# CIP/CIL Modelling

## Theory and Application

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WHEN YOU NEED TO BE SURE

# OUTLINE

- Introduction
- Background
- Opportunities and Value
- Methodology
- Inputs/Outputs
- Results (Case Studies)

# INTRODUCTION

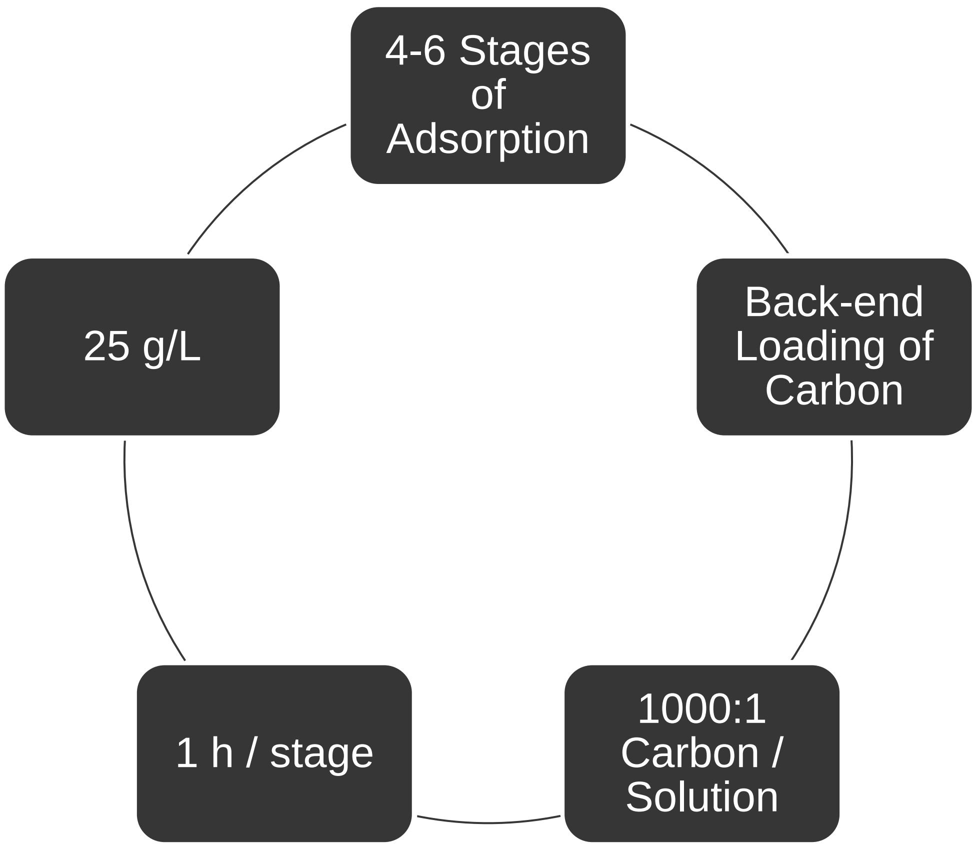
The SGS carbon-in-pulp (CIP) / carbon-in-leach (CIL) modelling packaged is used to:

- Estimate the performance of a full-scale CIP and CIL plant.
- Derive the optimum design criteria based on the results of small scale experiments.

Powerful design tool that uses results from standard leach and adsorption tests (bottle roll tests) to generate kinetic data that are fitted to leaching and carbon adsorption equations.

# BACKGROUND

- Early CIP plants were built using “rules of thumb” design criteria with minimal theoretical basis



# REALITY CHECK

- There is an economic optimum number of stages.
- Gold on carbon/gold in solution ratios of >1000:1 are achievable in many cases.
- The distribution of that carbon between the stages (within reason) is irrelevant.
- The concentration of carbon in the pulp varies with the size of the tanks, so it is irrelevant.
- Gold extraction efficiency is determined by:
  - The total amount of carbon in each stage in the plant.

# REALITY CHECK

- The processes in which gold cyanide is adsorbed on activated carbon are very robust mechanically and very efficient metallurgically.
  - Tolerant of plant upsets, changes in feed composition and “less-than-optimum” plant designs.
- Owners and operators often aren’t even aware that their plant design may be “less-than-optimum” because:
  - Gold extraction efficiency is usually good enough even under less than optimum conditions.
  - Economic payback is very good, even though capital costs, operating costs, and soluble losses may be higher than necessary.

# OPPORTUNITIES

## Existing Plants – Lower Opex and Losses

- Increase/decrease carbon concentration (g/L)
- Increase/decrease carbon advance rate (t/day)
- Better elution (< 50 g/t)  / regeneration (.90% of activity of fresh carbon  in every cycle)

## New Plants – Minimize Costs

- Optimize gold leaching and adsorption kinetics by optimizing pulp density
- Optimise Number and Size of  adsorption tanks
- Optimize carbon inventory
- Higher gold loadings (>1000:1) – minimizes elution and regen OPEX

# VALUE OF THE CIP/CIL MODEL

- Can replicate the performance of an existing plant and evaluate the consequences of making changes to the operating conditions in the commercial plant without actually making the changes.
- Can generate data for trade-off studies for a new plant, from which an economic optimum design can be derived.
- Can predict how a pilot plant will perform, and then use this information to set up the pilot plant operating conditions. Allows for rapid attainment of steady state, thereby shortening the duration of the pilot plant.

# SGS CARBON MODEL

*Based on the original Nicol-Fleming models. The overriding philosophy in developing the models was to strive for simplicity and user-friendliness, rather than precision through complexity.*

- The model assumes the rate of gold cyanide loading on carbon can be described by a single, semi-empirical rate equation.
- It assumes that equilibrium exists between gold in solution and on the carbon at the phase boundary, and can be described by a linear relationship.
- The model can be tested and verified using simple, inexpensive, small scale batch tests in the laboratory.

# CARBON MODEL METHODOLOGY

1
- Rheology testwork to optimize pulp density.

2
- Determine gold leaching kinetics ($k_s$).

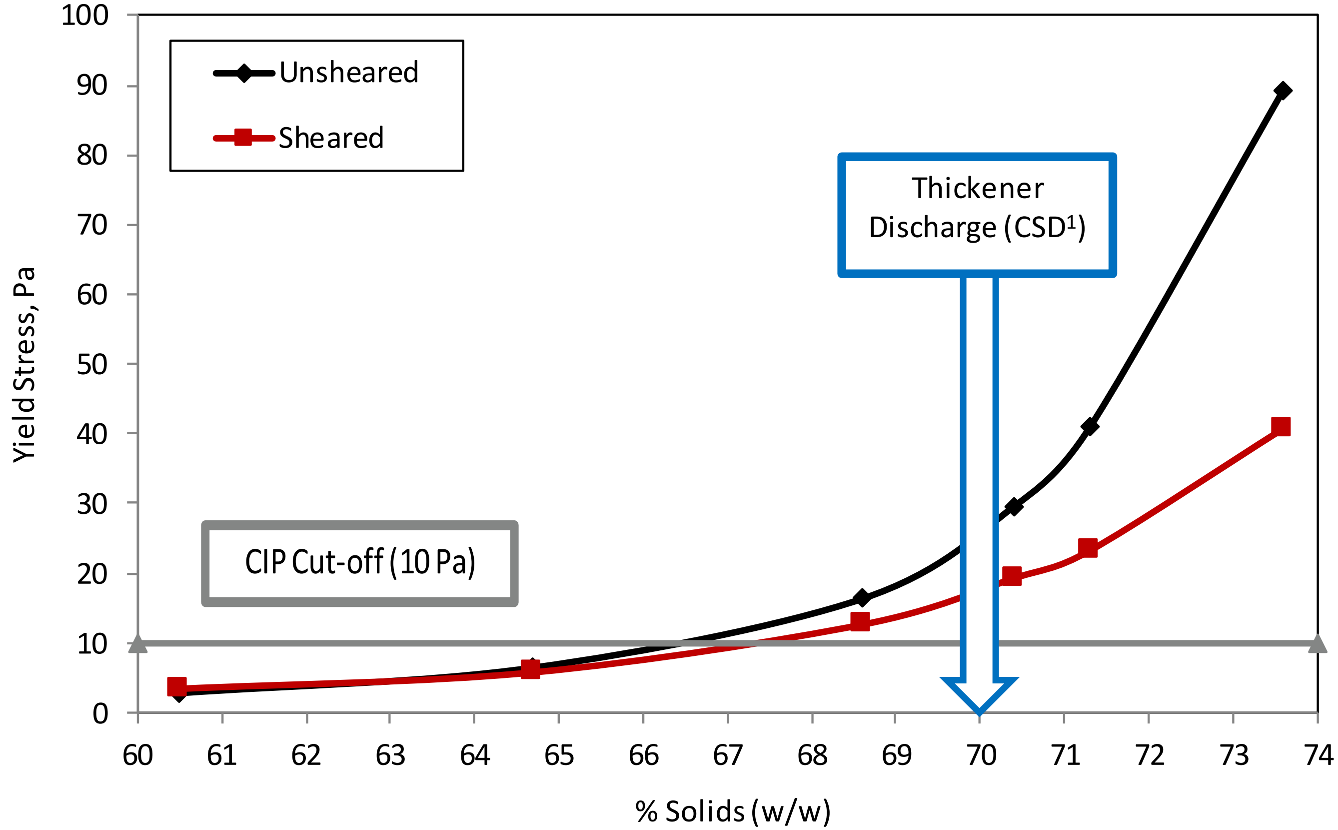
3
- Determine kinetics of gold adsorption on carbon (k and K).

4
- Model Data Fitting - Constants ($k_s$, k, K) entered into the rate and mass balance equations of the SGS model.

5
- Results - Gold concentration profiles and optimization based on metallurgical performance, plant design and operating scenarios.

# SLURRY RHEOLOGY TESTWORK

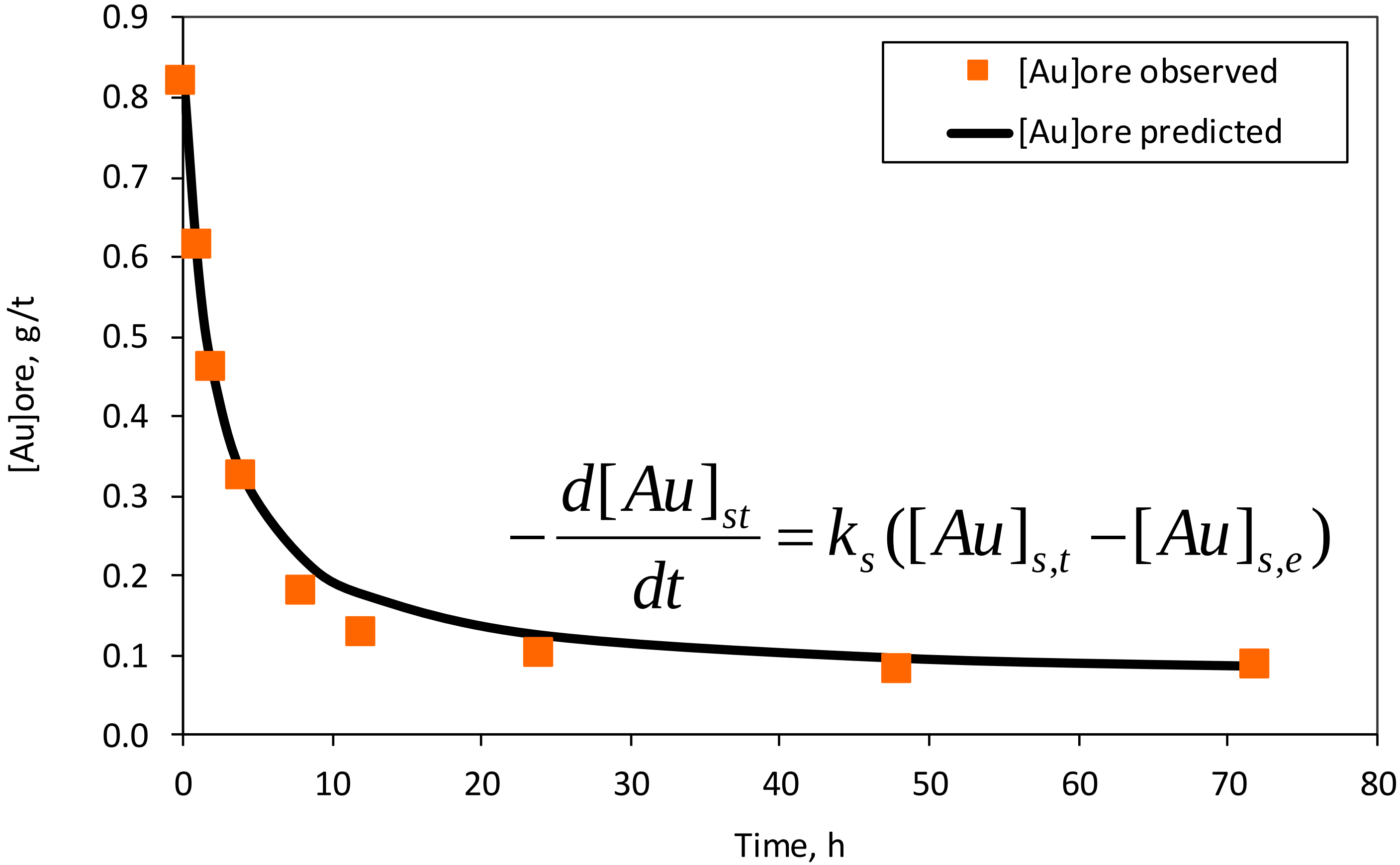
- Determine optimum pulp density for mass transfer and test the effect of pulp density on yield stress (thickener rake torque and pumping requirements)




[1] The Critical Solids Density (CSD) value is predictive of the maximum underflow solids density achievable in a commercial thickener and of the underflow solids density and pumpability ranges achievable in practice and with reasonable friction pressure losses for an economically feasible operation.

# LEACH KINETICS

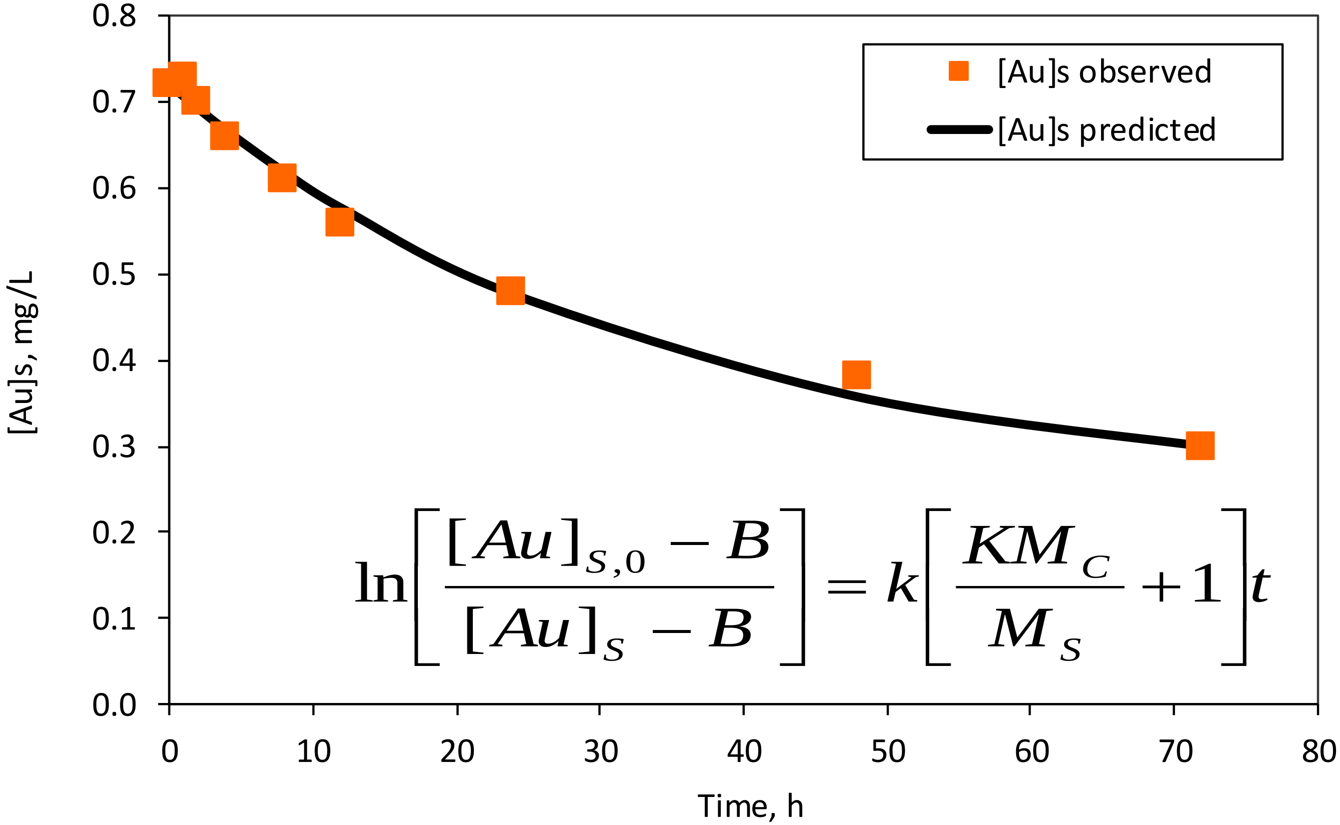
- Measure leach kinetics at selected pulp density in small scale batch test. Fit rate data to rate equation and generate constant, $k_s$.




$$-\frac{d[Au]_{st}}{dt} = k_s([Au]_{s,t} - [Au]_{s,e})$$

# ADSORPTION KINETICS

- Measure kinetics of gold cyanide adsorption on carbon at selected pulp density in small scale batch test. Fit adsorption data to adsorption equation and generate constants k and K.




$$\ln\left[\frac{[Au]_{S,0}-B}{[Au]_{S}-B}\right]=k\left[\frac{KM_{C}}{M_{S}}+1\right]t$$

# MODEL INPUTS / OUTPUTS

Leach and Adsorption Constants ($k_s$, k, K)

Number and Size of Adsorption Tanks

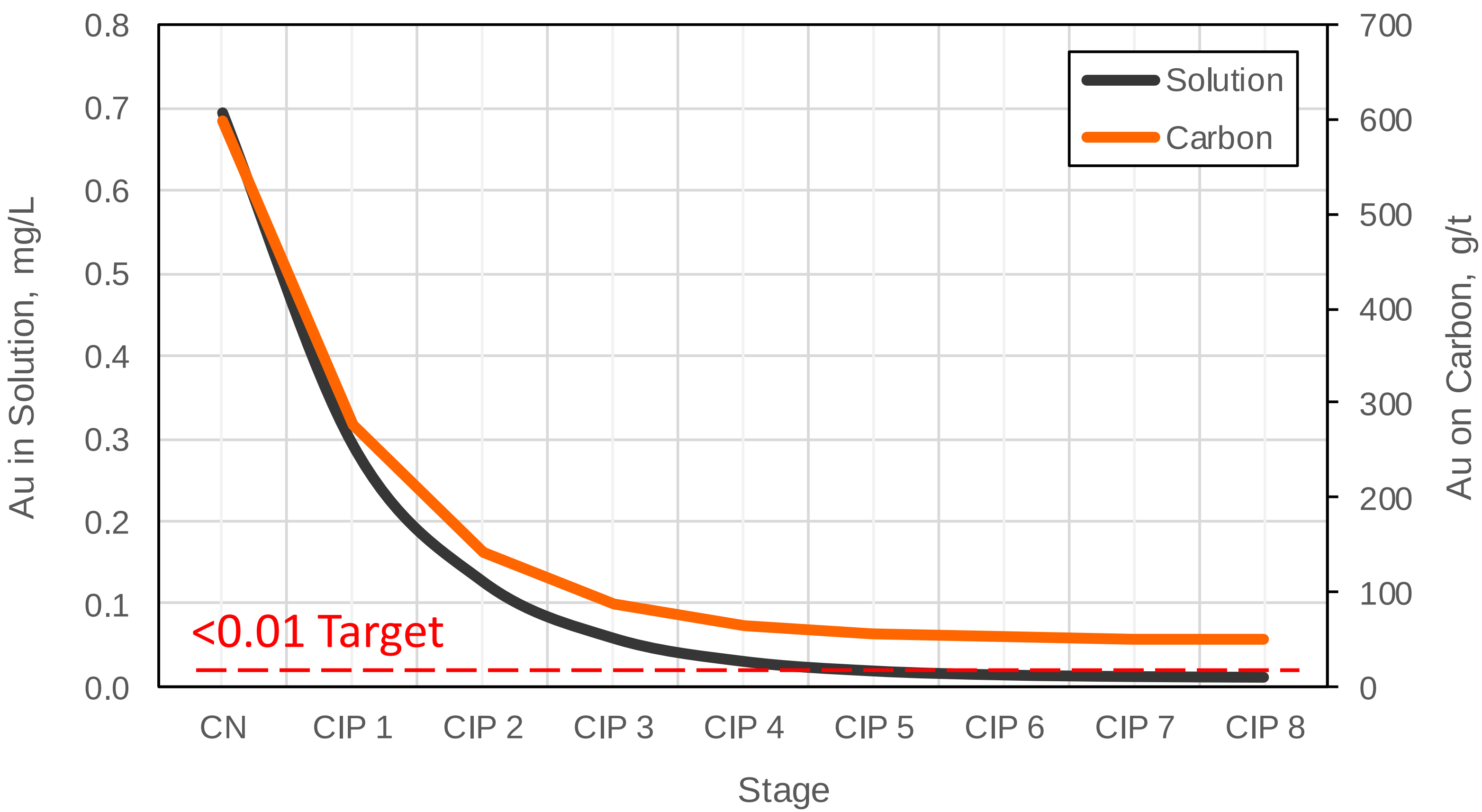
Tonnage, Density, Gold Head Grade

Target Gold Conc. on Loaded and Eluted Carbon, and Barrens

**SGS Model**

| |
|---|
| Concentration Profiles (gold in solution, in the ore, on the carbon) |
| Carbon Concentration (g/L) |
| Carbon Advance Rate to Elution / Regeneration |
| Gold Lock-up in the Plant |

# CIP OUTPUT PROFILE



# CASE STUDY #1 – CIP VS. CIL

- Russia – 100 t/h, gravity/leach plant, 50% solids, 0.82 g/t (after gravity), ~83% leach extraction after 24 hours, kK value of 52.

| | CIP | CIL |
|---|---|---|
| Circuit Configuration | 3 x 1080 $m^3$ (24h of CN)<br>8 x 120 $m^3$ (7h of CIP) | 6 x ~700 $m^3$ (31h total) |
| Carbon Concentration | 30 g/L | 15 g/L |
| Carbon Loading | 1142 g/t | 1130 g/t |
| Carbon Transfer | 1.5 t/day carbon transfer | |
| Carbon Inventory / Stage | 3.6 t | 10.1 t |
| Carbon Inventory (all) | 29 t | 61 t |
| Gold Lock-up on Carbon | 10 kg | 35 kg |
| Adsorption Efficiency | 98.2% | 93.6% |
| **Overall Gold Recovery** | **83.3%** | **80.8%** |
| **Barren Solution Losses** | **0.01 mg/L** | **0.03 mg/L** |

# CASE STUDY #2 – CIL CIRCUIT

- CIL Plant (Northern Ontario) treating combined flotation concentrate / tailing
  - 5 CIL (conc only) + **3 CIL (combined conc/tail)**
  - Gold in barren solution = 0.044 mg/L
- Testwork → Plant carbon (49 g/t) and multiple densities (50-65% solids)
- Modelling: variables examined → Increased carbon concentration, number of stages and carbon flowrate

| Parameter | OLD | NEW |
|---|---|---|
| Circuit Configuration | 3 x 2800 $m^3$ | 3 x 2800 $m^3$<br>2 x 800 $m^3$ |
| Daily Carbon Transfer | 5 t/day | 7.5 t/day |
| Carbon Concentration | 18 g/L | 18 g/L |
| Adsorption Efficiency | ~70% | ~85% |
| **Overall Gold Recovery** | **~40%** | **~49%** |
| **Barren Solution Losses** | **0.044 mg/L** | **0.021 mg/L** |

# CASE STUDY #3 – CIL CIRCUIT

- CIL Plant (Suriname) treating high tonnage low grade ore via: crushing, SAG/ball mill (gravity gold recovery in ball mill circuit), cyanidation and CIL
  - Ore throughput progressively increased by ~300% from plant design: 4.8Mtpa to 12.0 Mtpa over first 5 years; seven open pits – blend of soft and hard ores; saprolitic
  - Single CIL circuit (design) split into 2 parallel circuits – each with 1 leach tank and 6-8 adsorption tanks
  - Mill survey performed by SGS to assess further expansion strategies

- Testwork → Plant carbon samples collected and analysed for activity
- Plant carbon not being regenerated to the activity of fresh carbon.
- Soluble gold losses attributed to poor carbon activity

# CASE STUDY #3 – CIL CIRCUIT

- Comparison of gold cyanide adsorption efficiency from plant-regenerated carbons and fresh carbon samples (Conditions: 0.5L solution, 0.55g carbon, 48h)

| ADSORPTION CONSTANTS | LAB CARBON | FRESH PLANT CARBON | PLANT REGEN. CARBON |
|---|---|---|---|
| Gold on carbon @$t_0$ , g/t | 0 | 12 | 153 |
| Rate constant, k | 0.0055 | 0.0084 | 0.0095 |
| Equilibrium constant, K | 30,355 | 12,807 | 4,479 |
| Efficiency factor, kK | 166 | 108 | 42 |

- Loss in activity:  inadequate acid washing, elution and regen. – the capacity had not been matched with increases in amount of carbon advanced through CIL circuit as plant expanded.

# CASE STUDY #3 – CIL CIRCUIT

- Solving the Problem:
  - Acid washing (simple): sufficient residence time was identified, so solved by adding more acid in the strip solution to dissolve higher $CaCO_3$ levels that had built up (5-6% Ca)
  - How to improve elution and regeneration? – add extra capacity? Time/cost factors; Other options?
  - Reduce the rate of carbon advance through the 2 CIL circuits – *proposed by SGS* – provides more time for elution/regen and expect lower gold grade on eluted carbon and better activity
  - Counter-intuitive approach that required substantiation (via modelling) before implementing in commercial plant due to risks involved.
  - Combination of slowing carbon advance and increasing carbon concentration in the CIL tanks was assessed – with aim of increasing residence time in elution/regen and decreasing soluble gold losses to tails.

# CASE STUDY #3 – CIL CIRCUIT

- Laboratory testwork was performed to determine:
  - Gold leaching kinetics (and leach rate constant); Conditions: 10kg, 72h, 50% w/w, 0.5g/L cyanide, pH 10.5
  - Carbon Adsorption kinetics from leached slurry (plant regen carbon)
  - Equilibrium Carbon Loading Isotherm (new carbon)
- Data fitted to model and validation performed by comparing predictions with measured plant profiles; predicted worse than actual – attributed to bottle roll test vs CIL tanks in plant which give better mixing of viscous saprolitic slurry; alignment via correction factor to account for slower rate of gold mass transfer in bottle rolls.
  - Scenario 2: corrected model (base case)
  - Scenario 3: evenly distributed carbon inventory
  - Scenario 4: improved elution efficiency (150->50 g/t Au on carbon)
  - Scenario 6: slowing carbon advance rate by 50% and doubling gold loading on carbon in CIL 1

# CASE STUDY #3 – CIL CIRCUIT

- Summary of Scenario Changes modelled:

| | 2 | 3 | 4 | 6 |
|---|---|---|---|---|
| k | 0.019 | 0.019 | 0.019 | 0.005 |
| K | 3669 | 3669 | 3669 | 18,230 |
| kK | 70 | 70 | 70 | 91 |
| Carbon Dist. | Low/high | even | even | even |
| Eluted C; g/t Au | 153 | 153 | 50 | 50 |
| Regen Eff; % | 77 | 77 | 77 | 100 |
| Target Au loading; g/t | 1000 | 1000 | 1000 | 2000 |
| Gold locked up; kg | 97 | 108 | 83 | 129 |

# CASE STUDY #3 – CIL CIRCUIT

- Model- Predicted Responses: Carbon loading (Au g/t)

| CIL stage | 2 | 3 | 4 | 6 |
|---|---|---|---|---|
| **1** | 1001 | 1013 | 926 | 1849 |
| **2** | 710 | 691 | 602 | 904 |
| **3** | 453 | 433 | 336 | 378 |
| **4** | 305 | 291 | 191 | 177 |
| **5** | 223 | 215 | 114 | 99 |
| **6** | 178 | 175 | 72 | 66 |
| **Eluted** | 153 | 153 | 50 | 50 |
| | | | | |

# CASE STUDY #3 – CIL CIRCUIT

- Model- Predicted Responses: Solution (Au mg/L)

| CIL stage | 2 | 3 | 4 | 6 |
|---|---|---|---|---|
| **Leach 1** | 0.68 | 0.68 | 0.68 | 0.68 |
| **1** | 0.546 | 0.528 | 0.513 | 0.372 |
| **2** | 0.324 | 0.305 | 0.283 | 0.144 |
| **3** | 0.192 | 0.179 | 0.154 | 0.058 |
| **4** | 0.119 | 0.112 | 0.085 | 0.026 |
| **5** | 0.079 | 0.077 | 0.049 | 0.013 |
| **6** | 0.057 | 0.058 | 0.030 | 0.008 |
| | | | | |

- Scenario 6 – shows feasibility of halving carbon advance, and 2X increase in carbon loading in CIL 1 (zero capex), as plant alternative to installing larger kiln with predicted CIL performance declining only marginally.

# CASE STUDY #3 – CIL CIRCUIT

- Modelling/testwork recommendation outcomes:

  - Incremental slowing of rate of advance (10%/month); monitor gold losses closely; continue until target gold loading in CIL 1 of ~2000g/t achieved; and eluted carbon < 50 g/t and carbon activities consistently >90%
  - Keep current plant practice of increasing carbon concentration in back end of CIL circuit – to reduce gold lockup;
  - cf. modelling of Scenario 6 - only negative of slowing carbon advance rate was is the amount of gold locked up in the plant which increases in inverse proportion to the carbon flowrate
  - Increase amount of nitric acid used in washing stage until Ca concentration in circulating load of carbon is < 1%

# ACTIVATED CARBON QUALITY

- The quality of activated carbon is of critical importance to the recovery of gold in CIP/CIL. Losses of gold due to poor carbon performance can be classified as follows:
  - Gold adsorbed by preg.-robbing ore rather than carbon
  - Gold adsorbed by carbon fines
  - Gold in solution not adsorbed by carbon
- The properties of activated carbon that are critical for plant performance are:
  - rate of gold adsorption (kinetic activity),
  - amount of gold loaded onto carbon (equilibrium capacity), and
  - resistance of the carbon to fines formation (attrition resistance).
- Commercial products are supplied in specific size ranges and made from coconut shells or extruded carbon based on peat or coal. Quality of the Carbon made from coconut shells can vary with respect to activity and strength.

# SGS CARBON TESTING

- The following SGS standard laboratory tests are important for determining the properties and prediction of performance of plant carbons:
  - **Carbon Activity Test** – test data used in the Fleming model to calculate the kinetic behaviour of gold adsorption onto the carbon:

$$\ln\Delta[Au]_c = n \ln t + \ln k [Au]_s$$

where:

| | | | |
|---|---|---|---|
| $\Delta[Au]_c$ | = | change in carbon loading since time = 0 | (mg/L) |
| $[Au]_s$ | = | equilibrium solution gold concentration | (mg/L) |
| n | = | ranges from 0.6 < n < 1.2, and is a constant relating to the gold loading capacity | |
| t | = | time in hours | |
| k | = | rate constant | >250 for virgin carbon (typically) |
| | | | 180-250 for regen. carbon |

# SGS CARBON TESTING (*cont.)*

- Usually several carbon activity tests are carried out using different types of carbon or carbon at various degrees of fouling, together with a control test, which is freshly re-activated carbon.
- Other testing typically requires to characterise new (first use) carbon or existing  plant carbons are:
  - Attrition tests
  - Size analysis
  - Hardness
  - Elution (desorption)

# CONCLUSION

- **CIP/CIL modelling  based on plant surveys and laboratory testing can predict plant performance reasonably well and is a relatively inexpensive way of performing optimisation studies for an existing plant without disruption to plant operations or upset to plant conditions or economic risk to the plant owner.**

- Comprehensive carbon testing services are available through SGS Minerals Metallurgy (Perth), as well as process modelling utilising the SGS global network of inhouse experts – Tyler Crary, Chris Fleming etc

- Carbon analysis (via carbon ashing, aqua regia digestion with AAS finish) is standard service at the SGS Kalgoorlie lab.