Mineral Processing Simulations

using CHEMCAD v5.1.5

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1.0 Introduction

Trade based finance affects every part of the economic fabric of society. The movement of goods not only provides an engine for growth but also benefits the well being of populations through the of provision of essential raw materials, services as well as value added labour saving devices. In the case of many countries, trade based financial transactions provides an essential source of monetary support to government and/or corporations operating within that country whereby urgently needed equipment or working capital can be provided.

Many countries are deemed to have a poor credit rating with banks. As a result conventional methods of raising finance on the basis of conventional credit assessments are unworkable. Solens Consultants Ltd (SCL) is a company providing risk analyses to the financial sector for such trade-based transactions that are based on the export of metals, minerals or hydrocarbons. Here, the evaluation of the underlying performance risk constitutes a major element of the transaction; i.e. the capability of the borrower to perform its obligations under the terms of the loan agreement amounts to be effectiveness and efficiency of the processes and refining operations involved.

CHEMCAD software is primarily designed for the simulation of hydrocarbon treatment and polymer synthesis processes. Whereas refining and chemical processing operations are broadly covered by the unit operations (unitops) in the palette provided as part of the general program, the selection of operations relating to mineral processing and other metallurgical processes used is somewhat limited. As a result, SCL adapted the excel unitop facility to provide a series of mineral processing operations which it used in the simulation of various flowsheets which were the subject of risk analyses as part of work undertaken for clients.

This paper describes some of the unitop processes subsequently developed, and provides an example of the type of results and presentation of the metallurgical performance duly obtained. A comparison with plant practice is shown.

2.0 System Requirements and Development

Development of the Visual Basic code was performed in conjunction with representatives of P&I Design Ltd at Darlington, UK and Chemstations Inc. at Houston, Texas. Apart from creating icons using the symbol builder facility for the various operations, the only modifications to the CHEMCAD package was the required Visual Basic code as entered within the relevant section of the general excel unitop program.

Key points relating to the development of the appropriate code for mineral processing systems are as follows:

- Mineral processing systems in most cases involve the suspension of particles in water. Water is treated as an inept medium in which the mineral separations are affected. However to be able to maintain appropriate mass balances within the CHEMCAD program it is necessary to treat water as a component and make appropriate assumptions as to how much water is transferred with the required product (concentrate) as opposed to the process waste (tailings).

- The performance of mineral processing operations is usually represented in terms or the proportion of the required metal or mineral in the *dry* product stream. In mineral processing or metallurgical turns this is referred to as the grade or assay of the relevant metal or mineral. In addition to the level of concentration of the required metal or mineral in the product, it is equally important to evaluate the overall recovery; again this is based on the *dry product weight.*

- The components for a typical mineral processing pulp include a whole variety of mineral species, the majority of which need to be rejected as they constitute non-value waste. Examples include quartz, feldspar, calcite, various other rock forming silicates and oxides. Defining the mineral response for each mineral for such varying species can be not only inexact due to the complexity of the various interlocking of the minerals that occur but also *irrelevant* for the purposes of simulation. Grouping of such waste species in terms of "rock" or "silicate waste" and defining the component parameters in terms of a simple representative mineral, such as quartz, is not only appropriate but also entirely effective. As a result the total number of components in a mineral feed pulp amounts can be represented as:

  Total number of phase components = number of values required to be extracted (typically 1-3) + waste representative phase e.g. quartz (1) + water medium (1)

- Whereas such concepts are fully familiar to chemical engineers, the object for emphasising the points above is that the *method of presentation* of results for mining and metallurgical processes is somewhat different than that normally observed for oil processing or chemical manufacturing processes. As shown in the following section, the use of *grade-recovery curves* presents probably the most universal form for comparison of the effectiveness of mineral processing operations.

Generic unitops were subsequently developed for the following processes:

- Thickeners
- Gravity tables
- Dense medium separators (DMS)
- Centrifugal separators
- Flotation cells

These processes were essentially developed for simulations of gold recovery plants. In a typical gold process plant or mill, the ore feed is sequentially crushed, ground and sized prior to it being treated by sodium or calcium cyanide. The resultant leach liquor is separated from the rest of the remaining insoluble rock, which is then dumped in a tailings pond. The liquor – containing gold cyanide – is then typically absorbed on to carbon which is turn is separated from the liquor by screening or other dewatering processes. The gold loaded carbon is stripped using hydrochloric acid and the resulting solution containing gold is either electrowon, or precipitated using zinc. The gold is subsequently smelted in a furnace, typically on site to produce rough doré gold bars, which are then amenable to further refining by a centralised specialised gold facility.

The first three types of unitop fundamentally use differences in the relative density of the constituent particles in the pulp to produce a separation. Whereas thickeners are used essentially as dewatering devices, gravity tables and DMS units are used to extract higher density values from less dense waste (the exception being coal which is less dense than the entrained waste rock). Hence the determination of terminal velocity under laminar flow conditions using Stokes Law provides a means of assessing the rate of precipitation of the phases required and accordingly the devices could be sized based on the throughput and the typical geometry of equipment normally available. Sizings and costs for these units as well as other developed were duly sourced from information available through the Canadian Institute of Metallurgy.

Centrifugal separators represent a relatively new development in the metallurgical sector. Whereas centrifuges and hydrocyclones have been well established in the industry, the application of principles in both have been adapted to produce compact devices (c. 1 m high, c. 0.6-1 m diameter) which are capable of extracting dense coarse particles from within the screened or cycloned pulp forming part of a grinding circuit. Such separators are now finding applications within the gold industry where a significant amount of gold can be extracted and removed for further concentration before it enters the main leach train. Nugget gold presents one of the major challenges to the mineral processor given the malleability of relatively large grains which may not be reduced to the same size range as the associated feed. Consequently, there is a major possibly of such large grains actually being lost to the mill as a consequence of the residence time being insufficient to leach large particles completely such that the value enters a solution phase ready for further concentration. Centrifugal separators were subsequently modelled using the equations suggested by gravitation of particles under Stokes Law conditions.

Flotation represents one of the processes in mineral processing where art meet science. Notwithstanding the fact that it probably represents the most widely used process in treating sulphide and oxide minerals and has attracted widespread research to determine the flotation response as a result of the various operational parameters employed, there remains a significant element of empiricism regarding the modelling of such processes. Pilot plant tests thus heavily feature in any evaluation and scale up with the effect of various flotation controls (particle size, reagent dosage, air flowrate etc.) being summarised in terms of the likely flotation rate constant, k. The recovery of many minerals has been found to follow first order reaction rates, and is normally represented as:

Recovery (expressed as a fraction) = $1 - \exp(-kt)$

where t is the residence time.

In the Visual Basic code, parameters were supplied whereby flotation rate constants could be inputted based on experimental observation. This approach was also used in other unitops to represent phase separations which could not be fully taken into account by the CHEMCAD standard process selection. One case in point was the separation of carbon (loaded with gold) from the remainder of the pulp.

The fact that gold enters the process plant, is leached into solution, adsorbed onto carbon, stripped from the carbon and then recovered from the aqueous phase as the precipitated or electrowon metal presents an challenge from the point of view of representing such a process in CHEMCAD. If the issue was simply one of leaching followed by precipitation, then the current tools would suffice. It is the fact that the gold cyanide complex *is adsorbed onto carbon*, which in turn is physically separated from the waste rock particles, presents a dilemma with regards to the adaptation of the CHEMCAD unitop for this process. Accordingly, it was concluded that two phases would be need to represent gold in the system:

- Gold – present as the native form, and therefore modelled as a solid phase; and
- Gold cyanide complex – as this is an aqueous phase with physical properties akin to water and therefore most of the properties used were based on the library entries for water. However, as the phase is duly separated from the rock particles by being considered a solid entity for *the purpose of the carbon/pulp separation stage only* a separation process based on recovery rate kinetics as used for flotation was considered to be the most amenable, as well as the simplest to use, from the perspective of SCL.

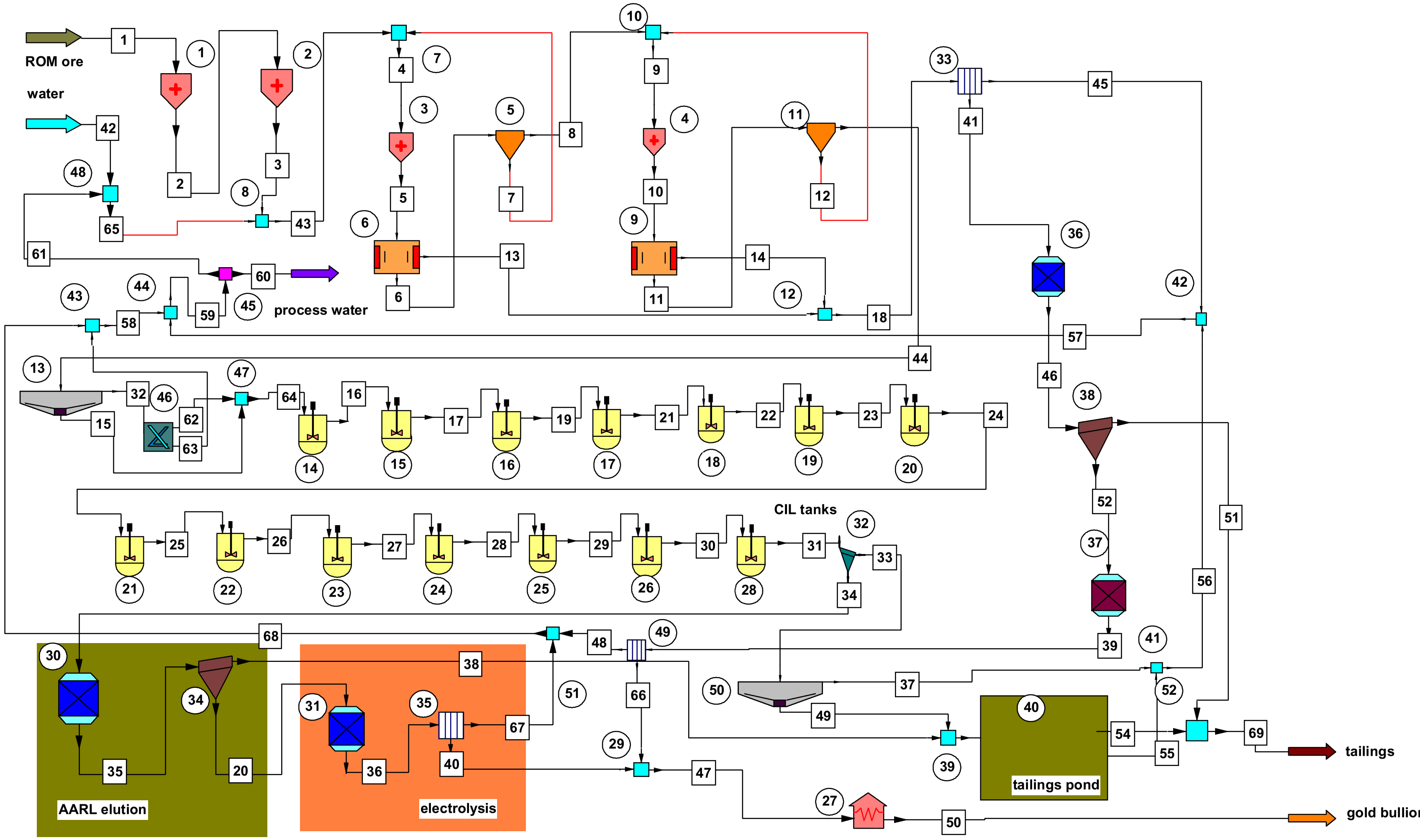
3.0 Result Formats and Analysis

Figure 1 shows a flowsheet of one of the gold processing plants reviewed by SCL. Whereas unit operations such as crushing, grinding, hydrocycloning and CSTR type reactors could be applied to represent the basics gold grinding-cyanidation elements of the process, this was not the case for other unitops, such as the thickeners, centrifugal separators, and the carbon/pulp separation stages.

- *Centrifugal separators – unitops 6 and 9, located within the grinding circuit;* here, the use of such separators has been proved to be effective in extracting coarse free gold (typical size being 100-300 microns). Adaptation of the centrifugal speed, in combination with the diameter produced an estimate of the likelihood of a coarse dense particle being thrown to the side of the separator (and therefore being caught).

- *Thickeners**-** unitops 13 and 50, located after the grinding circuit and prior to the tailings dump;* the dewatering of pulp is required so that the solid density is typically 40-50% for the subsequent leaching stages. This has particular ramifications with respect to the ensuring that water is contained within the mineral processing system due to residual cyanide levels that will prevail. In many such closed circuits systems there is no discharge of water to the environment. The need for top up arises in the main from losses due to evaporation.

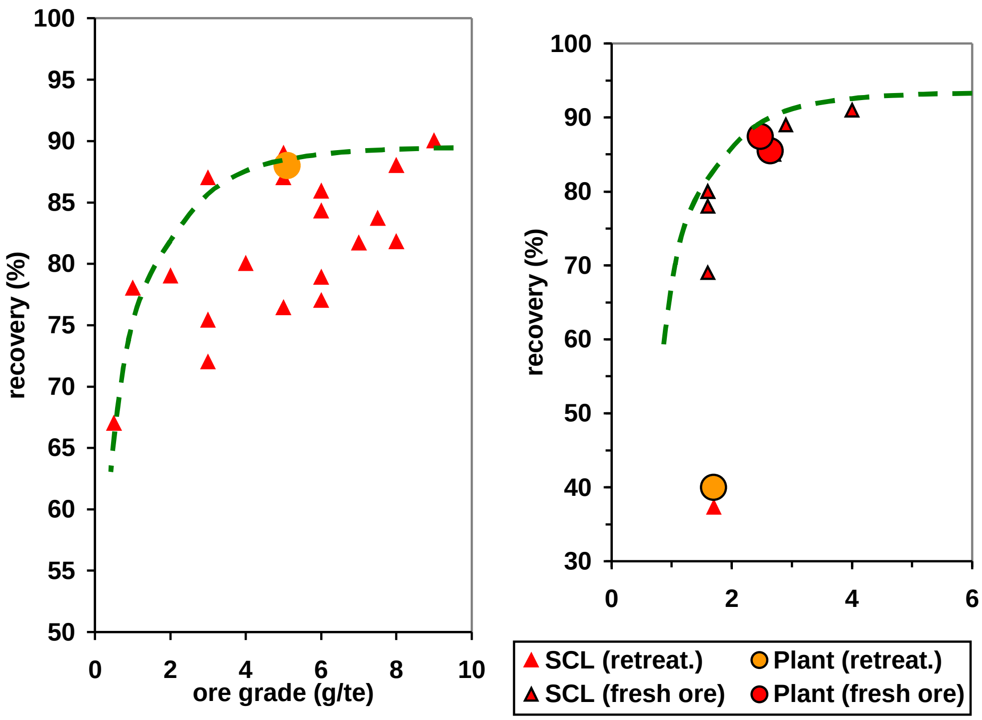
Figure 1: **Example Flowsheet of African Gold Processing Plant**



- *Carbon/pulp separation- unitop 32, located after the leach train;* the approach used for the flotation cells simulation was used where the recovery of the loaded carbon was estimated as being significantly greater than any of the other components. In practice the separation is achieved by a variety of means e.g. screens, tables. However, as noted earlier, the adaptation of the flotation recovery algorithms based on set rates of recovery was found to be the most appropriate approach here. The behaviour of gold cyanide was also modelled using this type of unitop model as part of the thickening stage in unitop 13 and the tailings pond (unitop 40).

Grade recovery curves for some of the gold processes simulated are shown in Figure 2 below. The curves show that the recovery of gold varies with the proportion of gold in the original feed. Recovery increases as the quality of the feed improves up to a practical maximum, which is shown by the levelling off of the curve. Conversely, as the grade is reduced, the recovery will fall off.

Figure 2: Grade Recovery Curves for African Gold Plants and associated SCL Simulations using CHEMCAD



The SCL CHEMCAD simulations are shown as red triangles represent different trials under various processing conditions to produce an overall recovery estimate for the gold . The green line in each diagram represents the trend which represents the envelope showing the best recoveries obtained for the various plant parameters tested. The plant data, shown as circles, shows that the current plant producers a grade recovery response in line with the SCL projections. Consequently, it would be reasonable to suggest that the metallurgical response of the plants within normal practical operational parameters for the equipment used. Selection of default recycle criteria is sufficient to ensure mass balances.

Observations arising from closed circuit (steady state) simulations:

- *The inclusion of gravity concentrators has a major effect on the overall recovery of gold.* Based on an empirical approach to the leaching of gold using standard cyanidation CSTR model it was clear that the impact of gravity concentrators could in raise overall gold recovery by 10-30%, as observed in some of the gold plants.

- *Gold cyanide levels within the circuit can be significant.* The levels of associated gold in solution can aggregate to levels where it is not possible to obtain satisfactory mass balances. This appropriately highlighted the need for effective control of cyanide. In the simulations it could be assumed that electrolysis and stripping stages efficiencies of 97% could be sustainable with respect to the levels of cyanide which would then be flowing around the circuit. The level of gold in cyanide could be of the order of 15% of the gold feed underlying the need for appropriate security within gold plant with respect to not only coarse gold concentrates but also loaded carbon which could also be subject to pilferage.

4.0 Conclusions and Recommendations

CHEMCAD unitops can be developed and integrated into the CHEMCAD system to simulate mineral processing flowsheets. The resulting grade-recovery responses generated are in line with plant data.

The nature of the unitops has to be significantly amended compared to those normally adapted for hydrocarbon processes. This arises from the fundamental approach taken by mineral processors whereby plant efficiency is based on a dried concentrate as obtained from a dry feed, even though the bulk of processing is done within a water medium.

The unitops so developed have to consider the levels of recovery as based on the quality of the feed presented. Recoveries represent the most usual parameters against which individual processes are assessed given the various parameters under test. Therefore the incorporation of the recovery of the value within the unitop is as important as the overall recovery figure for the plant.

The physical-chemical data required as part of entering new components into the CHEMCAD database does not represent any major issues. The existing CHEMCAD system for entering new phases readily accommodates the entry of mineral phases for the purpose of treatment by mineral processing systems. Pyrometallurgical systems present a different challenge, and is the subject of work being undertaken by SCL at this time.

Given the generality applicability of a mass balance approach it is possible to represent a number of physical separation processes using CHEMCAD. Despite the fact that of these processes present particular challenges given the empirical nature of the models that have to be used, plant flowsheets can be adequately represented with regards to preliminary risk analysis to identify those factors which have a significant effect on the performance of the plant. Combinations of CHEMCAD modules, which focus on *chemical reaction systems*, with other excel unitops, which describe *physical separation criteria*, should result in a broader range of application for CHEMCAD software. This is the subject of current studies by SCL.

References

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