BARRIERS TO BEST PRACTICE: VARIABILITY IN MEASUREMENT PRACTICES ACROSS THE GOLD PROCESSING INDUSTRY

By

G. Zwolak and P. Leckie

Orica Ltd, Australia

Presenter and Corresponding Author

Greg Zwolak
greg.zwolak@orica.com

ABSTRACT

The global gold industry loses an estimated $2-5B of theoretically recoverable gold each year, with a significant portion of the losses caused by variable (and unmeasured) process performance. Gold mines collect a large amount of measurement data in an effort to improve control and reduce avoidable losses, however: the amount, frequency, and analysis techniques can vary to a large degree. The result of this is avoidable gold losses: as the information used to make optimisation decisions may be compromised, and comparative analysis (i.e. performance benchmarking) requires adjustment of results for measurement method. Although the different techniques can be sometimes justified due to individual nature of challenges facing various operations, most of the time the variations are due to personal preferences of the technical personnel.

This paper reflects on observations from >50 sites as visited or examined by Orica's Cyanide Customer Solutions Team over the period 2014-present, with focus on the following areas:

- Typical range and profile of gold losses from CIL/CIP processing
- Common practices and shortcomings
- Recommended measurement regimes and standardised procedures, with particular focus on measurements that encourage action on gold loss reduction (*leachable gold in tails, carbon activity*)
- Experiences in benchmarking and process modelling in this environment, and possible future approaches

Keywords: gold processing, gold leaching data analysis, process performance evaluation, process benchmarking, process modelling, process data analysis, data collection best practice

INTRODUCTION

In 2014, Orica begun a concerted effort to use data to define 'best practice' gold processing, specifically as relating to cyanide leach systems. Firstly assembling top-down information from published recoveries and our internal intelligence, we estimated the scale of global gold losses to be in the order of $US16-20B at a gold price of $US1200/oz. Based on observed experience at the time, we estimated the scale of 'avoidable losses' (defined as solution losses plus gold leachable in a 24 hour bottle roll on process plant tailings) to be in the range of $US2–5B globally.

Over the period 2014-present, our Cyanide Customer Solutions team have visited and/or analysed operational data from >50 sites globally to validate the estimates above, determine the drivers behind the losses, and develop tools to accelerate our customers' capture of these losses.

During implementation of this program, we encountered a vast number of measurement and data collection practices: both from the perspective of the measurements obtained to drive optimisation decisions, and the methods employed to perform said measurements. It is our view that best practice is not achievable without a well-chosen and well performed selection of process measurements; this paper explores the variabilities found, suggests standardised routines, and explores the barriers to defining and achieving best practice created by variability in measurement practice.

GOLD LOSSES FROM CIL/CIP CIRCUITS: RANGE & PROFILE

Our characterisation and benchmarking of gold losses from operational sites (known as a *Process Health Check* service) considers the following factors:

- Absolute value of losses, particularly solution losses and leachable losses (gold leached from a shift composite of CIL/CIP tails in a 24hr bottle roll with added NaCN).
- Variability in losses in periods of relative stability, and frequency of upsets that result in higher losses
- Categorisation into one of 4 segments relating to Leach Complexity and Adsorption Complexity: allowing meaningful performance comparison with peers in the industry

Data collected during delivery of this service was combined with other internal information and a preliminary analysis conducted for the purpose of testing our top-down global gold loss estimate ($US16-20B total, of which $US2-5B is avoidable at a gold price of $US1200/oz: see *introduction*); with the following headline findings:

- Tailings losses from CIL/CIP plants on average were ~$US20M per site, comprised of:
    - ~$US2M of solution losses
    - ~$5M of leachable losses
    - The remainder as inaccessible gold
- Extrapolated out to our known makeup of the global industry, this equates to:
    - $US12B of total gold losses per annum (not including losses associated with Heap Leach operations)
    - $US4B of avoidable losses per annum

Further analysis, expanding our site database, normalising for throughput and applying the findings across Orica's industry profile is planned but was not completed in time for submission of this paper.

THE CASE FOR CHANGE

We believe that standardising measurement routines across the industry is 'worth its weight in gold' for the following reasons:

- The ability to make decisions regarding reduction of avoidable losses is only as good as the ability to measure and characterise them.

- Whilst all processes are different, the intent is the same: maximising economic recovery of precious metals. Measurement practices should reflect this.
- Recovery is a poor metric of how well a site is performing, both individually and on a comparative (benchmarked) basis. Recovery as a percentage of 'liberated gold' is a better measure of individual process performance, and this measure benchmarked across the industry (and similar sites) is the best way to set performance and optimisation goals: this is not achievable without standardised measurement practices.
- The size of the prize for getting this right is in the millions at site level, and in the billions across the industry!

COMMON MEASUREMENT PRACTICES & OBSERVED SHORTCOMINGS

This section of the paper explores our observations relating to common measurement practices, and observed inconsistencies, variability, and shortcomings.

Actual Gold Lost to Tails

Probably the most significant results of THE gold plant's laboratory are gold on solids and gold in solution in the plant tailings. One of the frequent inconsistencies we noticed, probably related to sample preservation, rather than sampling or analysis, were differences between averages of spot samples vs composite samples. The differences on some sites are significant – in one example composite sampling suggested that 0.02 ppm of gold was lost to tails, while spot samples averaged 0.06 ppm of gold in the same stream. Although frequencies of these two sampling regimes differed somewhat, we would expect long time averages to be very close. We suspect that these differences are related to reagents used to stop leaching in the composite samples, e.g. ferrous sulphate, and/or time delay between sampling and analysis (spot samples were usually filtered immediately and taken to the lab, while composite samples can spend some time on the tanks). These differences should be investigated, as depending on which samples are treated as more accurate, they can hide significant and avoidable gold losses.

Dissolved Oxygen

Understood to be a critical reagent in gold leaching, on par with cyanide, as originally reported by Elsner in 1846(5,10), and usually the rate-limiting reagent in gold leaching(3). However to our surprise, there were some instances, when its measurement was not performed or performed very rarely. Subsequent ad-hoc measurements revealed that DO in these processes can be quite variable to the point, where it can impact on precious metal recoveries. Also, DO variability is rarely analysed, rather explained as ore related or equipment related, without proper investigation. And, a factor which is very relevant for Australian operations, correction for salinity is not usually accounted for – this factor alone can lead to lower than expected gold recovery and also, unnecessary overdosing of cyanide and increased detox costs.(7)

One other related measurement – ore oxygen uptake test, is rarely utilized outside of the design stage. Periodic checks could lead to optimization of the blend with respect to resulting dissolved oxygen concentration. (6)

Cyanide Concentration and Consumption

Although implementation of automated sampling and dosing (and reliability of associated measurement technologies) progressed in the last decade it is still inconsistently applied throughout the industry. This is despite obvious advantages of automation over manual sampling control (see Figure **1**) – from our own experiences on average it can provide about 20% savings in cyanide consumed (range of savings in Orica's case studies is 8-48%, with similar savings observed in cyanide detox reagents). Variability in cyanide consumption is not given too much attention - %S and %Cu (especially reactive S and reactive Cu) can have a great impact on cyanide and oxygen consumption(2) and subsequent recoveries, but they are rarely measured.

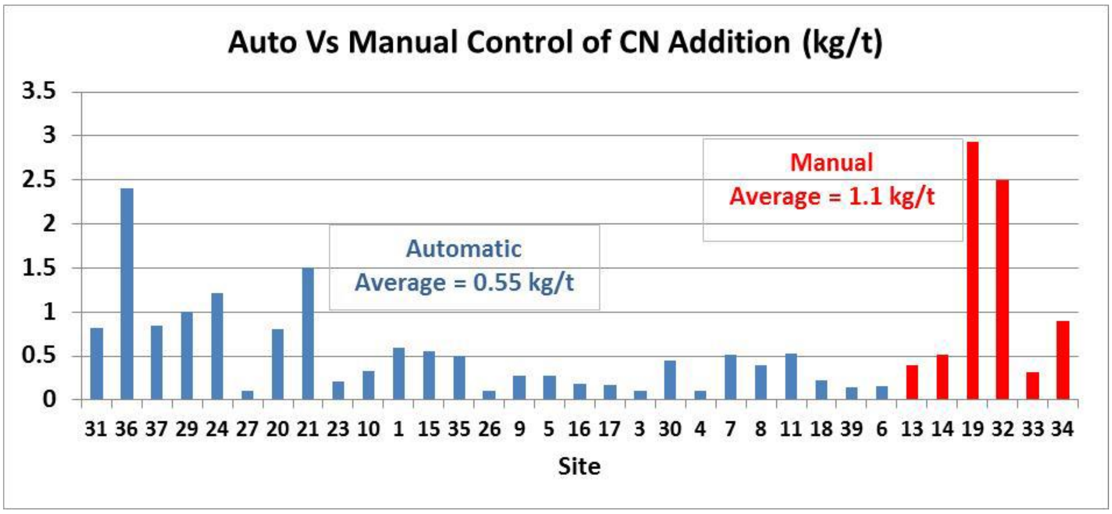

Figure 1: Sodium cyanide consumptions for manual and automatic cyanide monitoring[1]

Carbon Activity

We encountered various procedures to evaluate carbon activity, however most of them don't account for carbon particle size and specific density differences between fresh carbon and carbon at various stages of the carbon life cycle (loaded, acid washed, barren, regenerated). This is understandable, as accounting for these variables can be time consuming, however periodic check of the influence of these factors, coupled with simplified daily or weekly procedure, can provide more insight into better carbon management.

Another common mistake we encountered was in carbon activity calculation – gold adsorption is usually approximated as a linear process, when actually it is a first-order process with respect to disappearance of gold in solution[8]. This leads to misunderstanding in regard to relative activities of activated carbon, see Table 1 below for better understanding of this issue. A very simple correction to how the results are calculated (plot of $\ln([Au]_{soln})$ vs time[8]) leads to a procedure that is not only better in terms of relative results, but results are easily comparable to other sites.

Table 1: As can be seen from the table, because of the range of the results, carbon activities calculated using the on-site method could lead to wrong conclusions about average, maximum and minimum activities of plant activated carbon.

Carbon activity results	Carbon activity as calculated on-site (%)	Carbon activity as calc. using first-order plot (% of fresh carbon)
Average	97.4	53.0
Minimum	80.7	23.8
Maximum	99.9	100

Sizings and Size by Size Analyses

P80 is a very popular measure by which particle size is reported, however there were sites where full sizings (about 5 size fractions or more) results were not readily available. Periodic size by size analysis for gold and reactive minerals is another analysis rarely performed – it can give a great insight into liberation of the various species and how they are affected by grinding. [9]

Cyanide Speciation in the Tails

Frequency of this measurement differs significantly between sites, which is understandable because of its relative importance. However it is highly recommended to implement routine periodic checks, with additional checks during periods of unexplained process upsets, e.g. cyanide consumption increases or recovery decreases – it could lead to better understanding of the various competing reactions taking place, which could deliver more insights than more expensive ore elemental and mineralogy tests.

Residence Time

We are still to come across a measurement of the actual residence time in the tanks; by-passing and back-mixing are important factors, especially with ever-decreasing residence time due to increases in throughput(4) (other simple measurements like tank dipping can also assist). This is especially important, when evaluating process performance through batch tests, which can lead to overestimation of expected recoveries. This measurement can also be of assistance, when the flow is split between two trains of CIL tanks – unmeasured and uncontrolled split and differences in actual mean residence times can lead to unexpected differences in performance between the two trains. Other very simple measurement can also lead to improved troubleshooting, e.g. tank dips can assist in measuring actual volume of the tanks and also can lead to more timely maintenance of the agitators.

Bottle Rolls

This is probably one of the most important and simple measurements for a gold leaching process (and very important for our both tools). We encountered a few variations of this simple procedure, which leads to difficulties in performing a straight comparison in gold losses between sites (various starting concentrations for cyanide, or leachwell tablets used instead of cyanide – it probably leads to slightly higher recovery in some cases than can be expected with cyanide, and it makes assessment of the leach rate and probable nature of the unleached gold impossible). Some sites perform bottle rolls on the feed material, which can lead to confusing results because of different particle size distribution in the experiment vs. actual process - different grinding technologies and equipment can lead to different particle size distributions and hence, liberations(9), plus non-assessment of actual residence time distribution, and compare results to actual process performance. We think that bottle rolls performed on the tail samples with cyanide lead to better understanding of the nature of the unleached gold (modifications to the procedure, e.g. more frequent sample taking can lead to simple characterisation of the unleached gold – fast (due to by-passing or limited residence time) or slow leaching (gravity gold or slow-leaching electrum or tellurides).

These differences are however not great and comparisons can usually be performed. However we encountered errors related to interpretation of the results. As an example, on one site, two bottle rolls on the tail samples were performed, one with cyanide concentration as is, and one with added cyanide of ~500-1000ppm, which is ensuring that leaching is not cyanide-limited(5). The differences in gold recoveries were interpreted as insufficient cyanide at the front of the circuit. Subsequent analysis showed that gold losses were related mostly to insufficient dissolved oxygen concentration in the first tanks, and not cyanide. Even if the gold losses were determined to be a result of insufficient cyanide, one needs to be careful when interpreting bottle roll results, as dissolved oxygen levels can differ significantly between bottle roll experiments (where oxygen demand is largely satisfied) and actual DO at the front of the circuit.

Overall Data Analysis

Despite a significant effort and costs spent on data collection, data analysis on some sites is not performed to the extent possible. Point one on this list is a great example - a simple average of the two sets for gold in solution results shows a difference, which should result in an investigation to reveal which result is closer to reality (difference amounted to $M per annum) and how to improve the offending analysis. This is probably a result of many factors, including understaffing, inertia (analyses introduced by metallurgists no longer on site), and others.

CONCLUSION: PROPOSED MEASUREMENT REGIME FOR EFFECTIVE DECISION MAKING

We propose the following as a schedule of the measurements required for efficient and effective optimisation decision making on site:

Table 2: Proposed measurement regime

		Manual Tests, Frequency, Sample Type		
Test	**Automated**	**Daily / per shift**	**Weekly**	**Monthly**
Au, Cu, S Head Grade		Composite	Spot	Spot
Sizing		P80, Composite	Full, composite	
Au, Cu, S in Tails (solid)		Composite, spot	Spot	Spot
Au, Cu, S in Tails (solution)		Composite, spot	Spot	Spot
Leach tail Bottle Roll[1]		Spot		
Free CN	At dose point(s) and tails	Spot at dose point(s)	Each tank, spot test	
pH	First tank	Spot in first tank	Spot test, each tank	
DO	At dose point(s)	Spot at dose point(s)	Spot test, each tank	
WAD CN	At tailings	Spot test		
Pulp Density	At cyclone overflow **or**	Hourly spot test		
Gold Accounting[2]			Spot, each tank	
Carbon Activity[3]			Spot	
Carbon Concentration	Using Carbon Scout **or**	2 hourly, each tank		
Diagnostic tails leach				Composite

1. 24 hour test, no DO addition, one sample rolled as collected from process, one spiked to 500ppm CN. Solution assayed then solid grade back calculated.
2. Au on solids, in solution, on carbon.
3. Loaded, acid washed, eluted, barren, regenerated: activity rate (not % adsorbed) expressed as a % of fresh.

REFERENCES

1. AMIRA P420. (2013). AMIRA P420 Industry Survey 2013.

2. Bellec, S., Hodouin, D., Bazin, C., Khalesi, M. R., & Duchesne, C. (2009). Modelling and simulation of gold ore leaching, 51–60.

3. de Andrade Lima, L. R. P., & Hodouin, D. (2005a). A lumped kinetic model for gold ore cyanidation. Hydrometallurgy, 79(3–4), 121–137.

4. de Andrade Lima, L. R. P., & Hodouin, D. (2005b). Optimization of reactor volumes for gold cyanidation. Minerals Engineering, 18(7), 671–679.

5. Heath, A. R., & Rumball, J. A. (1998). OPTIMISING CYANIDE : OXYGEN RATIOS IN GOLD CIP / CIL CIRCUITS. Science, 11(11), 999–1010.

6. Kondos, P. D., Griffith, W. F., & Jara, J. O. (1996). The use of oxygen in gold cyanidation. Canadian Metallurgical Quarterly, 35(1), 39–45.

7. La Brooy, S. R., & Muir, D. M. (1994). Gold processing with saline water. AusIMM Proceedings, 299(2), 81–88.

8. Marsden, J. O., & House, C. I. (2006). The Chemistry of Gold Extraction (Second Edi). Society for Mining, Metallurgy, and Exploration, Inc.

9. Runge, K. C., Tabosa, E., & Jankovic, A. (2013). Particle size distribution effects that should be considered when performing flotation geometallurgical testing. The Second AUSIMM International Geometallurgy Conference, (October), 335–344.

10. Srithammavut, W., Luukkanen, S., Laari, A., Kankaanpää, T., & Turunen, I. (2011). KINETIC MODELLING OF GOLD LEACHING AND CYANIDE CONSUMPTION IN. Journal of University of Chemical Technology and Metallurgy, 46(2), 181–190.