Analysis of Agitation Leaching Data — Methods and Interpretation

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ABSTRACT

Agitation leaching data has generally not been analysed to extract the maximum amount of information that is available. Analysis of heap leaching systems has been developing over the last five years to include the underlying rate determining process. This has been found to be diffusion control for all copper leaching; irrespective of whether they are oxide or sulfide minerals. Extension of the diffusion model has enabled better scale-up protocols to be developed.

Acid consumption in copper heap leaching operations has been found to be a first-order chemical controlled system. The analysis of the data is relatively straightforward. However the interpretation and scale-up is not as direct as for leaching. The differences in the residence time distributions (RTDs) are required to properly account for the scale-up between test columns and field.

The leaching of oxide copper in agitated systems has also been found to be diffusion controlled. However, there are significant differences in the control mechanisms. Initially the leaching control is the supply of acid to the mineral surface. This is limited by the diffusion through the surface boundary layer and is thus subject to the level of agitation. Higher agitation provides thinner boundary layers and faster diffusion rates. Similarly, higher grade material creates a thicker concentration boundary layer and relatively slower leaching.

Acid consumption in agitated leach systems is also a first-order system. However, the interpretation of the RTD is easier from batch testing to continuous multiple CSTR series plant operations. Altering the method of acid delivery can significantly reduce acid consumption rates. Predilution of the acid minimises the local acid concentration near the addition point and can reduce the consumption by up to 50 per cent.

Modelling of the combined leach rate(s) and acid consumption rates in agitated systems allows comparison of various leaching strategies and selection of the most appropriate. Similarly, the model allows the identification of economic limits to leach recovery; where the cost of acid consumption is greater than the value of the copper recovered. From this analysis selection of residence times for agitation leaching can be determined. The modelling tools are useful in identifying optimum conditions for the leaching process.

INTRODUCTION

Agitation leaching data has not generally been analysed to extract the maximum amount of information that is available. Analysis techniques for heap leaching systems have been developing over the last five years to identify and include the underlying rate determining process (Miller, 1998, 2002, 2003 and Dixon, 2003). This has been found to be diffusion control for all copper leaching; irrespective of whether oxide or sulfide minerals are being leached. Extension of the diffusion model to agitation leach systems should enable better scale-up protocols to be developed.

Acid consumption in copper heap leaching operations has been found to be a first-order chemical controlled system. The analysis of the data is relatively straightforward. However, the interpretation and scale-up is not as direct as for the agitation leaching system. The differences in the residence time distributions (RTDs) are required to properly account for the scale-up between test columns and field. In the agitation leach system the CSTR RTD is a well-known model that can be used for acid consumption prediction.

A recent Zambian leach project has undertaken preliminary testing for agitation leaching of two ore samples. This information will form the basis of the process design and selection for the project. The ore is a ‘typical’ copper belt oxide ore with dominant malachite and significant mica and other platy particles in the gangue. The Run of Mine (ROM) grade is predicted to be 2.15 per cent ASCu (Acid Soluble Copper); but the samples tested have proven to be of significantly higher grade – at two to three times the anticipated ROM grade. As a result, interpretation of the leaching testing is required in order to try and predict the leaching characteristics of the ROM grade material.

LEACH RATE ANALYSIS

The leach rate analysis is divided into two parts:
1. leach rate with grind size, and
2. leach rate with grade.

All the leach extractions were recalculated to reflect the calculated head grade (based on solution and tails assays) as this provides the more accurate determination of the head grade. The procedure eliminates any anomalous +100 per cent recovery that may have been recorded in the primary laboratory data.

The leach recovery curves are shown in Figure 1. It would seem that there is no consistent pattern between the leach rate curve and the grind size. The only (negative) information is that the high-grade coarse grind did not achieve a +90 per cent recovery in the six hours time used in the testing.

![Leach recovery-time curves](image)

**Fig 1 - Leach recovery-time curves.**

The leach rates shown in the simple recovery curves are not all that amenable to analysis in this form. It has been postulated that the agitation leaching of copper is a diffusion controlled process; and that using this approach, further insights may be found. The leach information has been transformed into the diffusion controlled, Shrinking Core model (Miller and Newton, 1999) to see if this is an appropriate method. The recovery (R) is transformed (Tr(R)) by the Shrinking Core model:

\[ Tr(R) = 1 - 2/3R - (1-R)^{2/3} \]

which yields a straight line when plotted against time if the model is appropriate. The resultant leach curves are shown in Figure 2.

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It is evident from this analysis that the leaching curves have been transformed into straight lines. As such the leaching is diffusion controlled with a ‘shrinking core regime’. The slope of the line is the diffusion controlled leach rate. There are two separate lines in most of the leaching curves. This indicates that there has been a change in the underlying diffusion rate control mechanism during the leach period.

The fast and slow leach rates have been ‘normalised’ for the head grade (a technique that arises from the shrinking core leach model) and are plotted as a function of grade as shown in Figure 3.

The fast leach rate has very significant inverse grade dependence to a high degree of correlation. The implications from this are:

- The fast leach rate is mass transfer controlled with acid supply to the mineral surface through the boundary layer the rate-determining step. This is evident from the steep grade dependency where the higher grade consumes acid at a greater rate and creates a wider concentration boundary layer thickness, which acts to reduce the observed leach rate.

- The leach rate for the slow regime is particle diffusion controlled with only a small, acid supply, mass transfer component. The diffusion leach rate within the particles does not appear to be grind size dependent; probably due to the surface expression of the malachite mineral and the short and wide pores into the leached particles.

- The fast leach rate in the commercial plant will depend on the agitation intensity and the availability of acid to the surface of the ore particles. Thus the selection of the mixers will influence the leach rate that can be predicted for the project. As such high intensity mixers with high turnover rate will need to be used.

- The fast diffusion leach rate for a head grade of 2.15 per cent ASCu should not be extrapolated from this data with any degree of confidence. However, it is required in order to model the leaching process for ROM grade material. From the available data the extrapolated Grade Normalised fast leach rate would be of the order of 0.029. This figure has been reduced to 0.025 and used in the subsequent analysis reported here. Similarly a figure of 0.003 has been used for the Grade Normalised slow leach rate portion.

The change point in leach rate from fast to slow is also required for the analysis. It appears to occur at 120 minutes leaching except for the high grade -75 micron material; where there is no change from the fast leach rate. In this case the recovery is still quite low (70 per cent) and the leaching is continuing to be controlled by the supply of acid through the boundary layer. The change in leach rate for the lower grade material is around the 90 per cent (Tr(R) = 0.184) recovery level. This is an important observation as discussed later. The model uses a change at the 90 per cent recovery level.

**ACID CONSUMPTION RATE ANALYSIS**

The gangue acid consumption GAC is the nett consumption of acid that is not returned via the solvent extraction (SX) plant. It is an economic cost and needs to be modelled closely to confirm the economics of the process. All the GAC consumption profiles are shown in Figure 4.

It is evident from inspection of these curves that the GAC is a linear function of time. This means that as the leach time increases the total acid consumption increases directly. There is thus a relatively easy method of modelling the GAC with this linear time related consumption.

The consumption consists of two parts. The first is the GACo or that associated with the early leach where gangue is the main consumer of acid. The second is the linear time related increase in GAC and is the rate part of the equation.

The GACo appears to vary with a number of parameters. Figure 5 shows variation with size and Figure 6 with grade.

- The fast leach rate has very significant inverse grade dependence to a high degree of correlation. The implications from this are:
  - The fast leach rate is mass transfer controlled with acid supply to the mineral surface through the boundary layer the rate-determining step. This is evident from the steep grade dependency where the higher grade consumes acid at a greater rate and creates a wider concentration boundary layer thickness, which acts to reduce the observed leach rate.
  - The leach rate for the slow regime is particle diffusion controlled with only a small, acid supply, mass transfer component. The diffusion leach rate within the particles does not appear to be grind size dependent; probably due to the surface expression of the malachite mineral and the short and wide pores into the leached particles.
  - The fast leach rate in the commercial plant will depend on the agitation intensity and the availability of acid to the surface of the ore particles. Thus the selection of the mixers will influence the leach rate that can be predicted for the project. As such high intensity mixers with high turnover rate will need to be used.
  - The fast diffusion leach rate for a head grade of 2.15 per cent ASCu should not be extrapolated from this data with any degree of confidence. However, it is required in order to
The GACo dependence on grind size is expected with greater exposure of the fast leaching copper mineral (malachite) leading to a lower GACo for the finer material. The dependence on grade is a little more subtle. The higher-grade copper material consumes a greater proportion of the available acid than the lower-grade copper material. As a result there is an inverse relationship between grade and GACo that needs to be taken into account.

For a grind size selection of 55 per cent -75 microns a GACo of around 12 kg/t would be indicated. However, the grade dependency would suggest a GACo of 24 kg/t. This latter figure has been used in the modelling.

The time linear GAC rate is shown in Figure 7 as affected by grade, and in Figure 8 as by size.

As expected the copper grade has little effect on the GAC rate and is not included in the model. In this region once the initial GACo has been satisfied there is little or no dependence of GAC rate on grade. However, there is a significant increase in GAC rate with decrease in grind size. The data is still very scattered but it would suggest an average GAC at -75 microns of 0.11 kg/t/min; which has been used in the subsequent modelling.

**EFFECT OF ACID DILUTION ON GANGUE ACID CONSUMPTION**

Other recent work has shown that the addition of prediluted acid to the leach can lower the GAC (Grosse, 2004). The present work was conducted with 8 M 'dilute' sulfuric acid rather than with the 'normal' method of adding concentrated acid directly to the leach vessel. Figure 9 shows the affect of adding acid at various concentrations on the GAC. Figure 10 shows the mapping of copper recovery and GAC for the same tests.

As is evident from these results there is a significant reduction in the GAC when the acid is prediluted before addition to the ore slurry. The recovery of the copper (under constant leach time constraint) shows no real affect that can be demonstrated within the limits of the test accuracy. This has been confirmed anecdotally by Littleford (2005) for a similar operation leaching oxide zinc ores.

The response of the leaching and GAC to the acid concentration is consistent with the modelling developed for heap leaching (Miller, 2002). Lower acid concentrations show a significant lowering of the GAC and GAC rate for a fixed leach time. Lower acid concentrations also lower the overall leach rate. However, for the test parameters used the total leach time was sufficient to compensate for the slower kinetics. The use of diluted acid will show benefits in the economics of the leaching operation without adverse effects on the copper recovery; provided that the leach time allowance is sufficient to leach to the economic limit.
LIMIT OF ECONOMIC LEACHING

As discussed in the literature (Miller, 1998) there is a limit to economic leaching when the cost of the marginal GAC consumed exceeds the nett revenue from the marginal copper leached. This analysis generally results in a limiting nett acid:copper ratio of between 15:1 and 25:1 depending on the relative copper and acid prices. For a net marginal copper income of $US0.80/lb (after recovery costs) and an acid cost of $US100/tonne, the limiting acid copper ratio is 17.3:1. Once the acid consumption exceeds this then the leaching is no longer economic.

The comparison of the alternative leaching 'recipes' is best shown in a plot of the GAC as it varies with the Copper Recovery. This is shown in Figure 11 for the four test results.

LEACH PARAMETER SELECTION

The selection of leach parameters needs to be made so as not to exceed the economic recovery. A leach model has been developed to assess the relative merits of longer leach times. This is done by using the two-rate diffusion control leach model combined with the time-related GAC model. The differential recovery and GAC are calculated and plotted against the absolute recovery. The diffusion leach model is shown in Figure 12; while the resultant copper recovery curve is shown in Figure 13. The GAC model is shown in Figure 14. The overall GAC-Recovery and acid:copper ratio (A:Cu) are shown in Figure 15.

Analysis of the model output shows clearly that as soon as the leach rate changes from the bulk mass transfer control to the particle diffusion control the acid:copper ratio and the GAC rise exponentially. This is clear evidence that the leaching needs to be conducted in a regime that allows the copper to be extracted at as fast a rate as possible. This change point is the switch from acid transport boundary layer diffusion to particle diffusion control.

CONCLUSIONS

The leaching of oxide copper in agitated systems has been found to be diffusion controlled. However, there are significant differences in the control mechanisms. Initially the leaching control is the supply of acid to the mineral surface. This is limited by the diffusion through the surface boundary layer and is thus subject to the level of agitation. Higher agitation provides
thicker boundary layers and faster diffusion rates. Similarly higher grade material creates a thicker concentration boundary layer and relatively slower leaching.

There is an economic limit to the agitation leach extraction of the copper in the ore. There is clear evidence that the leaching needs to be conducted in a regime that allows the copper to be extracted at as fast a rate as possible. This change point is the switch from acid transport boundary layer diffusion to particle diffusion control.

Acid consumption in agitated leach systems is also a first-order system. However, the interpretation of the RTD is easier from batch testing to continuous multiple CSTR series plant operations. Altering the method of acid delivery can significantly reduce acid consumption rates. Predilution of the acid minimises the local acid concentration near the addition point and can reduce the consumption by up to 50 per cent.

Modelling of the combined leach rate(s) and acid consumption rates in agitated systems allows comparison of various leaching strategies and selection of the most appropriate. The model allows the identification of economic limits to leach recovery; where the cost of acid consumption is greater than the value of the copper recovered. From this analysis selection of residence times for agitation leaching can be determined. The modelling tools are useful in identifying optimum conditions for the leaching process.

The test results are limited in applicability to the plant design due to their significantly higher head grade.

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