

A BACTERIAL HEAP LEACHING APPROACH FOR THE TREATMENT OF LOW GRADE PRIMARY COPPER SULPHIDE ORE

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ABSTRACT

Mintek is currently developing a design approach for the heap leaching of low-grade primary copper sulphide material. Since the leaching of chalcopyrite requires elevated temperatures, the generation and management of heat within the heap is crucial. Furthermore, the precipitation of iron needs to be managed to prevent premature blinding of the heap, and acid consumption needs to be limited to contain cost and limit the dissolution of gangue impurities. Standard column tests using jacketed 1-m and/or 6-m columns do not allow accurate prediction of temperature changes and heat generation in an actual heap. Mintek therefore utilizes a computer model to calculate the energy balance and heat generation with time, based on the measured sulphide oxidation rates in the column. The temperature in the column is then adjusted to reflect the computer-predicted temperature in an actual heap. Using this approach, an overall copper extraction of 70% was achieved in 120 days, using 1-metre columns, when treating an ore blend containing 1.36% chalcopyrite, 0.23% chalcocite, 0.07% covellite, 3.8% pyrite and silicate gangue (92%). The chalcopyrite contribution to the total copper content in the feed was 75%. This was followed by 6-m columns using a similar approach, and the column results will be validated on a 23,000 tonne test heap.

Key Words: heap; bioleach; chalcopyrite

1. INTRODUCTION

Heap leaching is an environmentally friendly route of moderate capital cost, for the processing of large tonnages of low-grade material. It involves the loading of material onto an impervious base, irrigating the top of the heap with a suitable lixiviant, and treatment of the pregnant solution draining from the heap for the extraction of the dissolved metal values. Disadvantages of heap leaching include lower recoveries and long residence times (approximately 200-300 days for secondary copper sulphides^{(1),(2)}).

Figure 1 summarises qualitatively the relationship between ore grade and method of recovery for Cu ores. Heap leaching is currently employed for copper oxides and secondary sulphides, e.g. Quebrada Blanca (Chile)⁽²⁾ and Girilambone (Australia)⁽¹⁾. The application of heap leaching to more refractory chalcopyrite material is still under development.

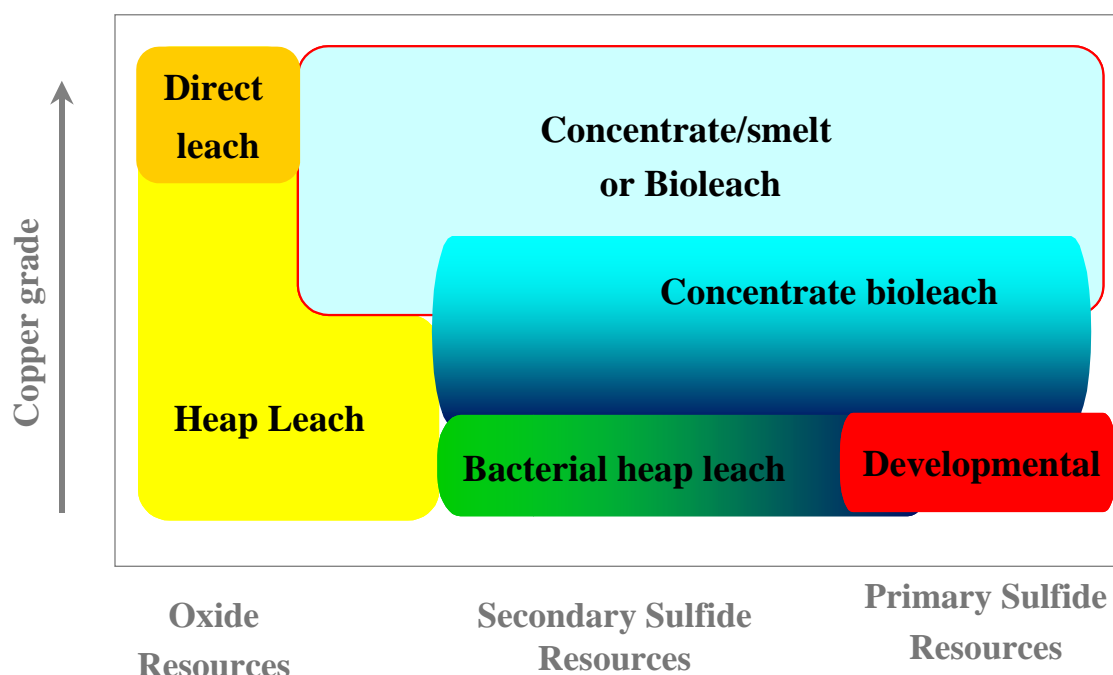


Figure 1 – Relationship between ore grade and method of recovery

During sulphide heap leaching, bacterial activity can be utilised to catalyse the oxidation of iron, which acts as an electron carrier between the mineral and oxygen for the conversion of sulphides. Indirect or direct bacterial attack on sulphur species can also generate sulphuric acid, which can improve the acid balance, and exothermic heat, which can be harnessed to raise the heap temperature and thereby improve kinetics. Whereas many heap leach operations have utilised natural convection to supply air to the heap, forced aeration has more recently been shown to reduce the residence time required to achieve around 80% copper recovery from 450 days to 200-300 days^{(1), (2)}

for a copper oxide/secondary sulphide ore. Forced aeration is achieved by installing a series of aeration pipes at the base of the heap, connected to a low-pressure blower.

Figure 2 shows the current worldwide copper production according to the process routes used. Copper is primarily produced by smelting and refining (80% of worldwide production), followed by oxide heap leaching (13%), secondary copper sulphide heap leaching (5%), and other hydrometallurgical routes such as concentrate pressure leaching and bacterial leaching. There are currently no heap leach operations processing primary (chalcopyrite) copper sulphides.

80% of world copper resources consists of low grade chalcopyrite, where the grade is too low to concentrate and which cannot be economically processed in any way other than heap leaching. Mintek is currently developing technology for the heap leaching of primary copper sulphide (chalcopyrite). The leaching of chalcopyrite requires elevated heap temperatures to obtain economic copper recoveries, and the heap leach design therefore focuses on the generation of exothermic heat, by utilizing bacterially-assisted conversion of pyrite and other sulphide species, with the aid of forced aeration. Heat and energy balances are used to predict the thermal behaviour in the heap, and column tests are carried out in order to simulate the temperature-dependent leaching kinetics and bacterial activity. Column results are usually validated on pilot-scale heaps of approximately 23,000 tons.

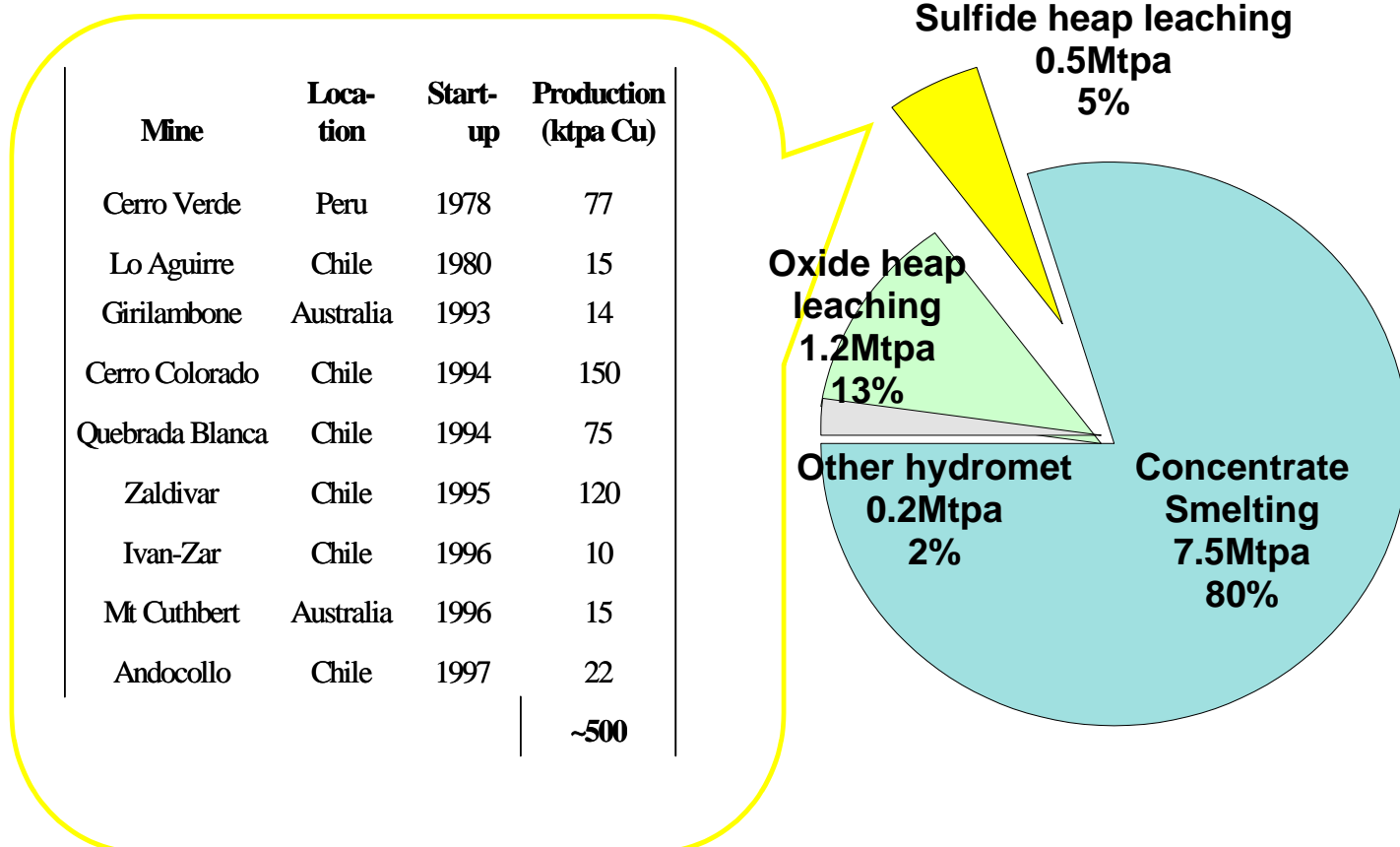


Figure 2 – Current worldwide copper production

2. HEAP LEACH APPROACH FOR PRIMARY COPPER SULPHIDES

Heap-leach design is currently based on non-standardised testwork at various scales, including the following:

- Roll bottle leach characterization tests to determine recoveries and acid consumptions.
- Small-scale column tests (typically 1m in height with varying diameter depending on the targeted crush size) to determine leach kinetics.
- Large-scale column tests (typically 6m or equivalent to the lift height of the proposed heap).
- Crib and/or small test heaps to verify the results obtained from the column data.

The above approach has been applied to the leaching of copper oxide ores and to a lesser extent secondary copper sulphide ores, where leaching can be carried out at ambient temperatures. The microbially assisted generation of ferric iron, at typical mine ambient temperatures, allows the recovery of copper from secondary copper sulphides, while copper recovery from chalcopyrite is limited due to the slow leaching kinetics. When processing chalcopyrite, elevated temperatures are needed, which may be achieved by the bacterially-assisted conversion of sulphur and the associated generation of exothermic heat of reaction. Figure 3 compares the leach kinetics of different copper species at typical heap leach conditions.

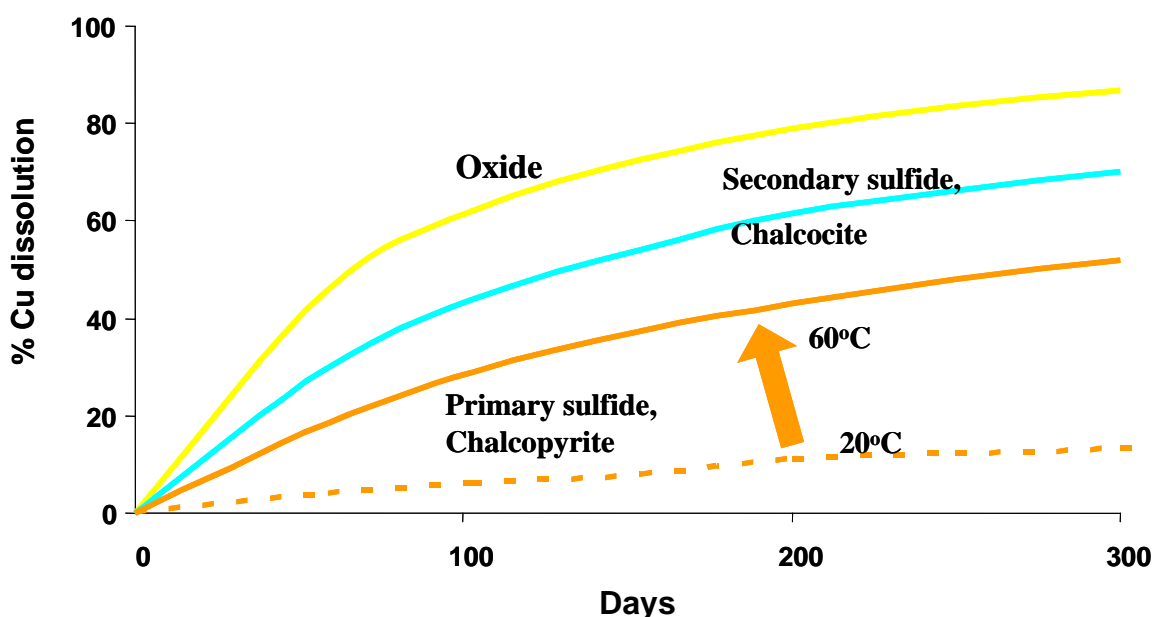


Figure 3 – Comparison of leach kinetics of oxide, secondary and primary copper sulphide ores

When using jacketed columns, it is difficult to simulate the temperature increase in an actual heap, since the bacterial activity, chemical reaction rates and heat generation are all influenced by temperature. The heat capacity of thermal insulation detracts from the

relatively small amount of chemical reaction heat generated in a column of ore, making a simple thermally insulated column undesirable. It is therefore necessary to develop more sophisticated tools to predict the heat balance and heap temperature profiles when designing a heap to process primary copper sulphides.

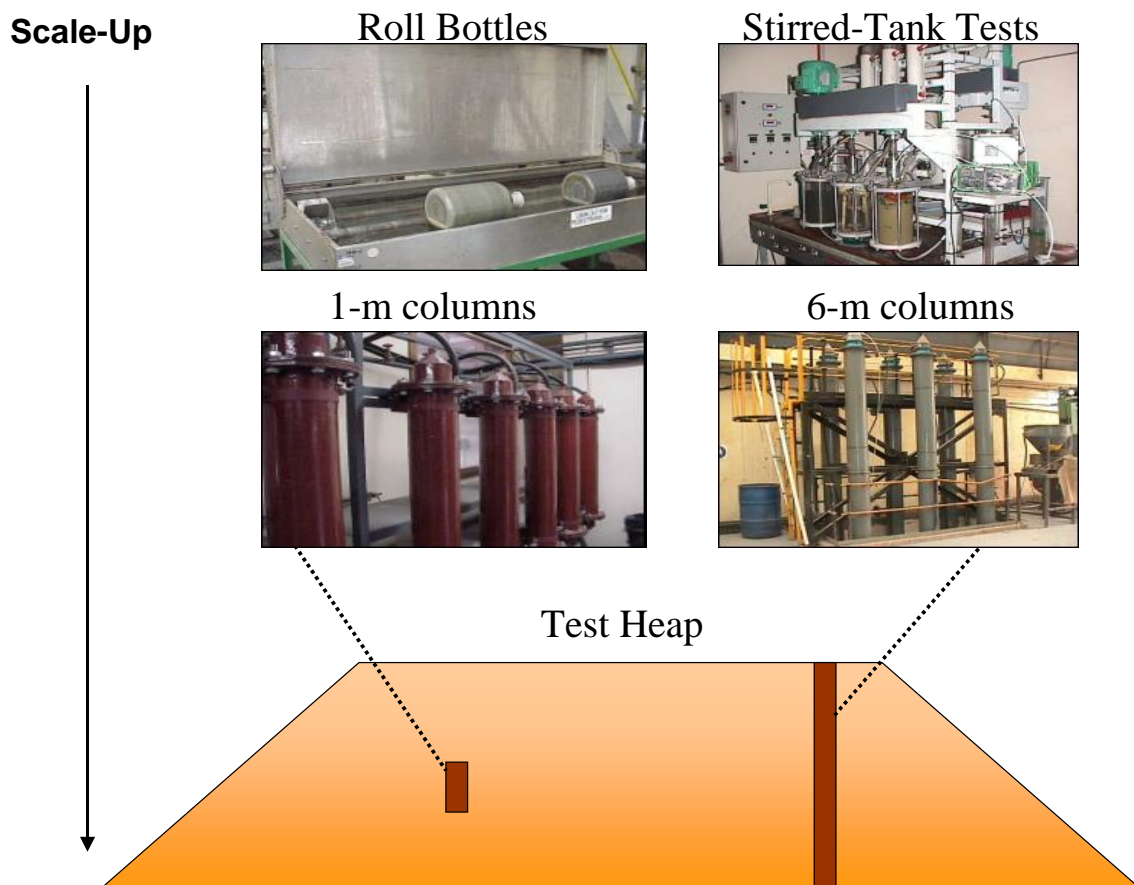


Figure 4 – Testwork Sequence for Heap Leach Design

Mintek uses a computer model to calculate the energy balance and heat generation with time, based on the measured sulphide oxidation rates achieved in the column. The temperature in the columns are adjusted to reflect the computer-predicted temperature in an actual heap. The column results are used to simulate industrial heap leaching with regards to leach kinetics, acid balance, impurity control and thermal behaviour.

Figure 4 shows the sequence of testwork employed by MINTEK during heap leach design. Testwork includes mineralogical characterisation, roll bottle leach characterization tests, stirred tank leach characterisation tests, 1m column tests and 6m column tests. The results of the column tests are validated on test heaps of approximately 23,000 tons.

3. MATHEMATICAL MODELLING

The computer model used by Mintek to describe the heat balance and temperature profile in a heap leach operation is similar to the one-dimensional heat balance for a sulphide heap derived by Dixon ^{(3), (4)}, namely:

$$\underbrace{\rho C_p \frac{\partial T}{\partial t}}_{\text{Accumulation term}} = \underbrace{k \frac{\partial^2 T}{\partial z^2}}_{\text{Conduction term}} + \left[\underbrace{G_l C_{pl} f_l(T)}_{\text{Liquid-phase advection term}} - \underbrace{G_a C_{pa} f_v(T)}_{\text{Gas-phase advection term}} \right] \frac{\partial T}{\partial z} + \underbrace{S}_{\text{Generation term}}$$

C = heat capacity

G_a = aeration rate

G_l = solution irrigation rate

k = thermal conductivity

T = temperature

S = Volumetric rate of heat generation inside heap

As shown in Figure 5, the energy balance is affected by the chemical reaction heat, conduction and radiation incidence and losses, as well as the convection flow terms due to liquor, gas and vapour movements. The major portion of ore inside a large heap is thermally insulated on the outside by more ore that is actively leaching and generating its own heat, and this is not emulated by simply adding thermal insulation wool to the outside of a laboratory column.

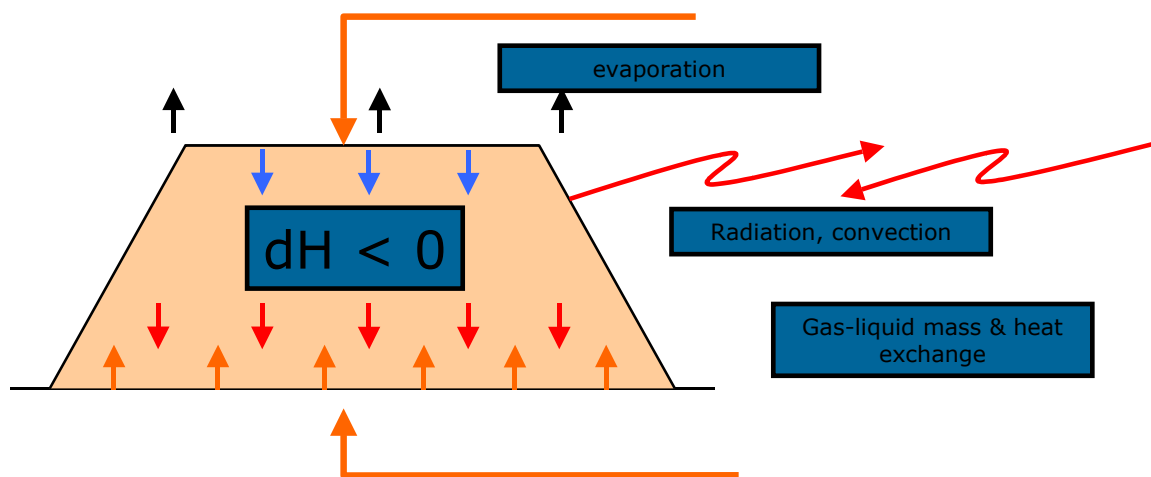


Figure 5 – Heap Energy Balance

Figure 6 shows the temperature profile for a typical heap leach operation, and the profile required for chalcopyrite leaching. The profile is based on a simulation with the following inputs: 6m lift height, 5L/m².h solution irrigation rate, 30% oxygen utilisation, 10°C ambient temperature, 90 days leaching time. In order to achieve the desired temperature profile, it is necessary to choose the correct ratio of irrigation rate and forced aeration rate, and to generate suitable conditions for bacterial growth. Also necessary is sufficient sulphur species in the ore, since the bacterially-assisted conversion of sulphur generates exothermic heat.

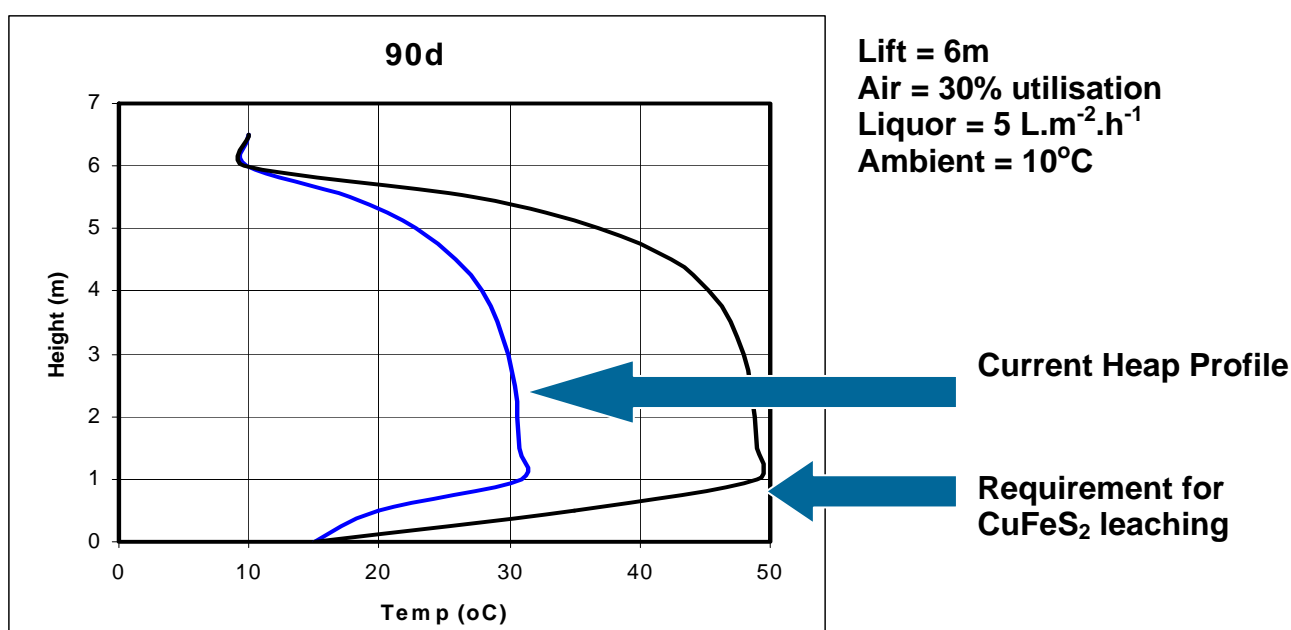


Figure 6 – Heap Temperature Profile

4. COLUMN TESTS

Tests are carried out in 1-m columns, consisting of a single segment, or in 6-m columns, consisting of instrumented segments, with the temperature in each segment controlled separately to track computer calculations, by independent water-jacketing. A picture of a segmented 6-m column is shown in Figure 7. A computer model calculates the energy balance and heat generation with time, based on the measured sulphide oxidation rates in each segment, and taking into account the axial convection effects of the flow of air, liquor and moisture. The temperature in each segment is then adjusted to reflect the computer-predicted temperature in an actual heap. In effect therefore, actual leach kinetics, as determined from measured sulphide oxidation rates in each segment, are used to reflect the evolving temperature profile with time. The time-course dissolution profile obtained will simulate the actual heap situation where temperature and kinetics are inter-dependent and the temperature profile varies with time. The columns are operated in closed circuit with a solvent extraction step and columns are

irrigated with return raffinate. Impurity build-up in the raffinate is monitored. A number of Smart Columns are run at various controlled parameters. The effect of these parameters on the acid balance, heat generation and bacterial activity (measured in the PLS) is determined.



Figure 7 – 6-m segmented column

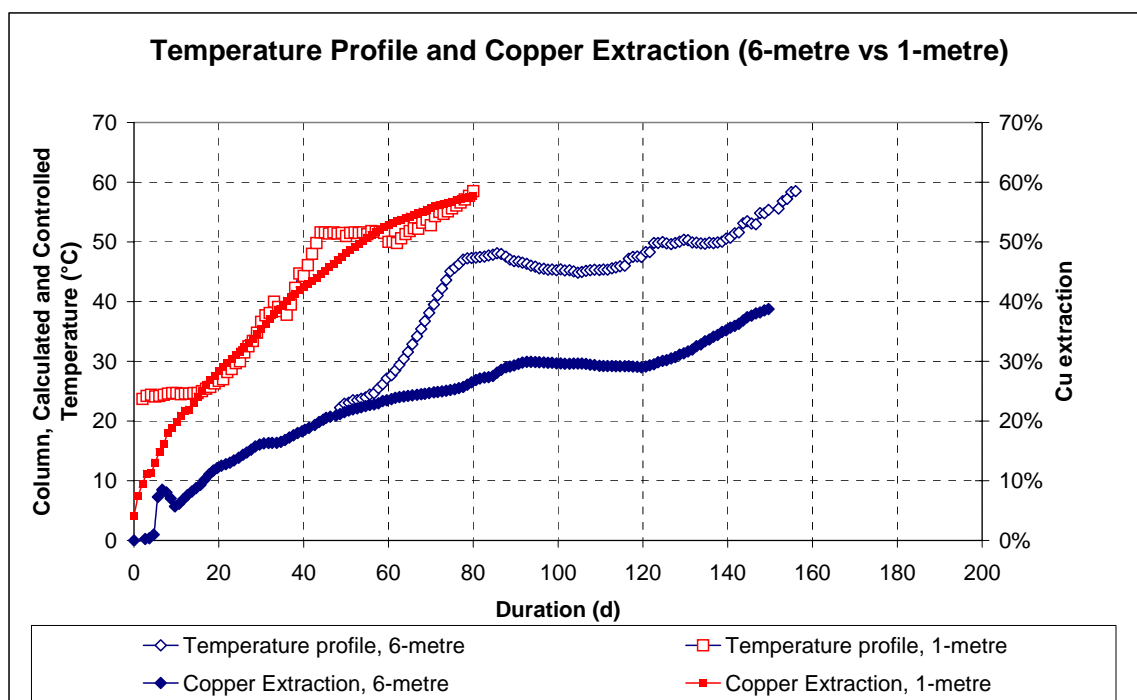


Figure 8 – Temperature Profile and Copper Extraction (1-metre vs 6-metre)

Figure 8 shows the results of column tests carried out on an ore blend containing 1.36% chalcopryrite, 0.23% chalcocite, 0.07% covellite, 3.8% pyrite and silicate gangue (92%). The chalcopryrite contribution to the total copper content in the ore blend is 75%. Copper recoveries achieved for the 1-m and 6-m columns are shown in Figure 8, along with the predicted temperature profiles. The 6-metre column lags the 1-metre column in both temperature generation and copper extraction, due to the difference in lift height, when irrigated at the same solution application rate per cross-sectional area. The difference in column lift height also results in differences in the lixiviant composition and microbial activity.

Figure 9 shows the redox profiles of the PLS exiting the 1-m and 6-m columns. The redox potential in the 1-m column rose quickly to 700 mV, indicating that all iron in solution has been converted to iron (III). The initial redox instability observed in both graphs is due to (1) precipitation of iron (III) due to the initial high pH exiting the column and (2) initial rapid consumption of iron (III) during the leaching of secondary copper sulphide species. Once the pH drops below 2.5, the behaviour of iron (III) stabilises. The stabilisation period of the 6-m column is longer, since the application rate per area per mass of ore is 6 times smaller than for the 1-m column.

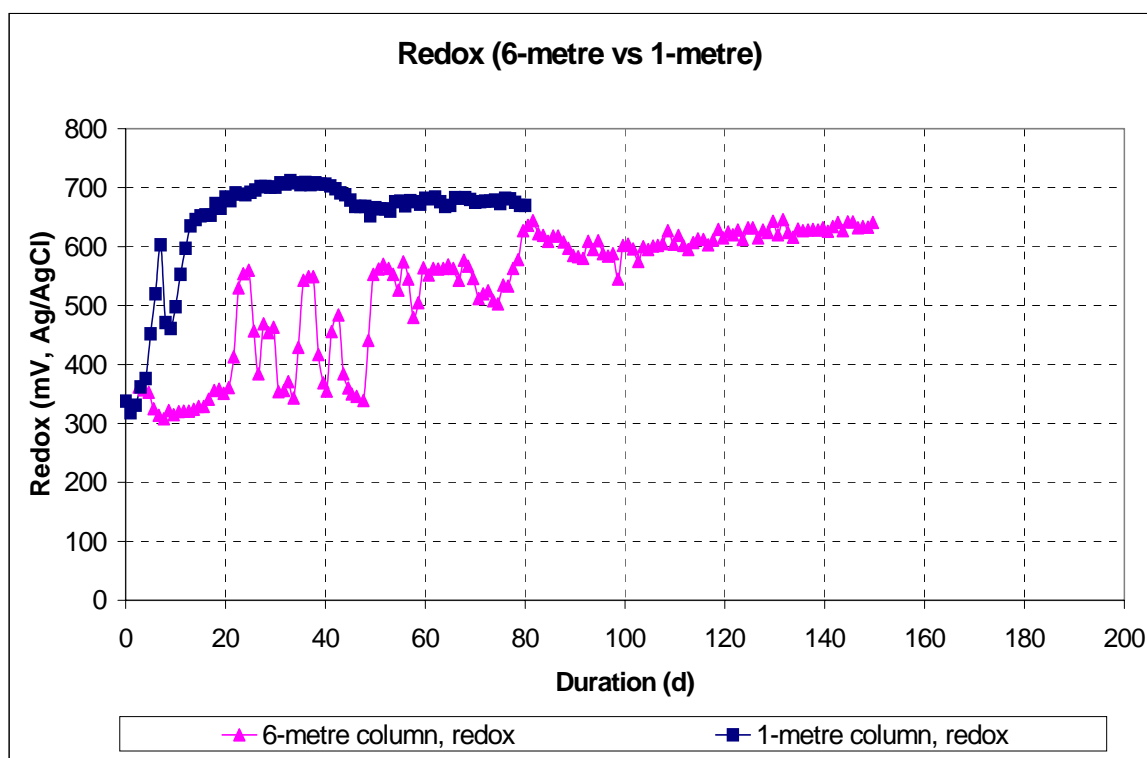


Figure 9 – Redox potential profiles in the 1-m and 6-m columns

Figure 10 shows the gangue acid consumption and acid addition to both the 1-m and 6-m columns. The gangue acid consumption is calculated as the difference between the acid entering the column in the return raffinate and the acid exiting the column in the PLS. The acid addition is the acid entering the column in the return raffinate. The acid addition for the 1-m column was initially equal to the gangue consumption, but later exceeded the gangue acid consumption once most of the gangue material had been consumed, resulting in a decrease in the pH exiting the column. The acid addition for the 6-m column had not yet exceeded the gangue acid consumption for the period shown, since the application rate per area per mass of solids was 6 times less than for the 1-m column.

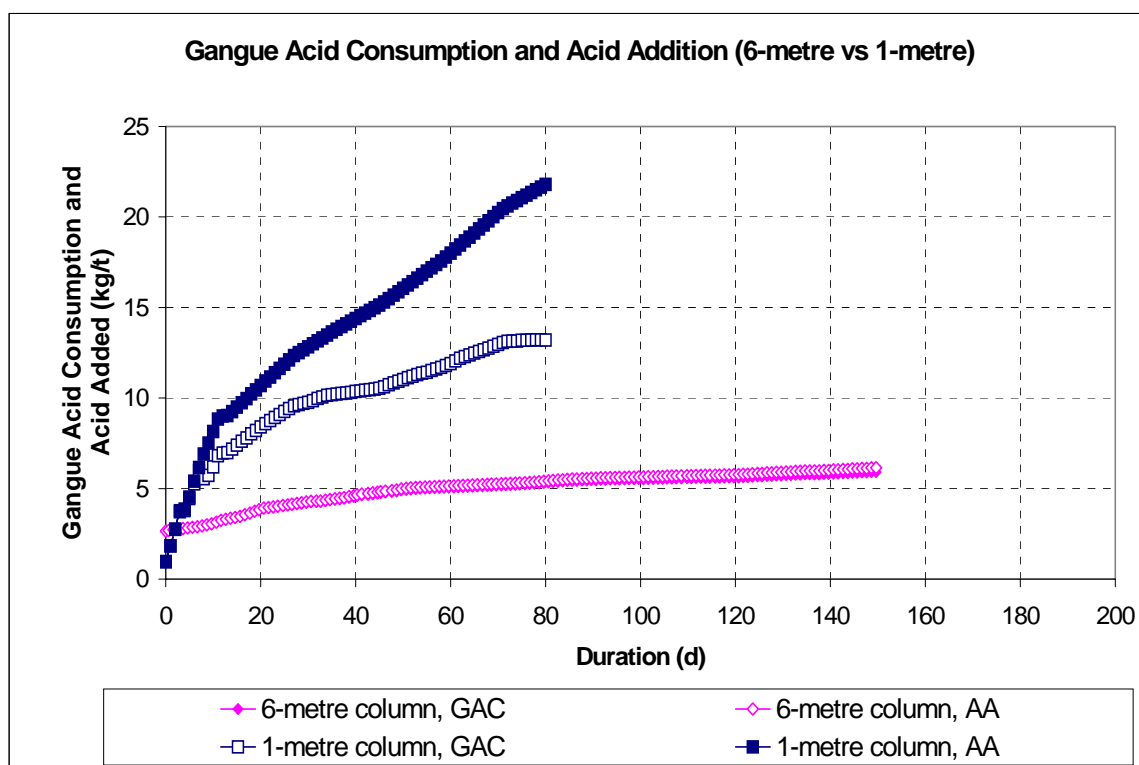


Figure 10 – Gangue acid consumption and acid additions in the 1-m and 6-m columns

5. DESIGN OF PILOT HEAP

Figure 11 shows the layout of the pilot test heap facility to be used for validating the laboratory findings on a 23,000 tonne heap. The aim of the test heap trial is to validate the results predicted by the column tests with respect to temperature profile, copper extraction and acid consumption. It also serves to verify the engineering design and control strategy, aimed at enhancing heat accumulation and heat retention in the heaps, managing the precipitation of iron, and optimising the acid addition which is related to acid consumption and gangue dissolution.

The proposed plant consists of 6 m heaps of approximately 23,000 tons each, stacked on a prepared base consisting of an impervious HDPE sheet, followed by an inert “humidification layer” containing the aeration pipes. Drainage pipes are located at the bottom of the heap on the HDPE sheet. The pond area consists of PLS ponds, raffinate ponds, inoculum ponds and auxiliary ponds. The solution drainage gravitates to the PLS ponds, and from there to the SX section. Return raffinate is pumped to the raffinate ponds, from where the heap is irrigated. Inoculum solution ponds are situated above the auxiliary ponds, making provision for storage of prepared inoculum. The PLS and raffinate ponds overflow to the auxiliary ponds, and provision is made for solution transfer between auxiliary and inoculum ponds.

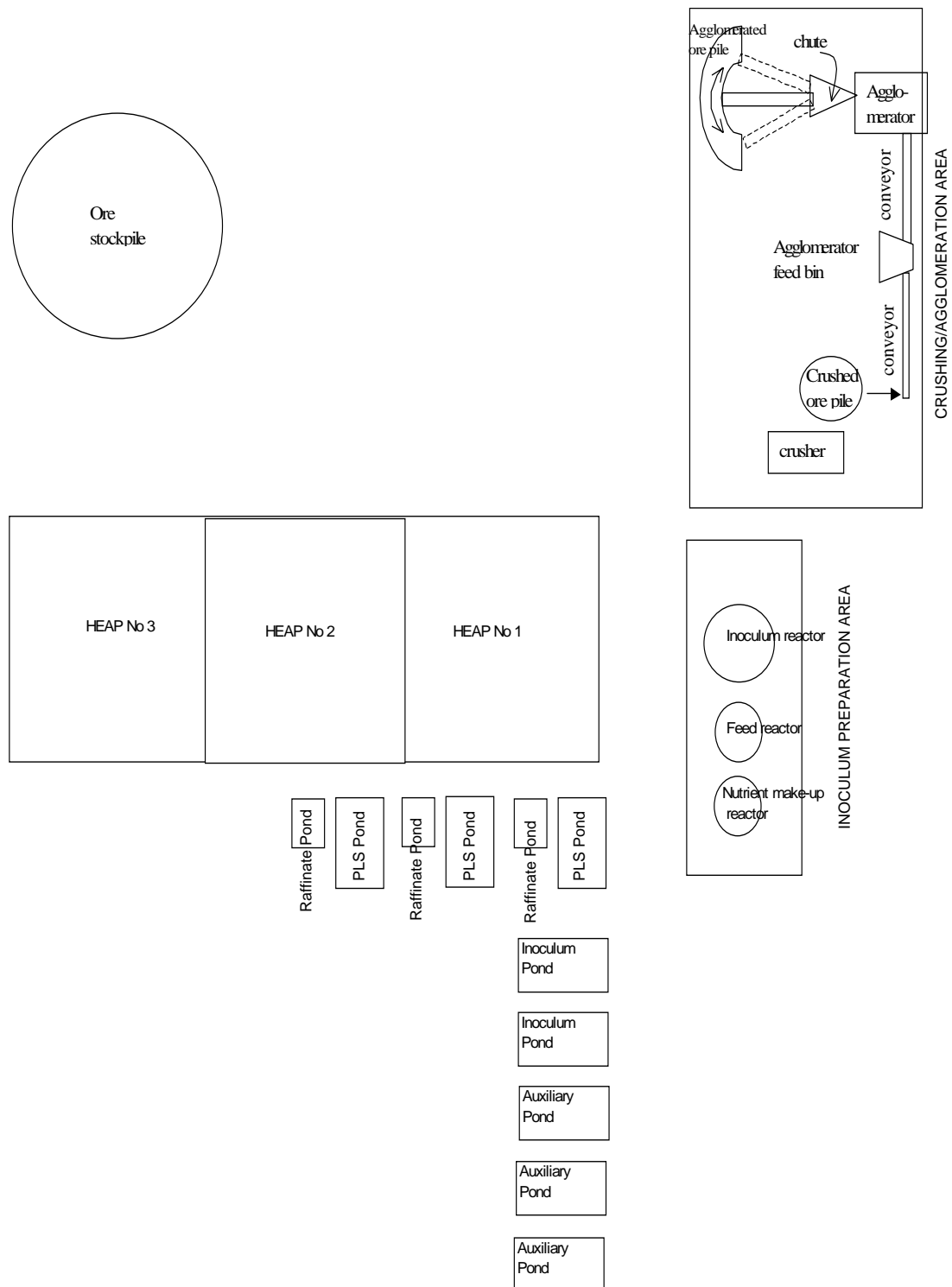


Figure 11 - Proposed test heap layout

The heap is irrigated with a series of drippers and sprinklers, which can be operated independently or in tandem to supply the total irrigation requirement. Solution is pumped from the raffinate irrigation ponds through the dripper and sprinkler manifolds,

from where it is directed through the dripper and/or sprinkler lines. The drippers and sprinklers are designed with a given flow vs. pressure relationship, and the irrigation system is designed to supply the desired pressure at the point of discharge.

The heap utilises forced aeration to supply the aeration requirement for the conversion of ferrous iron and sulphur species. The forced aeration design for the Quebrada Blanca secondary copper sulphide heap is described by Salomon-de-Friedberg⁽²⁾. It consists of a low-pressure blower, air supply pipes, manifolds and aeration stringers (perforated pipes inside the heap). The aeration stringers are typically located at the base of the heap inside the humidification layer. The two main considerations for aeration design are (1) even distribution of air through the aeration stringers, and (2) sufficient blower delivery pressure to overcome the pressure drops in the aeration piping and manifolds.

In order to obtain data relating to leach kinetics, microbial activity, solution composition and oxygen utilisation at different depths within the heap, Mintek has designed proprietary sampling equipment, which can be inserted in the heap at depth intervals of 1 m and 1.5 m. The data will be used to control external parameters such as irrigation and aeration rates in order to optimise heap performance. Proprietary augering equipment has also been designed to facilitate the insertion of the measuring devices.

6. CONCLUSIONS

- It is generally accepted that the processing of chalcopyrite-containing material would require elevated heap temperatures to obtain meaningful copper recoveries.
- The use of forced aeration has become accepted practice for enhancing bacterially-assisted oxidation for the heap leaching of secondary sulphide ores, and forced aeration will obviously also be an indispensable requirement for the heap bioleaching of chalcopyrite ores.
- Standard jacketed-column test experiments cannot adequately predict the temperature profiles in the heap, which affect the copper leaching kinetics and bacterial activity.
- Mintek's approach utilises column tests, together with an energy balance based on observed kinetics to predict the temperature profile in a heap. The experimental temperatures in the jacketed column are adjusted to reflect the temperature profile predicted by the energy balance.
- Predicted copper recoveries of up to 70% were achieved within 120 days in a 1-m column, loaded with an ore blend containing 1.36% chalcopyrite, 0.23% chalcocite, 0.07% covellite, 3.8% pyrite and silicate gangue (92%). The chalcopyrite contribution to the total copper content in the ore blend is 75%.
- Column test results are to be validated on a pilot test heap of approximately 23,000 tons. The test heap utilises forced aeration to supply air to the heap. The temperature profile within the heap is monitored, along with copper leaching kinetics and acid consumption. The heap is fitted with proprietary sampling equipment to obtain data relating to leach kinetics, microbial activity, solution composition and oxygen utilisation at different depths within the heap.

The data will be used to control external parameters such as irrigation and aeration rates in order to optimise heap performance.

7. REFERENCES

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