Special Purpose Simulator for Improved Estimation of Day-to-Day CIL/CIP Recoveries

P S B Stewart[1]

1. MAusIMM, Minsight, 21 Gareth Avenue, Beaumaris Vic 3193.
   Email psb_stewart@yahoo.com

ABSTRACT

Sampling of CIL/CIP circuits is typically done by compositing samples of feed and tails over eight or twelve hour periods. As the residence time in the leaching tankage may be approximately 20 hours, the tails from any period being derived from material entering the circuit 20 hours earlier do not correspond to the head from the same sampling period. Moreover, mixing in the series of tanks in a circuit also modifies correspondence between input and output.

A special purpose simulator has therefore been developed to allow for the mixing and delay in the tankage and permit estimation of the head assays corresponding to any tailings sample. Thus more accurate assessment of the day-to-day recoveries of gold and silver follows.

The model, programmed in Excel, assumes that the tanks are perfect mixers. By inputting the sequential head grades and considering that no leaching has occurred, the head grade which corresponded to the tailings for each period could be estimated. Allowance is made for variations in feed rate over the sampling period by computing the average flow rate of slurry and thus the residence time of each increment of the tailings.

This simple model and its application have been found to be subject to some limitations, which are discussed in the paper, resulting in some unresolved variability in results. However for a typical circuit even the simple model was able to greatly improve consistency of recovery data with variations being approximately halved by eliminating much of the anomalous variation arising from the lack of correspondence between head and tail when changes in head grade are occurring. Therefore, this permits genuine variations in metallurgy to be identified with greater confidence and thus operational shortcomings can be identified and addressed more quickly.

INTRODUCTION

A large part of metallurgical control in any mineral processing facility consists of constant monitoring of the recovery of target metals. A genuine change in short term recovery can signal a previously unidentified problem or a significant variation in ore requiring a change in reagents or procedures. For long-term metallurgical accounting, recovery is calculated from actual metal produced and loss in tails.

A primary requirement is the collection of reliable samples of appropriate products. This is contingent on appropriate sampling frequency and good sampling points, sampling equipment and sampling technique. It is general practice to composite a series of sample increments on a shift or alternatively a twelve hour basis. For management purposes, recovery is generally assessed for each sampling period and then on a day to day basis. This is generally satisfactory for flotation plants where the residence time to tails is of the order of half an hour and to concentrate, even in a plant with a complicated cleaning circuit, generally less than two hours. However, in a leach plant where residence times may be of the order of 20 hours, the feed to the plant over a sampling period may bear little if any relation to the tailings over the same period.

The lack of connection between feed and tails for the same sampling period has little impact if the feed grade is reasonably steady since the calculation of recovery is sensitive principally to the tailings assay with head grade having only a secondary effect. However if the head grade varies significantly then a high tail arising from high grade feed may be associated with a subsequent low head suggesting a poor recovery. The reverse may also occur, giving rise to apparently big swings in recovery. When faced with an unusually low or high recovery, it is important to know to what extent it is an artefact and to what extent it is real.

When recovery is calculated on a daily basis this lack of correspondence between head and tail is somewhat ameliorated but a very significant distortion from true recovery may still exist, sufficiently to abrogate valid interpretation of the data.

This paper presents a method for improving the estimation of true recovery opening the way to a more confident interpretation of plant performance. Approximately ten months plant data has been analysed and the results tested for validity in a number of ways.

THE MODEL

Program

In order to estimate the head grade more truly corresponding to the tailings from any period, a simple Excel program was written simulating the mixing and delay in the leaching tanks. This is distinct from the model, presented at a previous conference, which focussed on the leaching and adsorption in the tanks (Stewart, 2004) and permitted a generic study of the CIP process.

The present program was initially developed for a seven tank system and later extended for a ten tank system. There is no difficulty in principle in accommodating any number of tanks. Time was discretised and in the embodiment discussed in this paper, 12 time steps of one hour were used corresponding to the interval for sample increments in the plant and a 12 hour sampling period (referred to as a 'period' unless indicated otherwise). Half-hour discretisation made no difference to the output for either seven or ten tank models. The average ore feed rate, the % solids in the feed and the head assay for the twelve hour sample period are the inputs to the program and it is assumed that these are constant during any period.

A dynamic model of the system was approximated with two cells in the Excel program for each tank at each time step. A simple mass balance is computed for each tank to obtain firstly the final assay in the tank and secondly the average assay of the output over the time interval. The inputs to the calculations are mean residence time in the tank, the time interval, the initial assay (the final assay in the tank from the preceding time interval) and the assay of the output from the preceding tank during the time interval. The average of the output grade from the final tank for the twelve time steps is then the head grade corresponding to the tailing for that period. Further detail is provided in the appendix.

The percentage leached may be calculated from the adjusted head and the tailings grade. The inclusion of the tailings solution assay permits the overall recovery to be calculated.

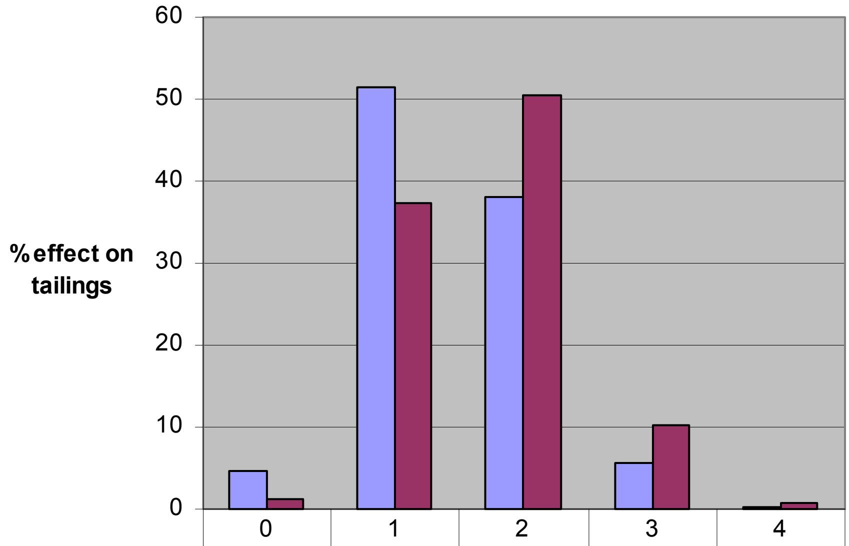
Assumptions

There are a number of assumptions implicit in the model. The assumption that the tanks are perfect mixers implies that all particle sizes and water in the slurry have the same mean residence time. This is most unlikely to be the case as the underlying principle of design of the mixing in the large tanks is to ensure that no settlement takes place, not uniformity throughout the tank. Apart from this the assumption would appear to be reasonable as the mixing turnover of slurry within a tank would be measured in minutes against a mean residence time of the order of two hours.

The assumption is made that the head grade and the residence time are constant during any sampling period. This is also most unlikely to be the case. It proved possible to evaluate the impact of these assumptions and this will be discussed later in this paper. The time step of one hour corresponded to the frequency of sampling and is logical on this basis. However use of a half hour time step made no significant difference to the computed data for the seven or ten tank configurations.

Model behaviour

The model may be used to explore the theoretical effect of the ore entering over various periods on the head corresponding to any tail. If ore with a set grade is fed to barren tanks in the model for one sampling period to be followed by barren feed, then the influence of the period on successive periods will be obtained. This is shown in Figure 1 for average conditions in both the seven tank and the ten tank configurations.



	0	1	2	3	4
Seven tanks 17.5 h average res. time	4.6	51.4	38.1	5.6	0.3
Ten tanks 20.6 h average res. time	1.3	37.3	50.6	10.2	0.6

Successive 12 hour periods

FIG 1: Theoretical influence of ore fed in a single period on tailings in successive periods.

As expected, there is very little influence on the tailings in the current period (Period 0) especially for ten tanks. The major impact is on the subsequent two periods with negligible effect by the fifth period. These data can be looked at the other way around, ie the tailings in any period being determined by the feed from the preceding periods in the shown percentages (eg for seven tanks 4.6% from current period, 51.4% from preceding period, etc).

The percentages are determined by both the number of tanks and the mean residence time. Varying flow rates and hence varying residence time preclude direct application of these weightings for standard day to day calculations. However as feed rates are incorporated in the model and these are input for each period it takes varying residence time fully into account.

DATA

Data sets have been studied from three distinct plant configurations:

- 369 sampling periods (approx six months) with seven tanks and no oxygen addition,
- 126 sampling periods (approx two months) with ten tanks and no oxygen addition, and
- 119 sampling periods (approx two months) with ten tanks and oxygen addition.

The broad characteristics of these data sets are summarised in following table.

Table 1: Data sets studied.

Set	A	B	C
No of tanks	7	10	10
Injected oxygen	No	No	Yes
No of sampling periods	369	126	119
Head grade (ppm) - average	4.98	3.63	3.08
- std deviation	2.96	1.38	1.07
% Gold leached - average	89.9	89.6	91.3
- std deviation	4.74	5.97	2.44
% Gold recovery - average	89.1	88.9	90.9
- std deviation	5.16	6.37	2.57
Mean residence time (h) - average	17.5	20.4	20.8
- std deviation	2.7	2.1	3.5

The increase in tankage from seven to ten has been exploited in part by an increase in feed rate (by approx 20%) and in part by an increase in mean residence time. The increase in residence time has permitted recovery to be maintained for Set B despite a significant drop in average head grade. The addition of oxygen significantly increased the gold leached despite a further drop in head grade.

Figure 2 shows a typical sequence of recovery calculated in the normal way by period, day and five-day average. The recovery data for the 12 hour sampling period is highly variable. As expected, the variation in the daily recovery is significantly less than the sampling period results. The heavy averaging in the five day data would seem to have hidden variations of real metallurgical interest. The standard deviation of the recovery for Set A thus progressively declined from 5.2 to 4.2 to 2.8% as the averaging period lengthened. This decline is less than would be expected if the data were independent from period to period.

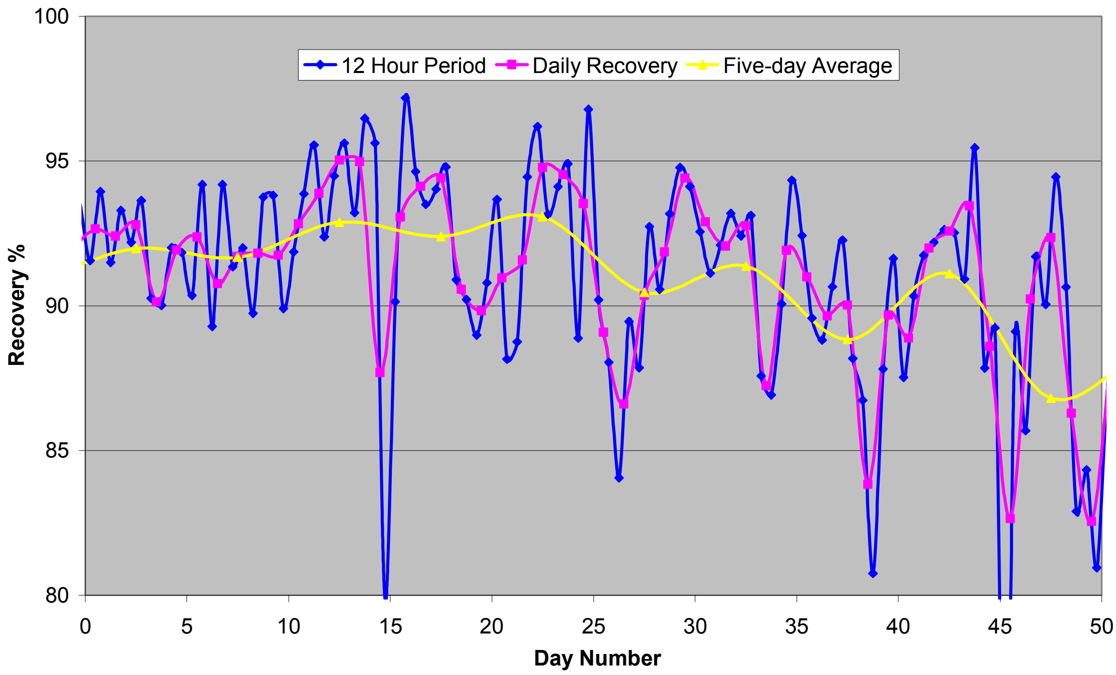


FIG 2: Recovery calculated in the normal way for typical 50 days – seven tank configuration.

DATA PROCESSING AND ANALYSIS

The tanks had a nominal active volume of 720 m^3. An arbitrary allowance of 5 m^3 was made for bubbles of injected air within the slurry and hence 715 m^3 was used as the tank volume in the calculations. Figure 3 shows the recoveries over the same 50 day period as Figure 2 using the head grade adjusted by the program. Figure 4 makes a direct comparison of the normally calculated sampling period recovery and that calculated from the adjusted data.

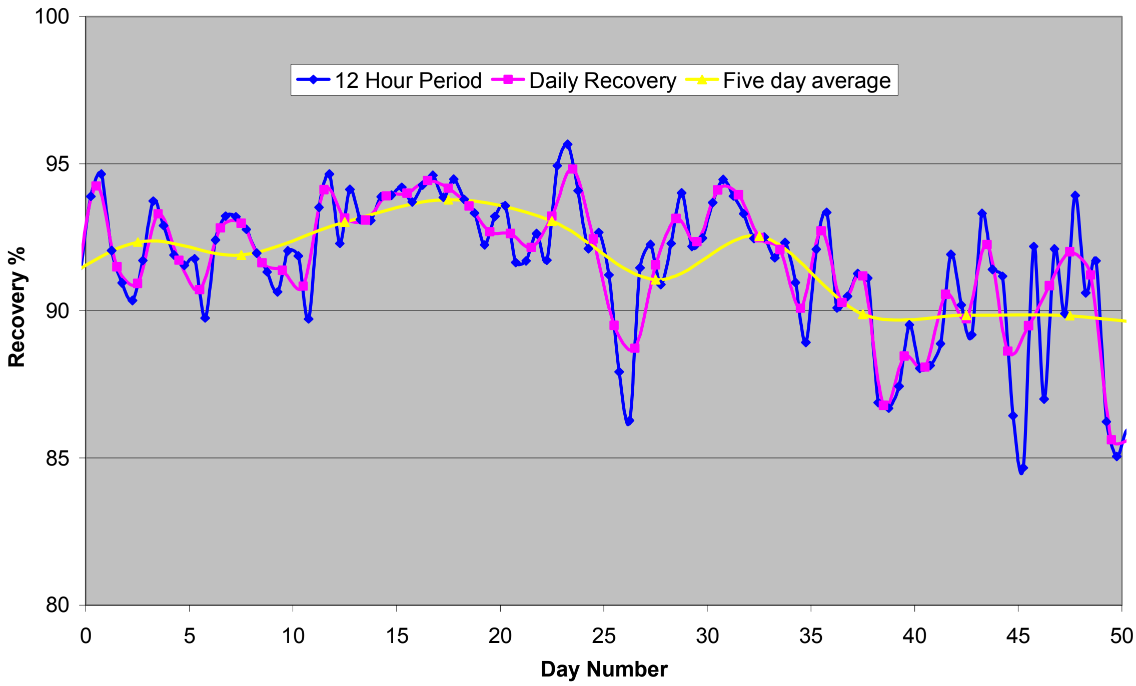


FIG 3: Recovery calculated using head grade adjusted for delay and mixing in the tanks.

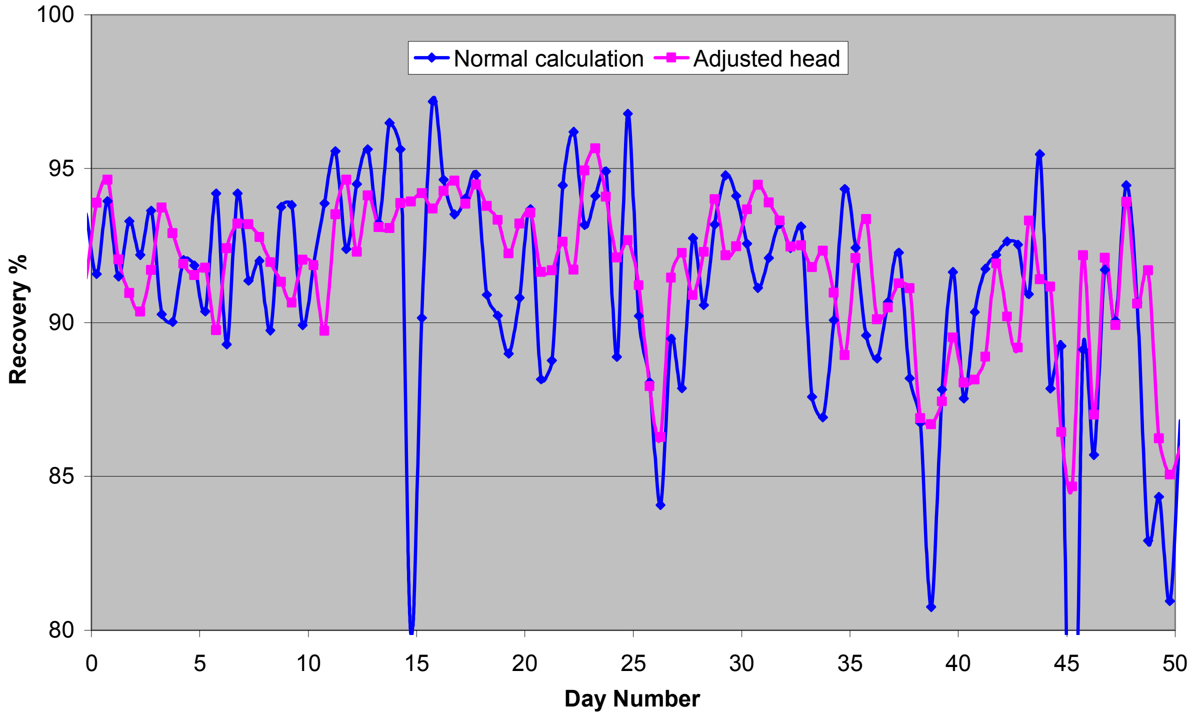


FIG 4: Comparison of recoveries for the 12 hour sampling periods calculated normally and those using a head grade adjusted for delay and mixing in the tanks.

For the adjusted data the daily results follow the period results closely, suggesting that the sampling period data is close to the 'true' result. Most of the large excursions have been avoided or greatly reduced and there has been a general reduction in variation throughout. Results for all data sets are summarised in Table 2. For Set A the standard deviations of the period, daily and five-day recoveries were 3.1, 2.9 and 2.2% respectively. The average difference for all data between normal and adjusted 12-hour period recoveries was 2.6% - 1.9% for daily.

Table 2: Per cent recovery and standard deviations for 12 hour period samples.

	Calculated Normally		Using Adjusted Head		Standard Deviation Ratio
	Average	Standard Deviation	Average	Standard Deviation	
Set A	89.1	5.17	89.8	3.11	0.60
Set B	88.9	6.37	90.2	1.94	0.30
Set C	90.9	2.57	91.2	2.00	0.73
Weighted mean	89.3	5.08	90.1	2.72	0.53

The respective standard deviations have all been very significantly reduced by the head grade adjustment. Although the deviation was approximately halved overall, there was still a significant amount of variation and it is of interest to examine the various possible sources.

Residual sources of variation

Solution loss

Variation in solution loss clearly adds to the overall variation. Table 3 shows the % leached which is unaffected by solution loss. Comparison with Table 2 shows that the average solution loss is 0.7% and its exclusion has reduced the variation for the adjusted head result by less than 0.2%.

Table 3: Percentage leached and standard deviations for 12 hour period samples.

	Calculated normally		Using adjusted head		Standard deviation ratio
	Average	Standard deviation	Average	Standard deviation	
Set A	89.9	4.74	90.6	2.91	0.61
Set B	89.6	5.97	90.8	1.81	0.30
Set C	91.3	2.44	91.6	1.93	0.79
Weighted mean	90.0	4.69	90.8	2.55	0.54

Head grade and mean residence time

It would be expected that head grade and mean residence time would have a major bearing on recovery. In order to explore this, the tailings assays were correlated with head grade and mean residence time for both the unmodified head and the adjusted results. This proved to be a major study and therefore these correlation studies are dealt with below as a separate topic.

Particle size

A study was made of the recovery from particles in narrow size ranges for leaching without oxygen addition. In order to obtain enough material for accurate assays and minimise short term variations, separate size fractions from daily sizings of plant head and tails were collected for a month. Each fraction was then blended and assayed and the recovery calculated size by size. The results are shown in Figure 5 for both gold and silver. As would be expected for both gold and silver there is a steady decline of recovery with increasing size due to mass transfer and liberation effects. Whilst the data for silver appear to be influenced by a nugget effect on assays in the coarse sizes the relative drop in recovery from fine to coarse would appear to be more severe than for gold.

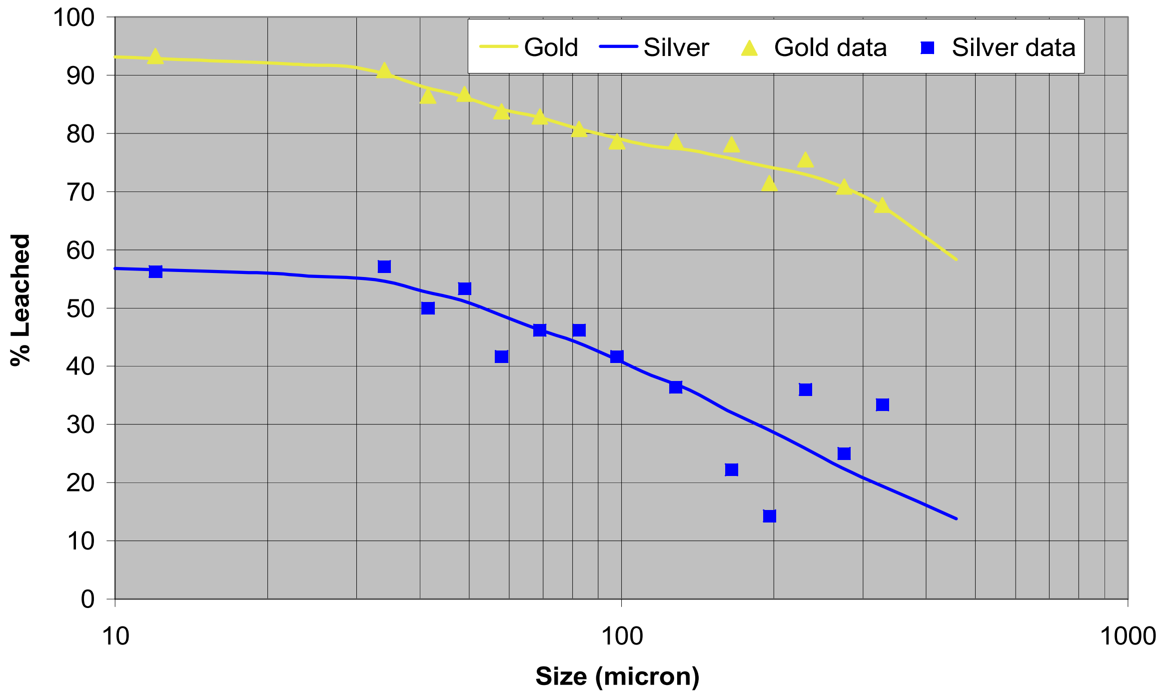


FIG 5: Size by size of recovery of gold and silver for a 30 day composite.

These relationships can be used to assess the effects of changes in size distribution on recovery. A ‘normal’ feed size distribution with D_{80} of 74 µm was derived from the regular sizings of plant products. A second distribution was formed by shifting the normal distribution one size coarser so that the D_{80} was 105 µm and the per cent passing 74 µm was 69.5%. On a conventional log-log plot this appears as a horizontal shift of the size curve as seen in Figure 6. This is typical of the way in which products from a closed grinding circuit change with variation in cyclone cut-point or hardness of the feed ore, provided clay content does not vary significantly.

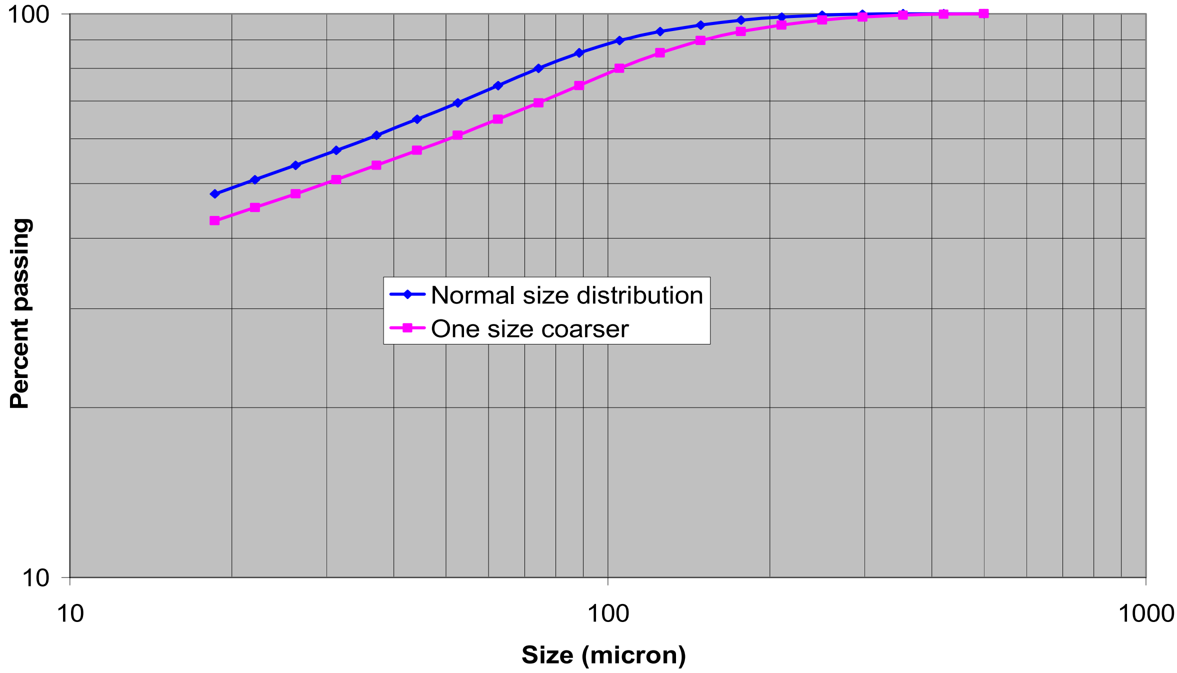


FIG 6: Typical size distributions of CIP feed.

The size distributions are compared in Figure 7 by grouping in three size ranges. It can be seen that the percentage in the 37 to 150 µm range is little changed whilst in coarsening the feed, the -37 µm fraction has fallen and the +150 µm increased by a corresponding amount – more than doubling the percentage in this latter size.

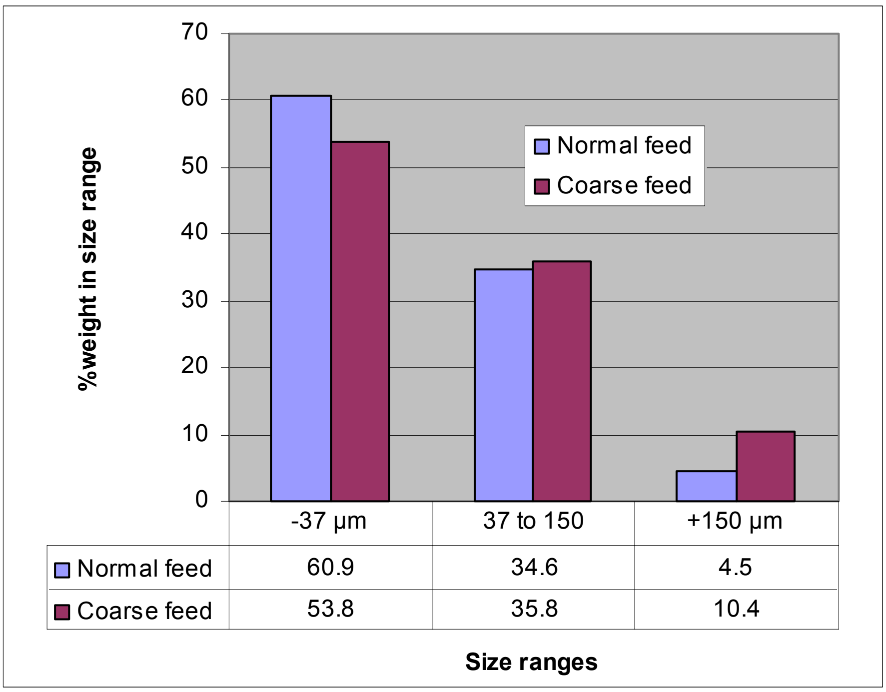


FIG 7: Per cent weight in three size ranges for normal and coarse feed.

The size by size recovery may be combined with the size distribution to obtain the overall recovery. The result of doing this for each of the test distributions is shown in Figure 8 where the loss in each of the size ranges relative to the total gold in the feed is shown.

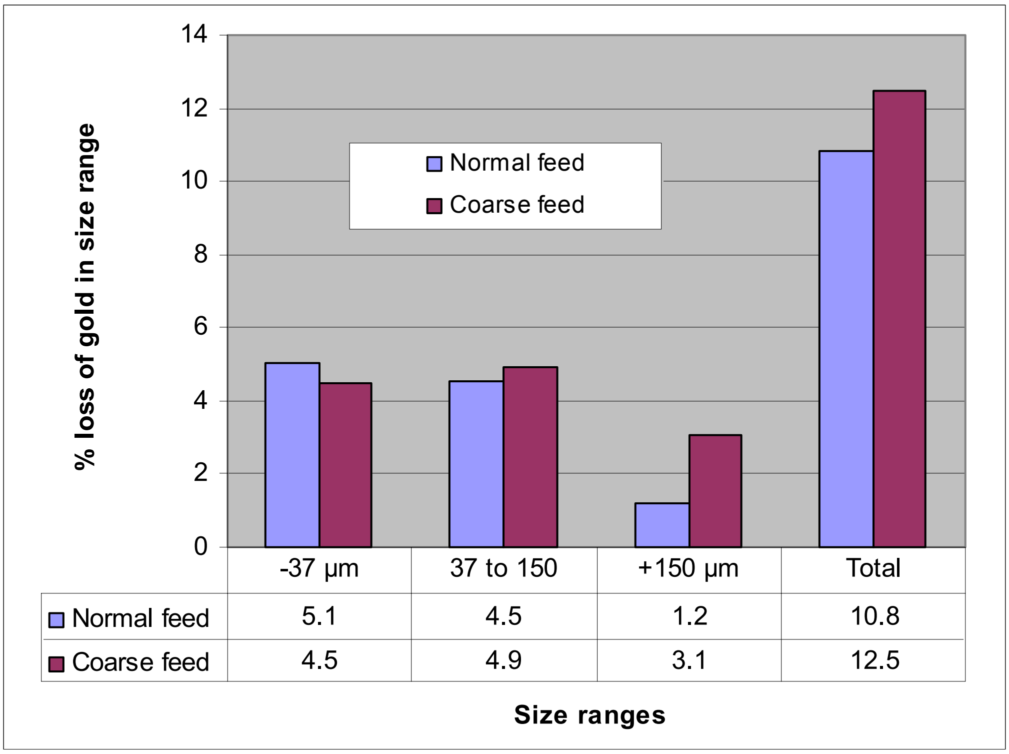


FIG 8: Loss of gold in the selected size ranges and in total for normal and coarse feed.

There has been a small drop in the loss in the -37 µm size due in the main to the smaller amount of material in that size. A small increase in loss in the 37 to 150 µm range results from a general shift in the bulk of the material in the range to coarser, less productive sizes. However the loss from the +150 µm material has more than doubled because of the large relative increase in the amount of material in this poorly leached size. The overall additional loss for the coarse shift was 1.7%.

The range of D_{80} from 74 to 105 µm encompassed about 80% of the size distributions produced in the plant (daily samples) over the study period. Assuming that the size distribution always has the same 'shape' and just moves to a different D_{80} the expected recovery may be calculated for any sizing using the size by size recoveries. It was found that recovery calculated in this way and D_{80} could be simply correlated. Using daily sizing data, this permitted an estimate to be made of the standard deviation in recovery due to size changes in the absence of any other influences. This was found to be 0.62% for the period when oxygen was not in use. This should be regarded as a minimum due to variations (albeit quite small) in the shape of the size distribution which would also have an effect.

There is a more subtle influence of particle size on apparent recovery after the delay and mixing correction has been applied. There is a strong possibility that the coarsest particles have a longer mean residence time in the tanks than the finest – which move with the water. (From a practical metallurgical point of view, this is a positive thing in that the more difficult to leach coarse particles have a longer exposure to leaching conditions.) Gold distribution in the feed was biased towards the finer sizes with 60 - 70% typically being finer than 37 µm and 88 - 95% finer than 150 µm. Even in the tails, with a bias towards coarser sizes due to lower recoveries from coarse particles (noted above), only 10 - 25% of the gold was coarser than 150 µm. The time response of the corrected recovery would therefore be dominated by the finer sizes. If coarse particles have a longer residence than the mean, then water and fine particles will have a shorter residence time than the mean and response may be faster than the mean residence time would suggest. This differentiation in size response could be responsible for some residual variation in recovery after head grade correction. It has not been possible to quantify this but it is likely to be small.

Model Limitations

In addition to perfect mixing the implications of which are discussed above, it is assumed that the feed to the circuit is steady both in flow and grade for each sampling period. This is quite clearly not true in practice. An artificial change in head grade during each period was applied in order to obtain an idea of how important this assumption might be.

Over the 12 hour sampling period for AM periods, the input head grade to the model was graded from about 20% more than the average head grade for the sampling period to 20% less. This meant that during any period the largest value was 1.5 times the least – a substantial but probably reasonably indicative variation – the average being unchanged. Thus if the average head grade for an AM period was 5 ppm, the inputs to successive hours were graded from six down to 4 ppm. A slope in the reverse direction was used in the following period and the slope was alternated in this way in successive periods. Hence for all AM periods a negative slope was used and for all PM periods a positive slope. This is illustrated in Figure 9. Applied to all periods, this was a fairly severe test.

The corrected heads and recoveries from this series of calculations were compared to the results of the original calculations for seven tanks. As would be expected the average values were unaltered. The standard deviations for both head grade and recovery were also not significantly different. The absolute difference between the constant feed and the graded feed results was calculated period by period. The average absolute difference in recovery for the paired data was 0.2%. When this comparison was done for daily recoveries the average absolute difference dropped to 0.08%. Thus for the seven tank system a small amount of the unresolved variation could be due to a failure to allow for head grade variations which have occurred within the sampling periods. The effect would be even smaller for the ten tank system with both more mixing and a longer mean residence time.

Other causes of residual variation

Remaining contributors to variation in leaching and recovery include process changes in such factors as cyanide concentrations, aeration and oxygen levels, pH, properties and management of active carbon, stirring efficiency, % solids and slurry viscosity. Ore changes directly affecting recovery would include change in the proportion of accessible gold, proportion and grade of slower-leaching electrum, the size of free gold particles or embedded gold grains and the presence of preg-robbing components in the ore. These factors have not been separately quantified in this study and in most cases specific investigations would be required to elucidate their influence. However, the correction for delay and mixing in the tanks makes it possible to work with plant data unobscured by the residence time effects.

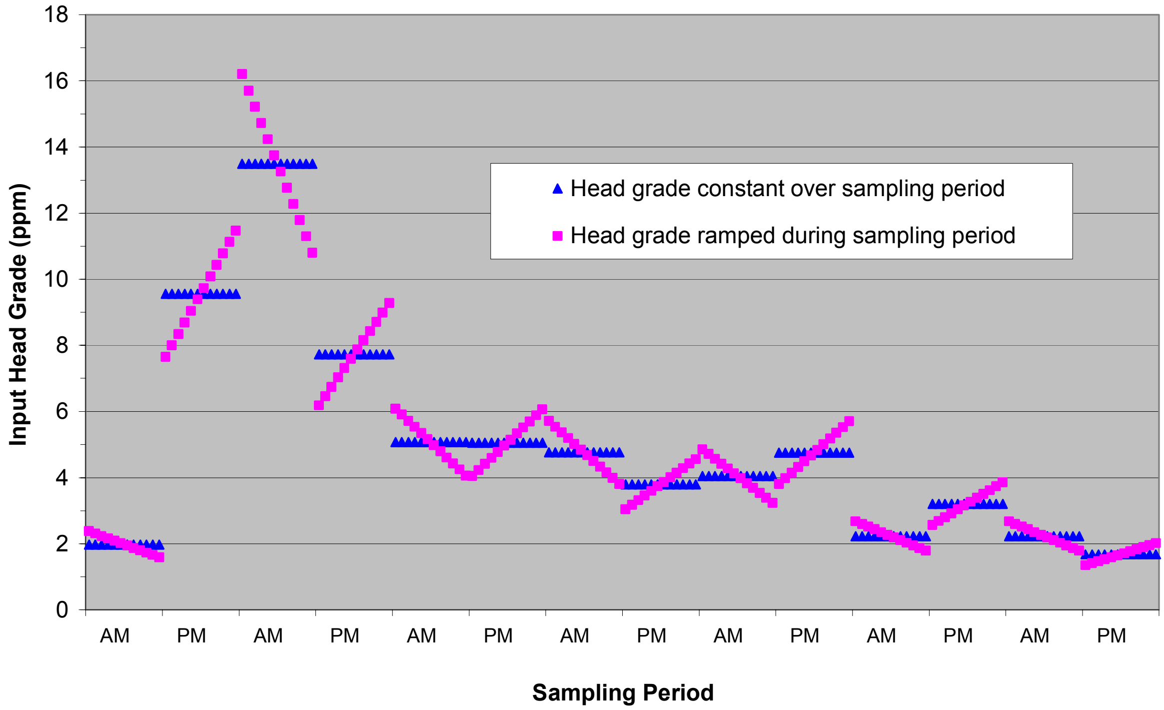


FIG 9: Illustrating ramping of input head grade within a sampling period to test the sensitivity of head grade adjustments to variation during a sampling period.

Correlation studies

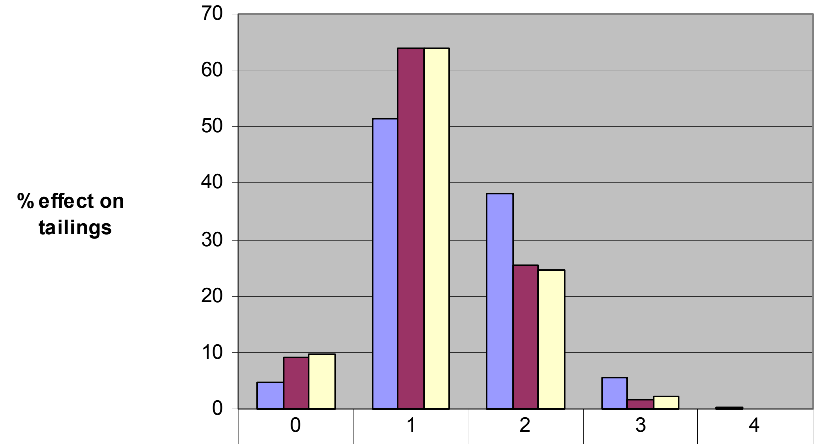
Unadjusted data

A simple correlation of the tailings with the head grade from the same period showed that the values were correlated with a coefficient (r) of 0.56 for the seven tank data (Set A). For the ten tank data the correlation coefficients were 0.25 and 0.41 (Set B and Set C respectively). The pooled correlation coefficient calculated from all sets was 0.48. All these correlations would be considered to be significant to highly significant. At first this high level of correlation seems surprising given the very limited theoretical correspondence between the tailings and the head grade from the same period (Figure 1). However the head grades in successive periods would not be expected to be independent of each other and when tested using all 614 observations a highly significant correlation ($r = 0.60$) was found between succeeding periods fully accounting for the simple direct head grade/tailings correlations as above.

In order to make a better evaluation of the influence of the feed in preceding periods on the tails in practice, tailings assays were correlated with the head grade for the current and the four previous periods. The residence times of the tailings were also included in the multiple correlations. For the correlation studies, the residence times of tailings were estimated using the mean flow rate for the period corresponding to the tailings plus the mean flow rates for a portion of the preceding period(s) corresponding to the balance of the residence time. A simple iterative calculation was required for this. Thus for a residence time of nineteen hours an average flow rate was calculated using that for the sampling period plus 7/12 of that for the preceding period.

There was a major increase in the correlation coefficient, the pooled value being 0.77 compared to 0.48 for the simple correlations above. For all data sets, the regression coefficients for the residence time and head grades for the same period as the tailings were of doubtful significance. The regression coefficients for the head grade in the two prior periods were highly significant statistically in all cases. However all head grade coefficients were informative, indicating the extent to which the feed in each period contributed to the final tail. This is shown in Figures 10 and 11 where the percentage effect on tailings obtained from the regression coefficients is compared to the theoretical values computed using the numerical model for two different tank volumes separately for the seven and ten tanks. As in Figure 1 the same period as the tailings is designated Period 0.

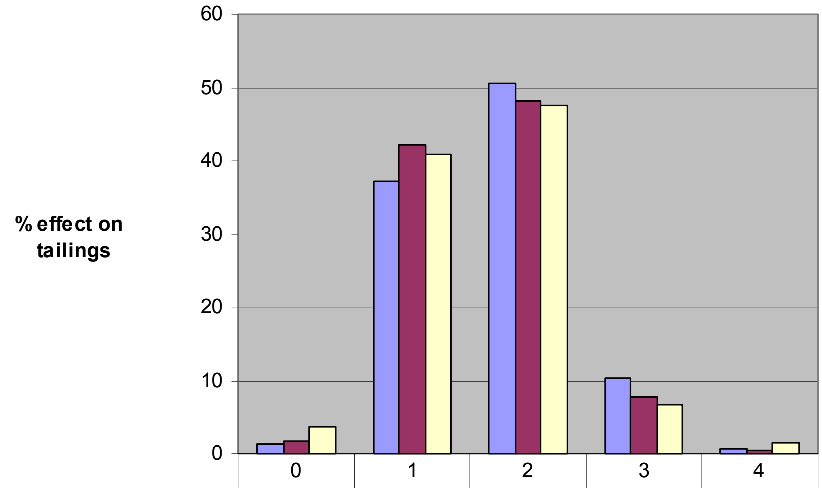
It can be seen that in both cases about 88% of the influence comes from Periods 1 and 2 confirming the initial premise of the need for adjustment to obtain meaningful period or daily recoveries. The data also indicates that the system has responded as if the tanks were smaller than actual size, this effect being more pronounced for the seven tank data where the average feed rate was approximately 20% lower.



	0	1	2	3	4
From model vol. 715 m3	4.6	51.4	38.1	5.6	0.3
From model vol. 586 m3	9.2	63.9	25.4	1.5	0.0
Actual (from correlation)	9.6	63.8	24.5	2.1	0.0

Prior 12 hour periods

FIG 10: Effect on tailings of the feed from prior periods for seven tanks.



	0	1	2	3	4
From model vol. 715 m3	1.3	37.3	50.6	10.2	0.6
From model vol. 678 m3	1.7	42.2	48.1	7.7	0.3
Actual (from correlation)	3.6	40.9	47.5	6.7	1.5

Prior 12 hour periods

FIG 11: Effect on tailings of the feed from prior periods for ten tanks.

Adjusted data

Multiple correlations of the tailings for each data set were done with the mean residence time, adjusted head grade and adjusted head grades for up to four preceding periods and the following period (this latter to check for over-correction).

A significant correlation for residence time was obtained for both Set A and Set B. For Set C, with oxygen addition and ten tanks, most of the available gold was leached rapidly in the first six or seven tanks and leaching rates were very low over the last few tanks. Recoveries were therefore little affected by the range of residence time covered in the data consequently the coefficient for residence time was low and not statistically significant.

For all data sets only the adjusted head grade corresponding directly to the tailing was significantly correlated with the tailings grade. The adjusted head grade from no other period either preceding or following had a significant regression coefficient showing that the adjustment for delay and mixing had been broadly effective.

As there was some evidence that the system may be responding as if the tanks were smaller than their actual size, the effect of the tank volume used in the calculation on the adjustment was investigated. Adjusted head grades and thus adjusted recoveries were calculated using volumes from 586 to 750 m^3.

A series of correlations of the tailings grade were done using the mean residence time and adjusted head grades as independent variables. An indicator of the efficacy of the adjustment was developed which depended on maximising the correlation coefficient and minimising the relative error of the head grade regression coefficient, the standard error of the correlation and the residual standard deviation of the adjusted recovery. The data for ten tanks was pooled. Figures 12 and 13 show the results. In both cases the assumed volume which gives the most effective head grade adjustment is less than the true tank volume, in good agreement with the indications from the statistical analysis of the unmodified data above. The implication is that different particle sizes do indeed have different residence times and that this effect is reduced as flow rates are increased.

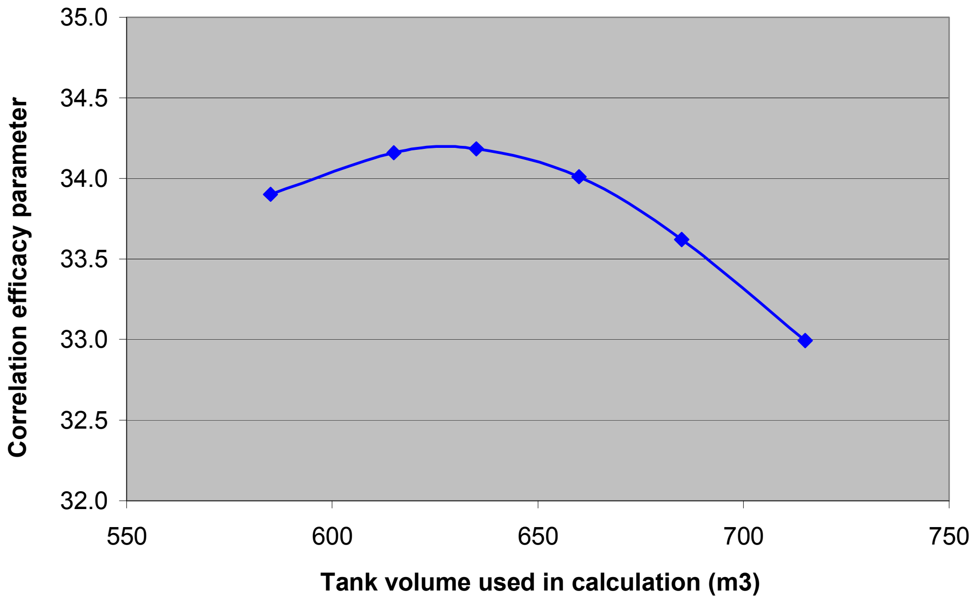


FIG 12: Seven tanks – optimisation of assumed tank volume.

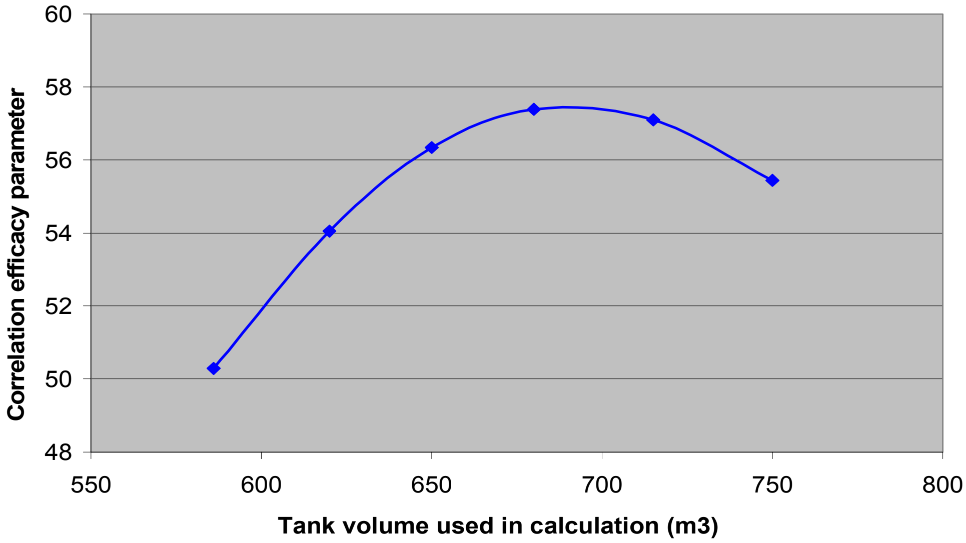


FIG 13: Ten tanks – optimisation of assumed tank volume.

This also showed that the correction to head grade was insensitive to assumed tank volume so that the effect of the assumed volume on the adjusted recovery was relatively small. For seven tanks the mean absolute difference between the recovery period by period for 715 m^3 and 635 m^3 (corresponding to the maximum in Figure 12) was 0.25% and for ten tanks for 715 m^3 versus 680 m^3 it was 0.12%. Thus, in practice, using the actual tank volume in adjustment calculations should generally be satisfactory.

An examination of the correlations for the two most diverse conditions is of interest. For seven tanks without oxygen and an assumed tank volume of 635 m^3 the relationship between tailings and head grade was:

$$T_{7,635} = 0.18 - 0.0041 * t_{res} + 0.068 * H_7 \quad (1)$$

The effect of residence time on tailings in this equation is less than would be expected. Whilst there are more appropriate mathematical expressions to represent the effect of residence time on extraction, a linear relationship should be a reasonable approximation over a small range of residence time. For these data (Set A) the standard deviation of the residence time was about 15% of the average. A direct study of residence time by 'down the bank' surveys showed that over a range of ± two standard deviations in residence time the linear approximation was good and that a linear regression coefficient of at least 0.014 would be likely. However this is very different to the observed regression coefficient of 0.0041. The reason for this discrepancy is not clear.

For ten tanks with oxygen and an assumed tank volume of 680 m^3, no statistically significant effect of residence time was identified and the relationship was:

$$T_{10,680} = 0.11 + 0.044 * H_{10} \quad (2)$$

Relationships between head grade and recovery may be calculated from these equations, inserting the average residence time of 17.5 hours for t_{res} in Equation 1. Recoveries as a function of head grade are shown in Figure 14. As these relationships are based on statistical analysis of data covering a range of ore types they should be regarded as indicative only.

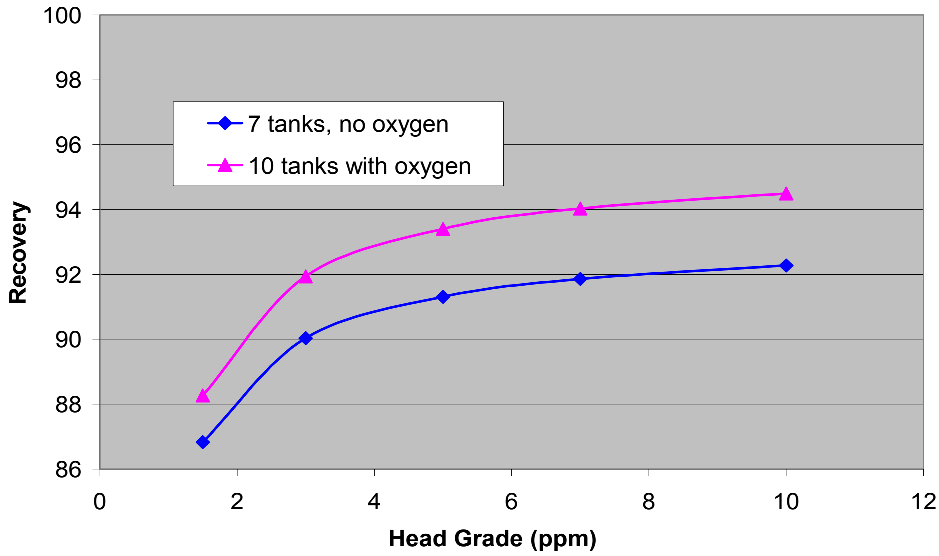


FIG 14: Indicated influence of head grade on recovery derived from statistical correlations.

CONCLUSIONS

The simple Excel program simulating delay and mixing in the CIL/CIP tanks proved to be very successful in calculating an adjusted head grade to obtain a more meaningful estimate of recovery sampling period to sampling period and day to day. The standard deviation of period recovery over the complete data set was approximately halved. The correction was robust, smoothing out minor variability in head assays and being insensitive to small errors in flow rates, tank volume or % solids.

The validity of the adjustment was confirmed by statistical examination of the data both before and after adjustment. Theoretical and data based studies showed that for both the seven and ten tank systems, tailings were principally influenced by the preceding two periods of feed. Any significant relationship between head and tails from the same period was because the feed in any period was generally related in part to the feed in the preceding period. The adjustment was of particular value when head grade variations period to period were large. For the data considered, it was also found that the speed of response corresponded to a smaller tank size than actual and this size appeared to be a function of flow rate and originate from size segregation effects in the tanks. However the recovery adjustment was insensitive to assumed tank volume.

The influence of model assumptions, size distribution, residence time and head grade on residual variations in recovery were examined and found to be relatively minor over the range of data considered. A good assessment of recovery was thus possible free of the distortions or uncertainties caused by delay and mixing in the tanks, permitting more direct and accurate appraisal or investigation of other factors affecting recovery related to ore or process. Using the adjustment procedure, genuine variations in metallurgy can be identified with greater confidence and any shortcomings addressed with certainty more quickly.

ACKNOWLEDGEMENT

The author gratefully acknowledges the permission of the Chatree Gold Mine, Thailand to use 2002/3 data from their plant. Products which had been sampled by plant personnel under the instruction and supervision of process engineers were assayed on site. The level of

analysis the data have been able to support is testimony to the care and skill exercised by mine staff in the whole process of data collection.

REFERENCE

Stewart, P S B, 2004, Insights from Simulation of a CIL/CIP Circuit, in *Metallurgical Plant Design and Operating Strategies 2004,* pp 437 - 456 (The Australasian Institute of Mining and Metallurgy: Melbourne).

APPENDIX

Symbols have the meaning shown in Figure A1 and the nomenclature table below. The computational arrangement is shown in Figure A2. Calculation is arranged as a matrix comprising, for one sample period, the appropriate number of tanks (in this work seven or ten) and number of time steps (here 12 steps of one hour).

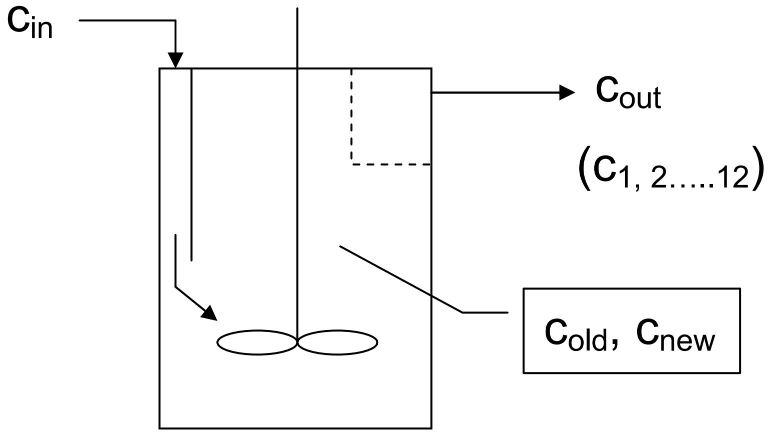


FIG A1: Representation of a fully mixed tank.

C_{in}	Assay of ore entering tank over the time step, assumed constant
C_{out}	Average assay of exiting ore over the time step
$C_{1,\,2.....12}$	Output of final tank for successive time steps
C_{old}	Assay of tank contents at start of time step, assumed uniform
C_{new}	Assay of tank contents at end of time step, assumed uniform
τ	Mean residence time in tank (calculated from input feed rate, tank volume and % solids in feed)
S	Time step in computation (eg one hour as here)

Assuming that the contents are fully mixed, a mass balance around a single tank gives the following relationships.

$$C_{new} = \left(C_{old} - C_{in}\right) * e^{-\left(S/\tau\right)} + C_{in}$$

$$C_{out} = \frac{\left[\left(C_{in} - C_{old} \right) * e^{-\left(S/_{\tau} \right)} - \left(C_{in} - C_{old} \right) \right]}{S/_{\tau}} + C_{in}$$

C_{out} becomes the input C_{in} for the calculations for the next tank in the series.

C_{new} becomes the input C_{old} for calculations for the same tank in the subsequent time step.

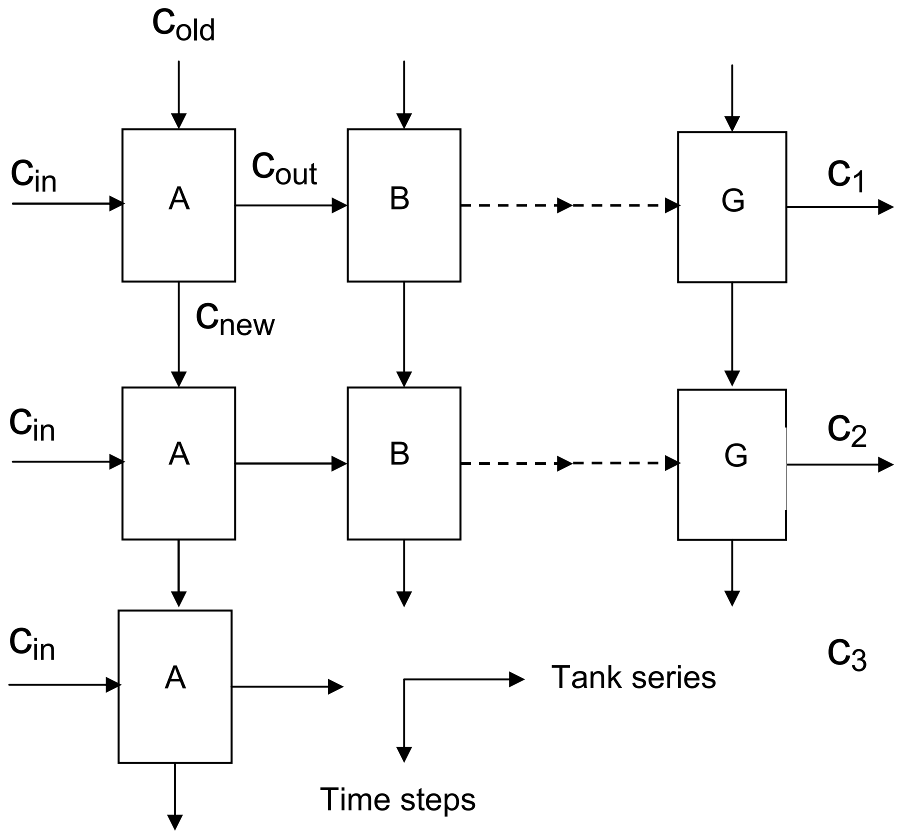


FIG A2: Computational arrangement for calculation of adjusted head grade.

The average of outputs C_1 to C_{12} from the final tank, corresponding to the 12 time steps, is the head grade corresponding to the tailings for that period.

In the current form of the program, seven days have been set up in series to accommodate a full week. An identical second worksheet accommodates a second week. The two worksheets are used in a flip/flop manner. The concluding state of the tanks at the end of one week is copied to the second sheet to provide the inputs to the start of the following week. The data from the first week is preserved until the end of the second week in case any assay corrections are required. At the end of the second week concluding data is copied back to the first sheet as input data for the third week and so on. Daily input data comprises the ore feed rate, % solids and head assay for each sampling period. Any tank volume may be set. Outputs are presented for seven and ten tanks but only small adjustments are required to provide output for any number of tanks up to ten.