CRUD FORX™ – ADVANCE IN SOLVENT EXTRACTION CRUD MANAGEMENT TECHNOLOGY

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ABSTRACT

Operational challenges associated with solvent extraction (SX) plants include the effective on-line management of solids introduced from a variety of process streams. In hydrometallurgy processing circuits that employ SX as part of their refining process flow sheet, solids can be carried over from leaching circuits to the SX circuits due to incomplete solid-liquid separation, or may be formed as a result of chemical precipitation before or within the SX circuits, or introduced from downstream electrowinning (EW) operations. Solids in SX settlers adversely impact plant availability and reduce optimized name-plate design capacity operation of the SX circuits. Most available SX crud and bottom solids removal systems are limited in their effectiveness to handle high levels of SX crud solids. Operations are often forced to take SX settlers off-line periodically for complete removal of contained solids. These settler cleaning operations are hazardous, high risk, labour-intensive and costly in terms of production down-time and organic extractant and diluent reagent losses. Production pressure results in operations often being reluctantly to take SX settler units off-line for solids clean-out and this results in continued operation of the SX unit operations at reduced levels of product mass transfer and increased impurity transfer performances. Crud Forx™ is an SX solids removal system that provides safe, on-line removal of interfacial and bottom solids associated with SX settler processes. A detailed case study of the application of the Crud Forx™ system conducted at an operating SX-EW plant in the African Copperbelt is discussed. The case study focuses on the improvement achieved in copper mass transfer in the SX circuits as a direct result of the implementation of the Crud Forx™ system. A second preliminary study is discussed in brief, with emphasis on the potential of the Crud Forx™ system to reduce impurity entrainment levels in the SX phases exiting the settlers. The third study covers operational conditions which proved challenging for the application of the Crud Forx™ system and the adapted application of the system to cater for these conditions. All three case studies demonstrated the effectiveness of the Crud Forx™ system as a tool for on-line SX solids management. Benefits identified were an overall improvement in SX fire risk reduction, SX occupational health and safety, an improvement in copper mass transfer, reduced settler phase-in-phase entrainment levels and an overall improvement in SX plant availability.

Keywords: Solvent Extraction, Crud Forx™, Electrowinning, Entrainment, Mass Transfer
INTRODUCTION

Hydrometallurgy copper extraction and purification processes are often associated with ultra-fine solid distribution profiles throughout the process flowsheet (Virnig et al., 1999). Many hydrometallurgy plants that employ solvent extraction (SX) processing as a copper upgrading and purification step have to contend with the formation of crud within the SX circuit, due to the introduction of solids from a variety of sources. Effective management of crud is essential to prevent excessive build-up of crud in SX settlers and to reduce the adverse effects of settler bottom solids and interface crud on optimized performance of the refining process flowsheet.

SX operational experience has shown that most systems available for online removal of crud from SX settlers are often limited in their effectiveness to handle the large influx of entrained solids present in incoming feed streams. This results in long periods of unoptimised SX operation followed by periodic plant unavailability for complete offline clean-out of SX settlers. This operational methodology results in reduced production, increased SX organic consumption, reduced downstream product purity and additional health and safety issues in SX plant.

The integrated Crud Forx™ system has proven successful as an effective online SX solids management system with its successful implementation at various copper hydrometallurgy operations.

BACKGROUND

Integrated Crud Forx™ System Defined

The integrated Crud Forx™ system (Figure 1) is a solids removal system designed for the online removal of bottom solids associated with hydrometallurgy SX processes. The system is compact, which makes it adaptable to most applications in SX settlers.

The system comprises a multi-piped slurry suction head, which is partially or fully immersed in the SX settler. The slurry section head can either be connected directly to a removable flexible hose coupling to remove solids from the sides of a settler, or to one or more modular lengths of rigid transfer piping to access areas further within the body of the settler for removal of solids. These applications are illustrated in Figures 2 and 3.

Figure 1: Crud Forx™ System
The correct application of the Crud Forx™ ensures a high solids removal rate from SX settlers, without taking the impacted settlers offline.

![Figure 2: Crud Forx™ Settler Side Application](image)

![Figure 3: Crud Forx™ Settler Body Application](image)

The Crud Forx™ uses a unique combination of fluid “lift” and “back-pulsation” technology that ensures SX settler bottom solids mobilization and removal is extended beyond the immediate deployment zone of the unit. The motive fluid employed is low-pressure plant compressed air. The transfer mechanism results in a high solids, low organic content slurry that can be pumped to downstream crud treatment operations. The high solids content of the removed slurry often results in a debottlenecking of installed crud treatment facilities due to lower volumetric throughput requirement to treat similar masses of removed solids.
Table 1 shows a typical composition of Crud Forx™ removed bottom solids slurry for a targeted zone in a copper SX settler. The distribution of organic, aqueous and solids is shown for slurry removed at the beginning of an application cycle (left measuring cylinder - image insert) and at the end of the application cycle (right measuring cylinder - image insert).

**Table 1: Typical Crud Forx™ – Removed Bottom Solids Slurry Composition – Copper SX**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Typical slurry composition (free-settled volume %)</th>
<th>Application cycle start</th>
<th>Application cycle end</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom solids</td>
<td>79.7</td>
<td>47.9</td>
<td></td>
</tr>
<tr>
<td>Aqueous</td>
<td>19.1</td>
<td>50.7</td>
<td></td>
</tr>
<tr>
<td>Surface organic</td>
<td>1.1</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Slurry density</td>
<td>1.097</td>
<td>1.087</td>
<td></td>
</tr>
<tr>
<td>Mass % solids</td>
<td>26.3</td>
<td>14.9</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4 shows a typical Crud Forx™ bottom solids slurry discharging into a Crud Barrow system used to pump the recovered bottom solids slurry to the crud treatment facility.

**Figure 4: Typical Crud Forx™ Bottom Solids Slurry Discharge into Crud Barrow**
Crud Forx™ Bottom Solids Profile Comparison

Figures 5 and 6 show the bottom solids profile of an operational settler before and after 8 hours of Crud Forx™ application respectively. It can be seen that approximately 24 vol% of bottom solids removal was achieved in the 8-hour application period.

Figure 5: Settler Bottom Solids Profile Before Crud Forx™ Application

Figure 6: Settler Bottom Solids Profile After Crud Forx™ Application (After 8 hours of Application)
IMPLEMENTATION OF CRUD FORX™

Impurity Transfer and SX Copper Mass Transfer

Introduction

The study was conducted at Glencore’s Mutanda Mining SARL, which is situated approximately 40 km southeast of Kolwezi in the Katanga Province, Democratic Republic of Congo.

Mutanda Mining SX Operational Challenges

Feed copper and cobalt ore grade fluctuations, along with instability in the national power grid, often result in extended periods in which copper throughput is below target production. In order to recover target copper mass transfer from these lower throughput periods the plant compensates by increasing volumetric flow throughput to the five SX circuits operated at Mutanda. High gangue acid (GAC) content in some feed ore results in periodic high levels of talc fines in the leach discharge slurries. This makes liquid–solid separation optimization in the post-leach thickeners and CCD thickeners more challenging. The combination of these operational challenges results in high average levels of total suspended solids (TSS) in the SX PLS. This translates into high volumes of bottom solids and interface crud having to be managed in the settlers of the five SX circuits. The impact of the high volumes of SX solids are:

- reduced SX volumetric flow throughput and copper mass transfer performance;
- higher impurity entrainments in SX product streams.

Mutanda Mining Life-of-Mine (LOM) Feed Grade Adjustment

At the end of 2013, the average copper feed grade for the Mutanda operation was gradually adjusted down from 6% to 3.8% contained copper. The reduction in the feed grade copper meant that a higher mass throughput of ore was required to maintain target copper production. The reduction in feed grade coincided with the commissioning of a 600 dry t/h capacity semi-autogenous (SAG) mill to increase the ore throughput. The adjustment in LOM processing plant feed grade and the inclusion of a different grinding mill mechanism resulted in increases in design mass flow throughput and altered the particle size distribution of the leach solids from January 2014. Figure 7 shows the TSS levels for PLS feed solutions to the five SX circuits for the period 01 January 2014 to 15 August 2014.

From the end of January 2014, once the 600 t/h SAG mill was commissioned and ramped up to design capacity throughput, there was a steady increase in PLS TSS levels for all PLS streams. The higher TSS levels reporting to the five SX circuits resulted in compromised SX performances and plant availability due to increased entrainment levels and more frequent bypassing of SX settlers for solids clean-out.

![Figure 7: Mutanda Mining SARL PLS TSS Levels (1 January 2014 to 15 August 2014)](image-url)
**Crud Forx™ Implementation**

On 22 March 2014, the first Crud Forx™ unit was implemented for SX settlers on-line bottom solids clean-out. The units were systematically rolled out to all five SX circuits.

**Impact of Crud Forx™ On-line SX Bottom Solids Management**

Figure 6 shows the average hourly copper mass transfer for each of the five SX circuits (Z4 HG SX, Z4 LG SX, LG SX, HG SX and SX1) at Mutanda from mid-December 2013 to mid-August 2014.

The impact of the Crud Forx™ implementation is most noticeable on the two largest Mutanda SX circuits (Z4 HG SX and Z4 LG SX), which feed the three largest EW tankhouse complexes. The improvement in copper mass transfer was primarily attributed to the Mutanda production team being able to run higher volumetric flows through the SX circuits without impacting on impurity transfer levels. This was directly attributed to effective evacuation of SX settler bottom solids and interface crud with the Crud Forx™ system.

The decrease in the HG SX circuit copper mass transfer was due to the forced removal of a parallel PLS stage duty from this particular SX circuit in May 2014. The cause of the forced modification to the circuit operating configuration was as a result of an in-line bypass organic valve failure which could not be repaired without significant plant down-time. This prevented the HG SX circuit from being operated at an optimum series/parallel/parallel extraction mixer–settler configuration (three PLS streams) and the circuit being reverted back to a series/parallel (two PLS streams) extraction mixer–settler configuration only. For the period between Crud Forx™ implementation and before the forced change in circuit configuration (11 May) however, copper mass transfer for the HG SX circuit increased.

The relatively constant mass transfer performance of the LG SX circuit was mainly due to constraints on the spent electrolyte flow to this circuit (mass transfer of copper in associated EW tankhouse being the limiting factor). There was also only a slight improvement in the SX1 copper mass transfer, as this circuit historically has excess capacity to transfer copper, however is limited by the associated downstream tankhouse rectifier capacity, similar to the case for the LG SX circuit.
Table 2 shows the conservative improvement in copper mass transfer for the individual and collective Mutanda SX circuits.

### Table 2: SX Circuit Improvements in Copper Mass Transfer

<table>
<thead>
<tr>
<th>SX circuit</th>
<th>Average copper mass transfer improvement (based on average hourly mass transfer) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SX 1</td>
<td>7.8</td>
</tr>
<tr>
<td>HG SX</td>
<td>–11*</td>
</tr>
<tr>
<td>LG SX</td>
<td>–8.8#</td>
</tr>
<tr>
<td>Z4 HG SX</td>
<td>12.1</td>
</tr>
<tr>
<td>Z4 LG SX</td>
<td>16.2</td>
</tr>
<tr>
<td>Combined SX circuits</td>
<td>4.7</td>
</tr>
</tbody>
</table>

*Reduced Cu transfer due to removal of parallel extract PLS stage for HG SX circuit

#LG SX limitation – Associated EW downstream capacity

### Entrainment Levels

**Introduction**

Jinchuan’s Ruashi Mining is a copper and cobalt mine situated in Lubumbashi, in the Katanga Province of the Democratic Republic of Congo. The mine comprises open pits with associated leach, SX and EW plants.

**Ruashi Mining SX Operational Challenges**

The operational challenges faced in Ruashi’s HG and LG SX circuits are also associated with high levels of TSS, mainly attributed to high talc content in the feed ore. Similar to Mutanda in this respect, optimized liquid-solid separation in post leach thickener and CCD operations is compromised, resulting in elevated TSS levels in SX feed PLS streams. At Ruashi, the primary operational challenge is focussed on reducing impurity transfer, rather than on copper mass transfer in the SX circuits, as the SX circuits have always performed well to maintain design nameplate copper mass transfer.

**Crud Forx™ Phase-in-Phase Entrainment Comparison**

Table 3 shows organic-in-aqueous entrainment reduction with the correct application of the Crud Forx™ in the SX settlers. A study done recently at Ruashi Mining (on the settler of HG SX circuit Extraction Stage 2) has shown that a reduction of more than 50% of organic entrainment in aqueous phase is achievable after effective application of the system.

### Table 3: Typical Crud Forx™ – Reduction in Organic-In-Aqueous Entrainment

<table>
<thead>
<tr>
<th>Raffinate flow rate (m³/hr)</th>
<th>Organic entrained in raffinate (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Crud Forx™ application</td>
<td>9360</td>
</tr>
<tr>
<td>24 hours after Crud Forx™ application</td>
<td>9360</td>
</tr>
</tbody>
</table>

*Note: Although there was an indication of an improvement in entrainment levels, the test campaign had to be cut short due to the plant being taken down for maintenance, shortly after commencing the trial. Future test campaigns may offer a more conclusive trend in entrainment level reduction.
High Density Compact SX Settler Bottom Solids Management

Introduction

First Quantum’s Cobre Las Cruces (CLC) is an open pit copper mine situated in Spain, which comprises a hydrometallurgy treatment facility.

Cobre Las Cruces SX Operational Challenges

The PLS streams to the SX circuits at CLC are associated with saturated levels of calcium, resulting in varying degrees of gypsum precipitation within the SX circuits. The rate at which the gypsum precipitation occurs is variable and is associated with fluctuations in processing parameters such as feed ore calcium content, operational temperature fluctuations and sulphate balance fluctuations within the intermediate SX extraction aqueous phases. CLC employs the deep settler design SX mixer settlers in the SX process flow sheet. Figure 9 is an example of the extreme levels of gypsum that occur in the CLC Primary SX circuit and that have to be removed during planned maintenance shut down activities during the year. These planned shut downs are extensive and impact on annual plant availability.

![Figure 9: Typical Gypsum Crud Build-up in CLC Primary SX settlers](image)

CLC also employs a secondary SX circuit, in which a bleed of primary SX raffinate is neutralized and filtered prior to being introduced into the secondary extraction circuit for additional copper recovery. The neutralizing reagent is lime, which adds to the calcium content of the secondary PLS and the associated gypsum precipitation in the secondary SX extraction settlers.

Crud Forx™ Application

Crud Forx™ System Conventional Application Limitations in the CLC Application Context

The Crud Forx™ system has proven effective on SX operations which have crud characterized by relatively low density and which is easily fluidized. This is one of the reasons why the system has proven to be successful in the African Copperbelt SX applications, where the crud associated with the oxide ore bodies being treated, generally have these attributes. Where the unit has proven to be less effective is in applications with deep, high density, compact SX settler bottom solids. The main reason for this is that the system is designed as a low pressure, fluidization and fluid transfer
system, which relies on a solid-liquid ratio of approximately 40 to 50vol%. For deep solids beds, the system has to be manipulated for some time at the start of the application in order to create a crater in the SX bottom solids bed. Once this is achieved, sufficient available aqueous phase is available to ensure continuous fluidization of the surrounding solids bed. The preliminary period of application of the system to create the crater can be restrictive in the rate of extraction of the bottom solids. This preliminary period is dependent on the settler bottom solids depth and the stability of the solids structure. At Cobre Las Cruces both these factors work against the efficiency of the system. In order to find a way to improve the efficiency of the system for the CLC application, a 5-day Crud Forx™ extraction trial was conducted at the CLC SX complex.

The first four days of the trial were spent applying a single Crud Forx™ unit on the worst-affected primary SX extraction settler (E2). A total of 23 hours continuous application of the unit was completed during the three days. Although the extracted slurry composition was good, as can be seen in Figure 10, the rate of slurry removal was slow. (Typical slurry discharge flow shown in Figure 11).

Figure 10: Crud Forx™ Application - CLC Primary SX E2 Typical Extracted Slurry Composition
Figure 11: Crud Forx™ Conventional Application - CLC Primary SX E2 Typical Slurry Extraction Flow Achieved
After 23 hours of application an approximate total mass of 4.5 tons of bottom solids was extracted (Figure 12) and only a small percentage of the total E2 settler area was evacuated. Figure 13 shows the approximate area of the settler which was evacuated of bottom solids during the 23 hours of conventional Crud Forx™ application.

Figure 12: Combined E2 Settler Bottom Solids Removed during Conventional Crud Forx™ System Application (23 hours)

Figure 13: Approximate Percentage of Total E2 Settler Evacuated during Conventional Crud Forx™ System Application (23 hours)

Crud Forx™ System Modified Application for Effective Management of the CLC SX Settler Bottom Solids

Historically many of the operations employing the Crud Forx™ system have attempted to increase settler solids removal rates by using the device as a simple “crud wand” siphoning system in conjunction with diaphragm or hose pumps. This methodology is largely ineffective, as the removed
Slurry is dilute, resulting in high volumes of co-extracted aqueous being required to be treated via the crud treatment facility unit operations for a relatively small ratio of solids removed. In general, this results in crud treatment facilities becoming the bottleneck process for effective SX solids management.

The 4th day of the trial at CLC was used to modify the Crud Forx™ installation in order to assess the impact of combining the Crud Forx™ fluid lift mechanism with that of the conventional "crud wand" operating philosophy. The temporary installation is shown in Figure 14.

![Figure 14: Temporary Installation to Test Effectiveness of Crud Forx™ System Used in Combination with a Diaphragm Pump](image)

The Crud Forx™ system was applied to an area of the E2 settler, as shown, with the discharge line connected to the suction of the diaphragm pump (flexible hose indicated in red). The discharge line of the diaphragm pump (flexible hose indicated in green) was directed to the receiving solids skip shown in Figure 16. Once the diaphragm pump pumping was initiated, a reduced volume of compressed air was applied to the Crud Forx™ head. By doing this, a balance was achieved in reducing the diaphragm pumping efficiency, to minimize slurry dilution and the Crud Forx™ head back pulsation and fluidization, for optimum concentration of solids in the product slurry. The resultant instantaneous and continuous slurry composition and rate of removal are depicted in Figures 15 and 16.
After 3 hours and 15 minutes of continuous application of the combined system, the E2 settler area shown in Figure 17 was effectively evacuated of bottom solids. An estimated 1.1 tons of solids was removed during this time period. Figure 18 shows the combined solids removed during the 3 hours 15 minutes of combined application.
Table 4 compares the conventional application test results with the combination application tests results.

Table 4: Comparison of Crud Forx™ Application Test Results

<table>
<thead>
<tr>
<th></th>
<th>Day</th>
<th>Total hours of application</th>
<th>Rate of slurry removal (m³/hr)</th>
<th>Rate of solids removal (t/h)</th>
<th>Estimated percentage solids (mass %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crud Forx™ only</td>
<td>1</td>
<td>3</td>
<td>1.7</td>
<td>0.33</td>
<td>19.4</td>
</tr>
<tr>
<td>Crude Forx™ only</td>
<td>3</td>
<td>23</td>
<td>0.45</td>
<td>0.20</td>
<td>44.0</td>
</tr>
<tr>
<td>Crude Forx™ and diaphragm pump combined</td>
<td>5</td>
<td>3.25</td>
<td>1.35</td>
<td>0.65</td>
<td>47.9</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Mutanda Mining SARL, Glencore 2014

**SX Operational Risk, Health & Safety and Housekeeping Improvement**
The implementation of the Crud Forx™ application at Mutanda Mining reduced the frequency of having to drain affected SX settlers for off-line solids clean-out. The off-line draining of SX settlers often results in large volumes of drained organic being transferred to the SX bunded area. The inherent increase in fire risk and occupational health risk associated with off-line SX settler solids clean-out has been mitigated by implementing the on-line bottom solids management with the Crud Forx™. Overall SX housekeeping standard, as a result of the reduced frequency of off-line settler solids clean-out, improved noticeably.
**SX Copper Mass Transfer Improvement**

The implementation of the Crud Forx™ application has had a significant impact in improved SX copper mass transfer at Mutanda and contributed positively to assist the operation in maintaining copper production targets for most of 2014. This positive trend has continued in 2015, with the operation increasing the number of Crud Forx™ units being applied to the SX circuits.

**Crud Treatment Unit Operations Availability and Utilization**

The Crud Forx™ application results in a higher solids density slurry being removed. This means that there is a higher solids mass removal per volume of crud slurry reporting to the downstream crud treatment circuits. At Mutanda, this resulted in a debottlenecking of the crud centrifuge operations.

**Ruashi Mining, Jinchuan 2016**

**SX Impurity Entrainment Indicative Improvement**

Although reported results are preliminary at this stage and additional follow-up confirmation test work is planned, initial indications are that the effective application of the Crud Forx™ system can assist in reducing entrainment levels in SX product phases.

**Cobre Las Cruces, First Quantum Minerals 2016**

**High Density Compact SX Settler Bottom Solids Management**

The implementation of the Crud Forx™ system in conjunction with standard diaphragm pump crud removal, offers operations that require evacuation of high density, compact, settler bottom solids, an effective bottom solids management system. The accelerated rate of solids removal achieved with the combined system also offers operations with less challenging crud and bottom solids, a system for more effective daily crud removal rates.

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**REFERENCES**
