

DEVELOPMENT OF EFFECTIVE SOLVENT-EXTRACTION PROCESS CONTROL—LOW COST IMPLEMENTATION VALUE-ADDITION TO HYDROMETALLURGICAL COPPER OPERATIONS

M Mwale and D C Megaw
Kansanshi Mining PLC, First Quantum Mineral Ltd &
Cognis Corporation (now part of BASF),

ABSTRACT

Solvent extraction as part of the copper hydrometallurgical extraction and refining flow sheet, is a well-established and globally implemented technology. The target operational philosophy of any hydrometallurgical copper operation is to safely achieve maximum copper mass transfer, with maximum impurity rejection at the lowest unit production cost. In dump, heap and in-situ copper leach operations, changes in copper and impurity tenors in pregnant leach solution occur gradually over an extended time frame (typically months to years). As a result, copper operations applying these leaching methods generally maintain consistently high extraction efficiencies across copper solvent-extraction circuits. For agitated leach operations, which are common in the African Copper Belt, the composition of pregnant leach solution, can vary considerably in a relatively short time (hours). In such operations, it is more challenging to balance good copper extraction and impurity rejection in solvent extraction and to operate the plant at consistently high efficiencies. First Quantum's Kansanshi Mining operation in Solwezi, Zambia, is an example of a hydrometallurgical copper producer, where copper ore grades fluctuate noticeably over relatively short processing time frames. This is mainly due to the plant feed ore mineralogy, which consists of three distinct ore types, processed through the same plant.

A key contributing factor to reduced efficiencies in agitation leach plants, is the reactive methodology that operations are forced to use, based on off-line laboratory analyses of process streams which have already been processed through the plant. Plant management uses these "after-the-fact" analyses to "predict" the best operating parameters for the subsequent short term operational time frame. These "predicted" operating parameters result in manual adjustments to process parameters which, if correct, facilitate higher copper extraction and higher impurity rejection. The level of success of these decisions is therefore subject to how well the operational staff interpret the status of the plant at any given time. Tighter control based on in-line stream analyses is both expensive and often impractical in copper hydrometallurgical processes, and is therefore almost always rejected as a process design option. A compromise between expensive in-line analysis-based control and common-practice "predicted" manual control can offer copper hydrometallurgy operations an inexpensive alternative to better operational efficiencies. The following paper explains the developed process control fundamentals and the results of the successful implementation of the control at First Quantum's Kansanshi Mining PLC.

1 INTRODUCTION

The use of solvent extraction (SX) in the hydrometallurgical refining of copper is a well-established technology, with most hydrometallurgy copper producers including SX as a unit operation in their overall process flow sheets. As a result of the successes of SX in this application, extractant manufacturers continue to optimize the formulation of their products to offer clients a reagent that conforms to all their processing needs. The key attributes that a client looks for in a solvent extractant is a product that is safe, inexpensive, robust and offers maximum copper mass transfer, with minimum chemical or physical transfer of impurities to the final refined copper solution. In this regard, extractant-manufacturers rely on their operating client base to operate their plants within the prescribed operational design criteria framework, as this often reflects on the performance of the reagent being used. It is therefore as much in the interest of the SX reagent manufacturer, as it is in the client's, to be intimately involved in the continuous optimization of the copper recovery and refining operation. This synergism is reflected in the developed SX control philosophy implemented at First Quantum's Kansanshi Mining PLC in Solwezi, Zambia.

2 KANSANSHI MINING PLC – A UNIQUE COPPER PROCESS

The First Quantum Mineral Limited-Kansanshi Operation has a unique challenge in the copper extraction and refining process flow sheet. The composition of feed to the processing plant varies considerably as a result of the ore grade variability. The developed ore body consists of three distinct ore types, sulfide, transitional sulfide-oxide and oxide, from which copper is extracted and refined. As a result of the fluctuation in process circuit feed composition, the compositions of product pregnant leach solutions (PLS) can vary considerably in a very short period of time (within hours). Figure 1 is a simplified diagram of the Kansanshi Mining PLC copper processing flow sheet.

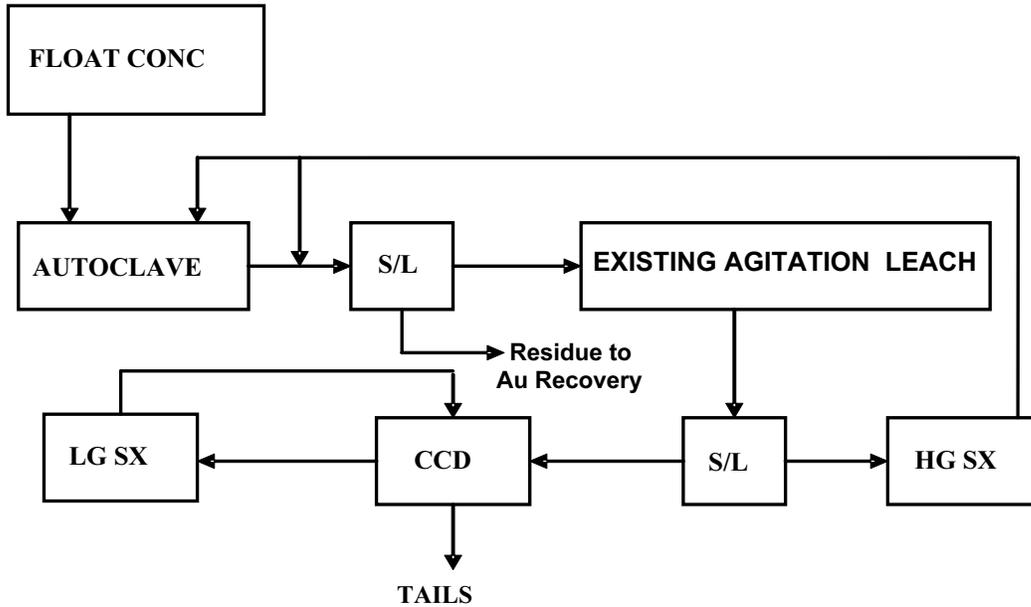


Figure 1
 Kansanshi Mining PLC Processing Flow Sheet

In addition to the fluctuating ore grades, two leach product streams (pressure leach product and oxide leach product) are combined. This adds to the variability in PLS composition feeding the SX circuits. Figure 2 shows the copper tenor fluctuations in Kansanshi high grade PLS over a 55-hour operation time frame. Copper tenors varied between 4 and 7.5g/L within 50 hours of operation.

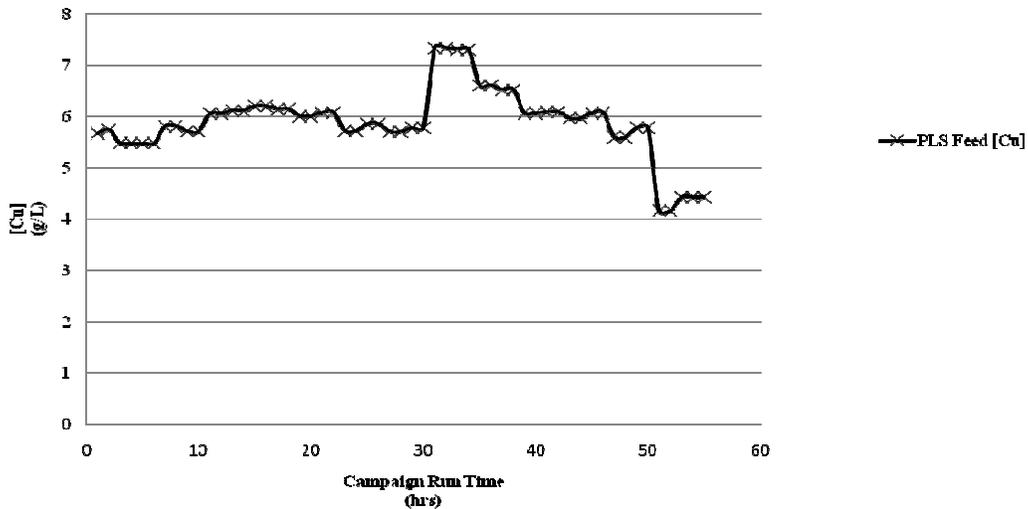


Figure 2
 Kansanshi Mining PLC High Grade PLS Copper Tenor (June 2010)

3 PROCESS OPTIMISATION TARGETS

One of the primary process targets at Kansanshi is to control iron reporting to the advance copper electrolyte, due to the negative impact thereof on electrowinning (EW) cell current efficiencies and hence, overall operating costs. Iron is transferred into the advance electrolyte in two ways:

- chemical extraction into the organic phase
- physical entrainment of PLS aqueous within the loaded organic advancing to the SX stripping stages

Chemical co-extraction of impurities is controlled by ensuring the organic is loaded as high as possible with copper, leaving few active sites available on the organic extractant for any impurities to co-extract. Physical entrainment is controlled by ensuring the plant is operated within the specified design parameters, so as not to push the SX mixers and settlers beyond the limit of their designs. A key factor to achieve both controls is to ensure that the SX circuit is running at the optimum organic to aqueous (O:A) phase ratio at all times.

4 KANSANSHI HISTORICAL SX PROCESS CONTROL

The installed process control on the SX circuits at Kansanshi is typical of most copper SX circuits, employing in-line electronic flow meters that give feedback to a central control system. Organic and aqueous flows are controlled by manual adjustment and setting of the relevant pump variable speed drive(s) by the control room operators. Once the pump variable speed outputs are set, they are generally maintained at these outputs. The control room operators monitor the 2-hourly and 4-hourly laboratory analyses of the SX feed and product stream samples and only adjust process flows in the event that any of the critical process control parameters trend towards unoptimised process conditions. Aqueous streams are typically analyzed every 2 hours with organic streams being analyzed every 4 hours. In many copper hydrometallurgical operations, where PLS compositions do not fluctuate noticeably over short periods of time, effective optimised control is readily achieved using this operating philosophy. Given the Kansanshi flowsheet, maintaining optimum copper mass transfer while minimizing iron co-extraction, is more challenging.

5 CIRCUIT SELECTION FOR PROCESS CONTROL IMPLEMENTATION

As shown in the simplified flow diagram in Figure 1, Kansanshi operates a Split Circuit™ post-leach, liquid-solid separation flow sheet. High grade copper PLS is treated through two high-grade copper SX circuits, while the low-grade copper PLS from the leach solids wash (CCD) train, is treated through the low-grade copper SX circuit*. Both high grade 1 and low grade SX circuits operate a standard series- parallel extraction stage configuration, while the high grade 2 SX circuit is configured as a series extraction circuit. The two typical circuit configurations are illustrated in Figures 3 (series) and 4 (series-parallel) respectively.

In SX, a series extraction circuit is configured with a single PLS feed stream entering the SX circuit and being contacted counter-current with a single organic extractant stream entering the circuit. A series-parallel extraction stage configuration implements the separate introduction of more than one PLS stream at different extraction stages).

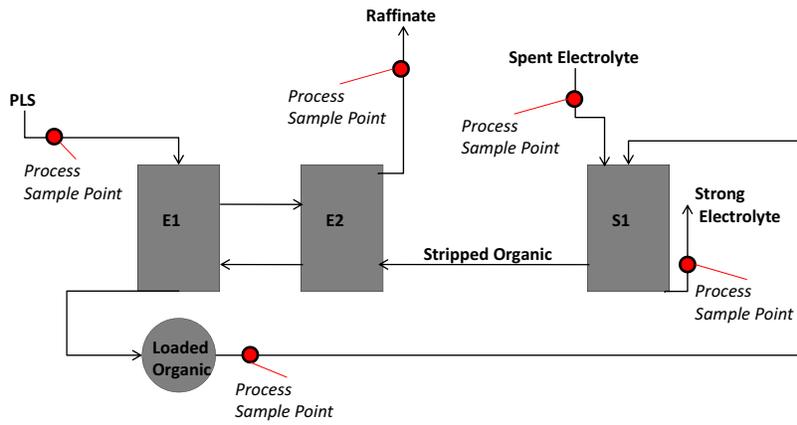


Figure 3
Typical Series SX Circuit Configuration Showing Process Control Sample Points
for Copper Analysis

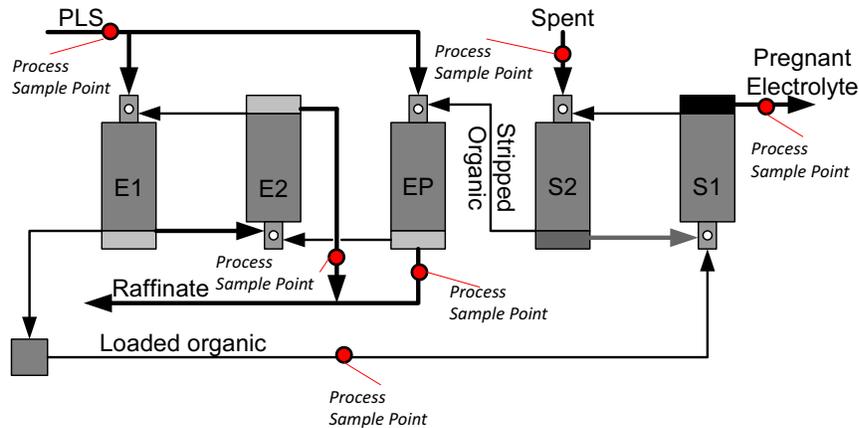


Figure 4
Typical Series-Parallel SX Circuit Configuration Showing Process Control
Sample Points for Copper Analysis

Based on the configuration of the high grade 2 circuit, it was decided to trial the process control on this circuit, first. Once the control was proven, the control was systematically implemented and optimised on the low grade circuit and finally on high grade 1 circuit.

* As part of a capacity expansion strategy, Kansanshi are currently in the process of reconfiguring the 3 available SX circuits with two circuits only treating low grade PLS and one circuit dedicated to treating high grade PLS.

6 CONTROL PHILOSOPHY BASIS EXPLAINED

6.1 Copper SX Fundamentals

The control basis uses the fundamentals of copper SX mass transfer:

6.1.1. For extraction-stage series configurations (Kansanshi HG 2 SX circuit – ref. Figure 3):

The controller uses available process input data, such as monitored process flows (from in-line flow transmitters) and process-stream copper analyses (from process-sampled analytical results) to adjust the mass flow of organic extractant for optimum copper extraction and impurity rejection.

A target raffinate copper concentration is used as the basis of the organic flow controller solver:

$$Of_{target} = PLS_{flow} \times \left[\frac{[Cu]_{PLS} - [Cu]_{Raffinate\ Target}}{[Cu]_{L.O} - [Cu]_{S.O}} \right] \dots\dots\dots (1)$$

- Of_{target}** = Organic flow set point
- PLS_{flow}** = Operating PLS flow rate (feedback from in-line electronic flow meter)
- $[Cu]_{PLS}$** = PLS copper concentration (process sample analysis)
- $[Cu]_{Raffinate\ Target}$** = Production-required target raffinate copper tenor (process sample analysis)
- $[Cu]_{L.O}$** = Loaded organic copper concentration (process sample analysis)
- $[Cu]_{S.O}$** = Stripped organic copper concentration (process sample analysis)

For circuits that use extraction-stage series-parallel configurations (Kansanshi HG 1 SX circuit and LG SX circuit – ref. Figure 4):

The controller uses available process input data, such as monitored process flows (from in-line flow transmitters) and process-stream copper analyses (from process-sampled analytical results) to adjust the mass flow of organic extractant for optimum copper extraction and impurity rejection. As a result of dual PLS streams feeding the series-parallel circuit configuration, the required mass flow of organic for optimised copper mass transfer, is solved for both PLS streams.

$$Of_{target} = \left[\left[\frac{PLS_{E1flow} \times [Cu]_{PLS\ E1} - [Cu]_{Raff\ Target}}{[Cu]_{L.O} - [Cu]_{S.O}} \right] + \left[\frac{PLS_{EPflow} \times [Cu]_{PLS\ EP} - [Cu]_{Raff\ Target}}{[Cu]_{L.O} - [Cu]_{S.O}} \right] \right] \dots\dots\dots (2)$$

- PLS_{E1flow}** = Operating PLS flow rate into E1 (series) extraction stage
- PLS_{EPflow}** = Operating PLS flow rate into EP (parallel) extraction stage
- $[Cu]_{PLS\ E1}$** = Series PLS copper concentration (process sample analysis)
- $[Cu]_{PLS\ EP}$** = Parallel PLS copper concentration (process sample analysis)

6.2 Control Rules

Due to certain characteristics applicable to typical copper agitation leach operations, certain control rules (control limits) had to be applied when developing the organic flow control basis:

6.2.1 SX mixer continuity for series extraction configuration

In order to manage crud formation in the mixer and settler stages of the copper SX circuits, copper agitation leach process flow sheets typically run all extraction and stripping stages in organic-continuous mode.

In order to maintain mixer organic continuity, the following control basis rule was included in the controller:

For condition:

$$\left[\frac{[Cu]_{PLS} - [Cu]_{Raffinate\ Target}}{[Cu]_{L.O} - [Cu]_{S.O}} \right] < 1.05, \text{ then } Of_{target} = PLS_{flow} \times 1.05 \dots\dots\dots(3)$$

This ensures that at any given time, the controller organic flow is always 1.05 times greater than the PLS flow.

6.2.2 SX mixer continuity for series-parallel SX configuration

In order to maintain organic continuity for series-parallel extraction configurations, the controller sets the default organic flow condition as explained in equation (3), according to the higher of the two feed PLS streams. In this way mixer organic continuity in any extraction stage mixer compartment is achieved, while minimizing the amount of “unnecessary” organic that will increase impurity (iron) co-extraction.

For series-parallel process circuit condition:

$$\left[\frac{[Cu]_{PLS} - [Cu]_{Raffinate\ Target}}{[Cu]_{L.O} - [Cu]_{S.O}} \right] < 1.05, \text{ then } Of_{target} = PLS_{flow} \times 1.05 \dots\dots\dots(3)$$

Where

$PLS_{flow} = PLS_{E1flow}$ for condition: $PLS_{E1flow} > PLS_{EPflow}$

and

$PLS_{flow} = PLS_{EPflow}$ for condition: $PLS_{EPflow} > PLS_{E1flow}$

6.2.3 Organic Maximum Loading

In solvent extraction, organic maximum loading or “Max Load” is a measure of the maximum available capacity of the organic extractant to extract target species from aqueous solutions. “Max Load” is expressed as grams of target species extracted per litre of organic per vol% of extractant concentration (g/L/vol%). Due to process efficiency losses, any operating copper solvent extraction circuit will run at a certain level below this “Max Load” value.

For any operating circuit, in the event that:

- copper tenors in the feed PLS suddenly drop off or,
- there is a step-change increase in copper mass transfer from loaded organic to copper electrolyte in the stripping section of the SX circuit, the net result is a sudden increase in available organic extractant returning to the extraction stages of the SX circuit.

When this occurs, copper tenors on the analysed loaded organic samples tend to lower (Even though either of the contributing step-change conditions mentioned will, once again, converge towards system equilibrium, the interim imbalance tends to be weighted towards lower loaded organic copper values). Because the basic organic flow controller (ref. equation 1) relies on loaded organic copper tenor inputs to be high, in order to maintain a high equation denominator, when the difference between loaded and stripped organic copper tenors is reduced, the controller incorrectly interprets this as a process demand for additional organic extractant to achieve the required copper mass transfer. The overall output response of the controller is to increase organic flows even further.

In order to negate the issue of low copper loading on loaded organic, a “Max Load” factor was included in the control – (this is based on historical plant data, updated on a weekly basis). The weekly copper “Max Load” for the SX circuit is input into the control system together with the calculated system efficiency (expressed as a percentage of “Max Load”) – the system then calculates a more realistic system optimum loaded organic value $[Cu]_{L.O \text{ system}}$:

$$[Cu]_{L.O} = [Cu]_{Max \text{ Load}} \times \% \text{ system efficiency}$$

If $[Cu]_{L.O} < [Cu]_{L.O.system}$ then

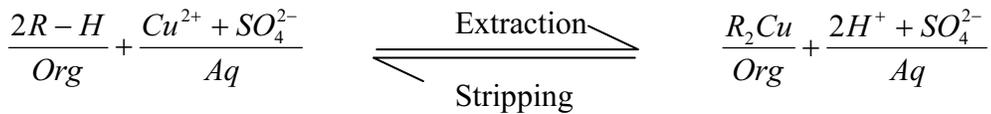
$$Of_{target} = PLS_{flow} \times \left[\frac{[Cu]_{PLS} - [Raff]_{Target}}{[Cu]_{L.O.system} - [Cu]_{S.O}} \right] \dots\dots\dots(4)$$

If $[Cu]_{L.O.} \geq [Cu]_{L.O. \text{ system}}$ then

$$Of_{target} = PLS_{flow} \times \left[\frac{[Cu]_{PLS} - [Raff]_{Target}}{[Cu]_{L.O.} - [Cu]_{S.O.}} \right] \dots\dots\dots(5)$$

6.2.4 PLS pH factor

In the recovery of copper, upstream agitation and pressure copper leaching unit operations are optimised for maximum dissolution of acid soluble copper. This sometimes results in excess free acid reporting to the downstream PLS feed to the SX circuits. The balanced equation for copper in solvent extraction is as follows:



In order to achieve optimum copper mass transfer in the extraction stages of the SX circuits, feed PLS pH values play an important role, as these define extraction equilibrium conditions. PLS pH values of less than 1 begin to significantly favour stripping equilibrium conditions. In the event that PLS pH values are low, a typical response by operations is to increase organic flows to try and compensate for extraction equilibrium pH conditions. Although this is an undesired response, it sometimes is the only available operating mechanism to achieve raffinate target copper tenors, without having to neutralize free acid in the PLS.

In order to ensure that the organic flow controller can accommodate low PLS pH scenarios, a PLS pH factor was included:

If $PLS \text{ pH} < 1$ then

$$Of_{target} = PLS_{flow} \times \left[\frac{[Cu]_{PLS} - [Raff]_{Target}}{[Cu]_{L.O.} - [Cu]_{S.O.}} \right] \times \frac{1}{pH_{PLS}} \dots\dots\dots(6)$$

The inclusion of the pH factor in the controller also offers more on-line control logic, as feedback from an in-line PLS pH meter can be used for continuous controller logic update. (The inclusion of an in-line PLS pH meter has not yet been implemented in the control at Kansanshi but is a consideration for future ongoing controller optimisation).

7 CONTROLLER COMMISSIONING AND OPTIMIZATION RESULTS

7.1 Target raffinate copper tenors and iron co-extraction

Figure 5 shows the copper loading on the Kansanshi HG 2 SX circuit organic and the associated raffinate copper tenors achieved during one of the organic flow control optimization campaigns.

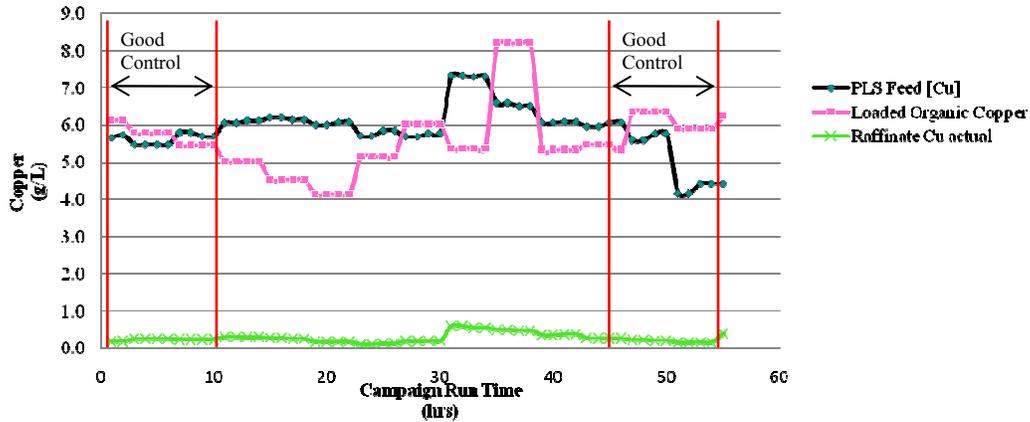


Figure 5
 Kansanshi Mining PLC HG 2 SX Organic Flow Control Optimization Campaign
 – Raffinate Copper (June 2010)

Figure 6 shows the total iron reporting to the loaded organic phase expressed as a function of copper transferred for the same HG 2 SX controller campaign period depicted in Figure 2.

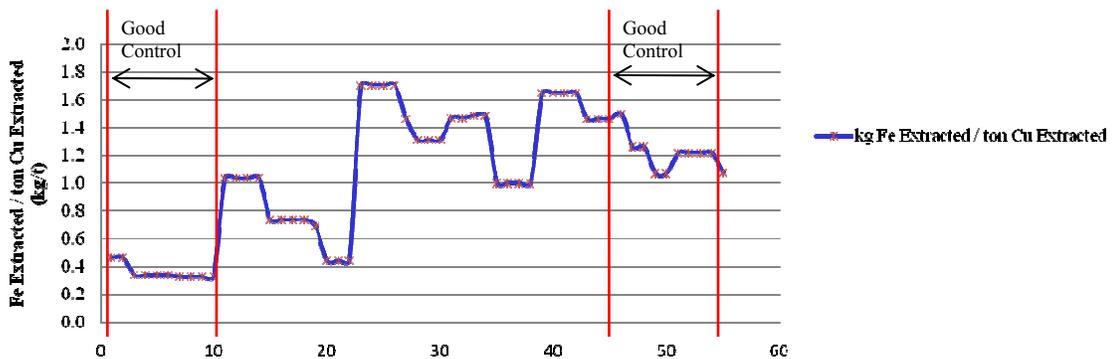


Figure 6
 Kansanshi Mining PLC HG 2 SX Organic Flow Control Optimization Campaign
 – Co-extracted Iron (June 2010)

Figure 7 shows the copper loading on the Kansanshi LG SX circuit organic and the associated raffinate copper tenors achieved during one of the organic flow control optimization campaigns. Total iron co-extraction is depicted on the same graph.

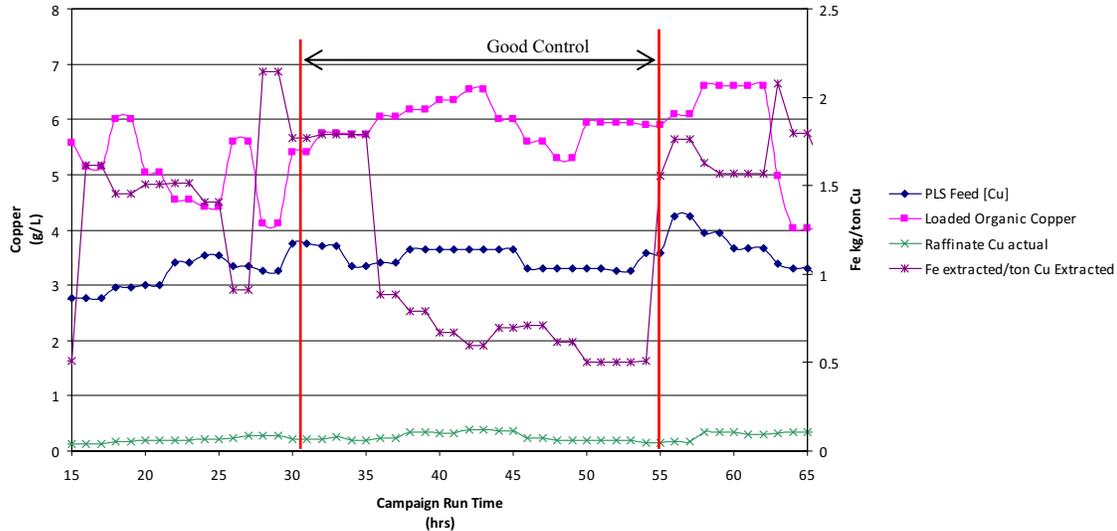


Figure 7
 Kansanshi Mining PLC LG SX Organic Flow Control Optimization Campaign
 (October 2010)

Note: Areas indicated on the graphs, where good flow control was not achieved, were as a result of the design constraints of the installed organic pump unable to deliver the controller-required organic flow rates.

It must also be noted in the reported results that no distinction is made between chemically extracted iron and iron reporting to the loaded organic due to physical-entrained PLS aqueous.

For both HG SX 2 and LG SX organic flow control campaign examples, when good control was achieved, iron rejection from the loaded organic was effective, while still achieving target copper raffinate tenors. For HG SX 2 results, the level of iron co-extraction for 0 to 10hrs is far lower than for 45 to 55 hrs, even though loaded organic copper tenors are similar and PLS copper tenors for 45 to 55 hours are lower than for 0 to 10hrs. One would expect similar iron deportment to the loaded organic. The anomaly could be due to one or a combination of the following process conditions:

- Entrainment levels of iron in the loaded organic phase may have been higher for run time 45 to 55 hours. Entrainment levels in loaded organic are often increased with increase in total suspended solids introduced with the PLS.
- the system may not have been at an advanced stage of equilibrium after the control-upset run time between 10 and 45 hours.

8 CONTROLLER LIMITATIONS

Although the controller has demonstrated that effective rejection of impurities can be achieved while maintaining good process copper mass transfer, there are identified limitations:

- **Installed plant design limitations:**
In the case of Kansanshi, it was apparent that the controller would give maximum benefit when controller calculated organic flow rates were within the operating range of the installed organic pump. From the data presented it can be seen that much of the time, the plant is operated below the required organic flow for optimum control. This is as a result of the limit of the organic pump design capacity.
- **PLS composition and the impact on copper mass transfer :**
The challenge to optimize available soluble copper recovery in agitation leach often results in product PLS solutions with elevated free acid and higher copper tenors – both these attributes are unfavourable for good copper mass transfer in solvent extraction. (Elevated copper tenors in the PLS results in higher acid per volume of aqueous generation in the initial extraction stages which reduce extraction equilibrium kinetics for subsequent extraction stages. Although the impact of these conditions would be similar on process performance, regardless of whether the control is implemented or not, they are viewed as significant factors limiting the effectiveness of the control.

9 DISCUSSION

The organic flow control basis implemented at Kansanshi Mining PLC, offers an inexpensive operating philosophy that can be adapted and tailored to most copper SX unit operations. Because the controller is based on fundamental SX principles, the control philosophy is applicable to most metal SX processes and could be readily adapted and tailored for similar effective control benefits on these processes.

10 REFERENCES

- Cognis Operation of Copper Solvent Extraction Plants – A Cognis Overview, 2009
- Implementation of the Split Circuit TM Concept into Copper Agitation Leach Plants, Andrew Nisbett, Angus Feather, Graeme Miller

