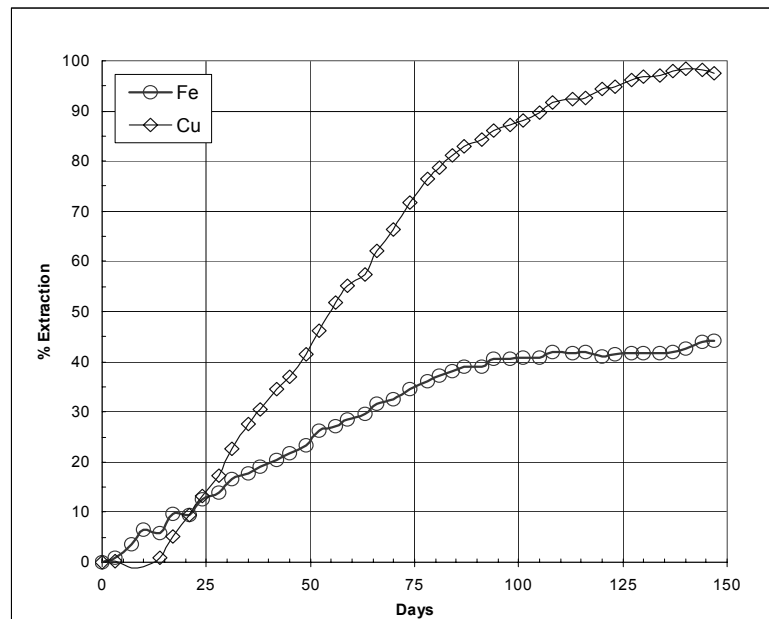


Figure 12
Metal Extraction from Chalcopyrite Concentrate A

The nature of this concentrate requires that near complete oxidation is required to achieve high copper extractions as indicated by Figure 13. This data is a compilation of completed and operating test data derived from solid samples taken from various column locations and time intervals. As indicated a near linear relationship exists when the copper extraction is plotted against the sulphide biooxidation.

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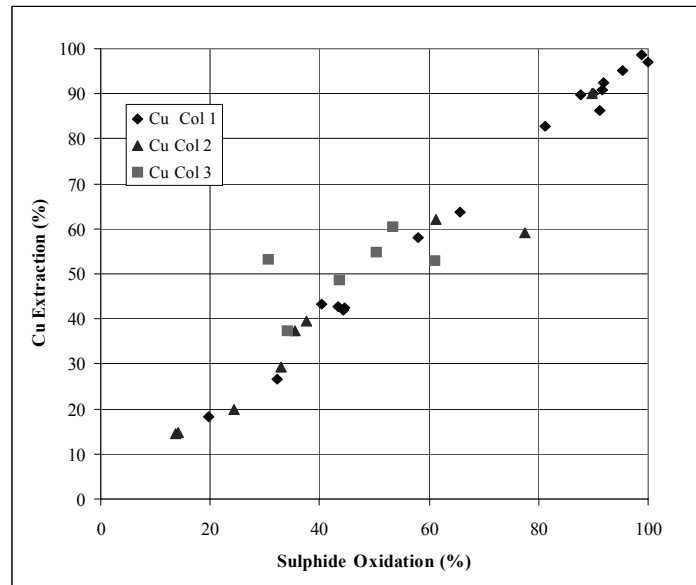


Figure 13
Copper Extraction vs. Sulphide Oxidation for Three Concentrate A Columns

Preliminary results from the tests on Concentrate B indicate that the copper extraction rate approximates that of the first Concentrate A column and that the addition of pyrite to the system provides pH buffering and will likely result in further rate enhancements. Work is continuing on this concentrate.

4.2.2 Gold Extraction

Since many chalcopyrite concentrates contain significant quantities of precious metals the ability to recover these metals after biooxidation is important from an economic standpoint. Concentrate A had an initial gold grade of 12.0 g/t with negligible silver. After biooxidation the residue gold grade was increased to 20.6 g/t due to the weight loss incurred. This sample lost 58% of its mass. Mass loss will vary during biooxidation depending on the concentrate and the amount of iron precipitated in the heap. In the case of this concentrate 91.6% sulphide oxidation was achieved while only 44.1% of the iron was solubilized. The precipitation of iron within the heap provides the advantage of having less iron to treat in the downstream processes. However, this precipitated iron could cause problems in the form of mineral occlusion. It is evident from the test that the precipitated iron did not adversely impact the copper extraction. Unfortunately it may play a role in the lower than expected gold recoveries.

Concentrate A can not be subjected to conventional CIL processing prior to biooxidation as the cyanide consumptions are uneconomic due to the high chalcopyrite levels. Biooxidation liberates the gold and removes the copper so the gold should be relatively free leaching in a conventional CIL plant. Table 4 shows the initial CIL gold extraction for Concentrate A biooxidation residue.

GeoBiotics, LLC
12345 West Alameda Parkway, Suite 310
Lakewood, Colorado 80228 USA
1-303-277-0300
1-303-277-1772 Fax

Table 4 Preliminary Gold Extractions						
Treatment Time (days)	Conditions	Lime kg/t Bioox Feed	Cyanide kg/t Bioox Feed	Au Feed g/t	Au Residue g/t	Gold Dissolution (%) Solids
Feed – 0	2000 ppm NaCN	49.9	49.9	12.0	9.3	25.0
Composite -140	500 ppm NaCN	9.1	6.2	20.8	10.6	49.6
Composite -140	1000 ppm NaCN	10.1	10.2	20.8	6.1	71.2
Composite -140	2000 ppm NaCN	9.7	16.8	20.8	5.2	75.4
Composite -140	5000 ppm NaCN	6.5	20.4	20.8	2.9	85.9
Composite -140	Regrind 2000 ppm NaCN	12.2	16.2	20.8	5.8	72.3

As shown by Table 4 the maximum gold extraction achieved was 85.9%. This is less than expected and at much higher cyanide consumptions than typically found in highly biooxidized residues. There are several possible factors contributing to the lower than expected gold extraction including potential jarosite or elemental sulphur or sulphide encapsulation,

Given the amount of iron precipitated during the test it is quite possible that jarosite encapsulation is the root cause of the low gold extraction. However, a fine grind should have liberated additional gold but this was not found to be the case. It is suspected that the grind may not have been fine enough to achieve the desired results. Unfortunately, at the time of writing the grind size of this product is not yet available. A more definitive test is currently under way using a hot sodium carbonate leach to displace the jarosite.

If the gold is occluded by sulphides or elemental sulphur than the planned diagnostic leach using hot nitric acid will reveal this. This is unlikely since sulphur speciation of the residue indicates very low elemental and sulphide sulphur levels. Additionally, a longer CIL test of 72 hours is planned at a maintained cyanide level to check for slower dissolving species. Mineralogical investigations are underway.

4.2.3 Temperature Dependence

Heat balance modeling of Concentrate A has indicated that a period of 14 to 21 days would be required for the heap to reach operating thermophilic temperatures. This was calculated using very small length columns. Since heap heat up is an extremely important factor it was decided to test these results on the large-scale columns.

A series of two columns were established to determine the amount of copper that could be solubilized in a given temperature regime. The first column, established with the same parameters as the column discussed above, was inoculated with mesophiles and held at 35°C until no further copper was extracted, the column was then ramped to 50°C and inoculated with moderate thermophiles and held until no further copper was extracted. Finally, the column temperature was increased to 70°C and inoculated with extreme thermophiles as shown in Figure 15. The second column was treated in a similar fashion except that it was started at the moderate thermophile level as shown in Figure 16. It is envisioned that some heaps may ramp very quickly through the mesophile range thus obviating the use of mesophiles.

Figure 14 shows the biooxidation of Concentrate A under the three temperature regimes. At 25 days the copper extraction rate began to slow down and the column was ramped to 50°C, at 53 days the rate again slowed and the column was ramped to 70°C. Figure 15 shows a similar trend but the column was started at 50°C in the moderate thermophile range. After 26 days the column temperature was elevated to 70°C as the copper extraction had slowed.

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Lakewood, Colorado 80228 USA
1-303-277-0300
1-303-277-1772 Fax

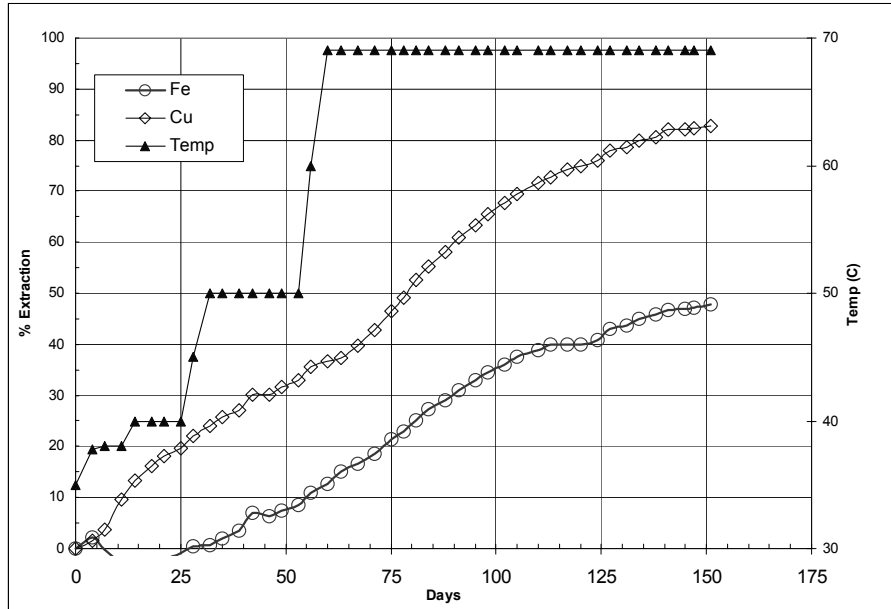


Figure 14
Mesophile, Moderate and Extreme Thermophile Biooxidation

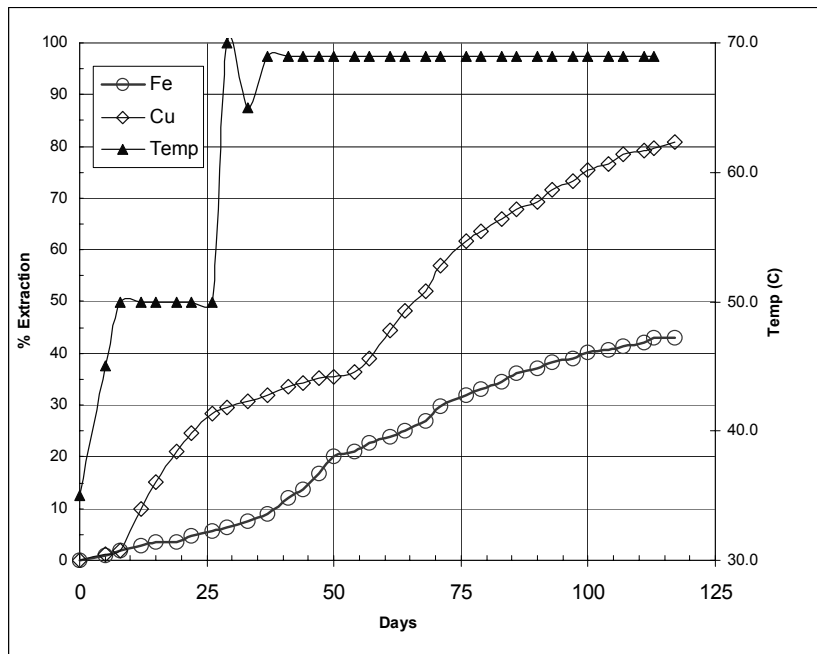


Figure 15
Moderate and Extreme Thermophile Biooxidation



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Lakewood, Colorado 80228 USA
1-303-277-0300
1-303-277-1772 Fax

Both of these columns are still under biooxidation and the ultimate copper extraction is expected to be similar to the first column that has been completed. The length of time under biooxidation for these columns is not significant due to the imposed lag times between inoculations and temperature increases. Samples have been taken from these columns for mineralogical examination to determine if the ramp through the various temperature and inoculum ranges has impacted the mineral surfaces.

It is obvious from this data that the chalcopyrite Concentrate A can not be effectively biooxidized under mesophilic or moderate thermophilic temperature regimes in a heap environment. However, enough iron sulphide and copper sulphide can be oxidized to enable the heap to obtain thermophilic temperatures. Additional modeling will be conducted using this data to verify these results. A large-scale demonstration heap is planned in the near future to show conclusively that adequate temperatures can be achieved to maintain thermophilic biooxidation.

5.0 SUMMARY

The GEOCOAT® process possesses many inherent advantages over conventional pyrometallurgical methods for copper extraction. Additionally, the melding of conventional heap leaching with biotechnology provides further advantages over the developing hydrometallurgical processes.

GeoBiotics, LLC proprietary GEOCOAT® process is being successfully applied to chalcopyrite on the laboratory scale. Copper extractions in excess of 97% have been achieved. Work is continuing on defining the system parameters including enhancing the leaching kinetics, downstream processing, and precious metal recovery. A large-scale demonstration heap will be the culmination of this program.

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