TECHNICAL CHALLENGES OF MIXERS AND SETTLERS OPERATING IN COPPER SOLVENT EXTRACTION PLANTS OF THE DEMOCRATIC REPUBLIC OF CONGO

By

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ABSTRACT

The first commercial copper solvent extraction plant of the Democratic Republic of Congo was successfully commissioned in 2008. Over the last 14 years more than 40 small, medium, and relatively large size copper solvent extraction sites have joined this challenged contest of “fast-track” projects implementation. In 2021, electrowon copper cathodes have contributed by 81% to over 1,6 million tons copper exported by the country, making it rank among the 3 top world copper producing countries. Over this period, opportunity was given for learning from various technical challenges faced by most of these operations at various stages of their still ongoing journey. This paper aims to offer a non-exhaustive review of some of these many learnings. This could serve as a background for possible upcoming upgrades of running operations and for the design of better documented greenfield projects still to come. Mixers and settlers design and operation have an impact on the stability of emulsion phase continuity and on the control of impurity transfer from the leach solution to the electrolyte. Mixer O/A ratio can be increased without affecting copper production either by recycling organic or by increasing the organic flow. Solvent extraction plants of the democratic Republic of Congo that were designed with the possibility of increasing organic recycle and/or organic flow without reducing mixer residence time below 2 minutes and/or increasing settler specific flow above say 3.5 $m^3/h/m^2$ were better prepared for the control of mixer continuity in the presence of aqueous contaminants like colloidal silica even without the need of using a coagulant to reduce the content of colloidal silica in the leach solution. On the other hand, they achieve the least transfer of impurities from the leach solution to the electrolyte even without the need of a washing stage in the solvent extraction configuration.

Keywords: challenges, copper, solvent extraction, democratic republic of Congo

INTRODUCTION

Copper mining in the Democratic Republic of the Congo (DRC) mainly takes place in the Copper Belt of the southern Haut-Katanga and Lualaba provinces of the country. In the DRC the Copperbelt is about 70 kilometres wide and 250 kilometres long between Lubumbashi and Kolwezi towns. It includes some of the highest-grade copper deposits in the world. In some reserves the grades are above 5% copper. Many orebodies also contain relatively high grades of cobalt. There are large deposits that have yet to be explored using modern technology, so the size of the reserves may be understated. Copper demand is growing, currently led by China. Between 1970 and 1988 DRC copper metal production was roughly constant at between 400,000 and 500,000 tonnes, the DRC Government owned Gécamines being the main contributor. Production then dropped steeply to under 50,000 tonnes annually between 1992 and 2001. Attracted by the new incentive mining code released in 2002, some audacious investors gained interest for the mining sector of the DRC. Since then, production has steadily grown, reaching about 300,000 tonnes in 2008. According to DRC provisional statistics published in Jan 2023, the country exported about 2.4 million tons copper in 2022(1).

Up to the year's nineties, the hydrometallurgy route for copper production included typically flotation concentration, sulphatising roasting of sulphides concentrates, leaching of copper oxide concentrate and sulphatised concentrates, followed by direct electrowinning. Relatively high-grade leach solutions (55 to 60 g/L copper) were submitted to electrowinning (EW) without inclusion of solvent extraction (SX) as a purification route.
In an SX plant copper is selectively extracted from a pregnant leach liquor solution (PLS) and transferred into the EW electrolyte. A direct current is then used to plate copper mostly onto stainless steel cathode plates.

The DRC site where copper cathodes were first produced via a process including copper solvent extraction was Ruashi Mining in August 2008. It was followed two months later by Chemaf with their Usoke plant. From that time up to 2022, not less than two mining sites including copper SX were commissioned on average every year in the region. Some of the more recent projects used lessons learned from drawbacks of earlier DRC SX plants to design SX plants better adapted to process DRC type of leach solutions. Unfortunately, many are still being designed with "weaknesses" such as the absence of organic recycles at mixers, too low throughput O/A ratio…
This paper reviews some of the main technical challenges faced by DRC SX plants involving directly or indirectly solvent extraction mixers and settlers from 2008 to 2022. Among others these include the management of silica, organic in aqueous and/or aqueous in organic entrainment, depending on SX plant design and operation.

SPECIFICITY OF SOME DRC SX MIXERS AND SETTLERS DESIGN

Specificity of some of SX Plant Design parameters

It is assumed that most of earlier engineering of DRC SX plants was mostly inspired by experience from existing American and/or Australian plants, although most were designed for different operating conditions (heap versus agitation leach, low versus high content of suspended solids, moderate versus high silica content, low to moderate versus high copper grade…).

Table 1. A few design data of a few DRC SX plants

		Chemaf Usoke	**MMG Kinsevere**	**Ruashi**	**Chemaf Etoile**
	Start-up & Expansion	10/2008 & 09/2013	05/2011	08/2008	11/2016
SX layout	Number of trains	1	2	2	1
	Configuration	2E, 2E, 2S, 1W	2E, 2S	2E, 1S, 1W	2E, 2E, 2S, 1W
Mixers	Organic recycle	Yes	No	No	Yes
	Achievable O/A	**HG: 3**	**1.4**	**HG: 2.4**	**HG: 2.4**
	Tip speed [m/s]	4.9 – 5.9	5.0	4.7 – 5.4	4.0 – 5.0
Settlers	**Specific flow $[m^3/m^2/h]$**	**HG: 2.7 – 3**	**4.6**	**3.9 – 5.1**	**4 – 4.5**

Many factors may have significant impact on SX plant performance. In the current evaluation we have mostly taken in consideration two of them. The first is the “achievable” mixer O/A ratio (adjustable preferably by increasing the numerator to avoid affecting copper production if PLS flow is reduced). The second is the settler specific flow. Our understanding is that they have been very determinant in DRC SX plant behaviour over the period under review. Both affect capital cost. We have summarized them for a few typical DRC SX plants in table 1. The impact of variations of mixers tip speed was difficult to evaluate as in both SX plants where we our investigations were carried out interstage phase transfer was seriously affected below 90% of maximum tip speed.

Recommended settlers’ specific flow varies with sources from a relatively small range of 3.6 to 4.8 $m^3/m^2/h$ (2), through a medium range of 3 to 5.5 $m^3/m^2/h$ (3), to a relatively wide range of 2 to 6 $m^3/m^2/h$ (4). To mitigate crud related issues with relatively high concentrations of fine solids encountered with DRC agitation leach PLS, mixers of all SX stages are set to run organic continuous (OC). This makes the settler crud compact at the organic/aqueous interface rather than being dispersed into or on top of the organic phase when mixers are running aqueous continuous (AC). In “normal” conditions (moderately contaminated aqueous and/or organic), an O/A ratio of at least 1.1/1 is enough to set a mixer to run organic continuous. The reverse applies when aqueous continuity is desired. Not much information was found in the literature regarding highest achievable mixer O/A ratio required to sustain organic continuity when aqueous and/or organic phases are contaminated significantly. In this regard colloidal silica is a common DRC aqueous contaminant. Its presence has required setting up uncommonly high mixers O/A ratio to sustain organic continuity or using a coagulant to reduce its concentration. O/A ratio cannot not be increased above say 1.5 in many earlier DRC SX plants without reducing PLS flow.

DRC “extreme” examples as far as achievable mixer O/A ratio and settler specific flow are concerned include Chemaf Usoke and MMG Kinsevere. The first could achieve O/A ratios as high as 3 when needed to sustain organic continuity. For extended periods, Usoke SX plant was mostly running at relatively low throughput compared to design. Settlers’ specific flows were mostly below 3 $m^3/m^2/h$. On the other hand, Kinsevere settlers operate mostly above 4.5 $m^3/m^2/h$ of settlers’ specific flow. In this plat organic recycles were not installed during construction. The O/A ratio that can be achieved without reducing aqueous flow below design is 1.4 only.

The common objective of organic recycles is to adjust mixer O/A ratio close to 1.1/1 even when PLS and advance organic flow are quite different, to ensure good mixing efficiency. In the presence of aqueous contaminants like colloidal silica, to sustain organic continuity in a mixer it is required in many DRC SX plants to increase the O/A ratio well above 2. Where possible this may include opening organic recycles valves.

COLLOIDAL SILICA

Introduction

One of the major challenges faced by many DRC copper solvent extraction plants is the disturbance of mixer stability associated with the presence of colloidal silica in aqueous phases (leach solution and/or electrolyte). The magnitude of the impact which the silica has upon the solvent extraction process is dependant upon several factors including the physical form or forms in which the silica is present, the particle size distribution of the silica particles, the chemistry of the pregnant leach solution and the magnitude of the pH shift in the mixer as protons are exchanged for copper. Changes in the physical form of the silica can result in increased process disruption without a large change in total silica concentration of the PLS. This can make management of the situation problematic as crud runs are not easily predicted. In most plants where silica is present in the PLS, there are issues with increased crud formation and slower phase disengagement resulting in increased transfer of undesirable impurities to the electrowinning circuit, significant increases in reagent losses to raffinate and in some cases transfer of electrolyte to extraction further reducing extraction efficiency due to reduced pH in the PLS. Phase disengagement in aqueous continuity tends to be most severely impacted and crud formation in aqueous continuity can occur in very large volumes. Unfortunately, it can also be very difficult to maintain organic continuity in the mixer boxes when silica is present in high concentrations. As a consequence of the surface-active nature of the silica colloids mixer stability is not maintained, the emulsion flips to aqueous continuity and massive crud runs through the plant can occur very quickly. Production losses in both quantity and quality are almost unavoidable in this case. Depending on the design of the SX plant, silica related issues could be mitigated so far in two ways in the DRC:

- The addition of a coagulant to reduce silica content in the leach solution. This has the advantage of being virtually applicable to all plants. A key point is to dose the coagulant well ahead of the solid liquid separation, like in the last leaching tank. It has an impact mostly on the operating cost.

- The increase of organic to aqueous (O/A) ratio above standards values. This requires having enough organic inventory in the SX circuit. This solution is applicable only in plants designed to run either with high advance O/A ratios or where organic recycles are provided.

If capital incurred is available for a DRC Cu project expected to last at least 10 years, calculations have shown that it makes sense to invest in a relatively big and operationally flexible SX plant (settler specific flow 3 ≤ $m^3/h/m^2$, mandatory organic recycles and high organic inventory) (5).

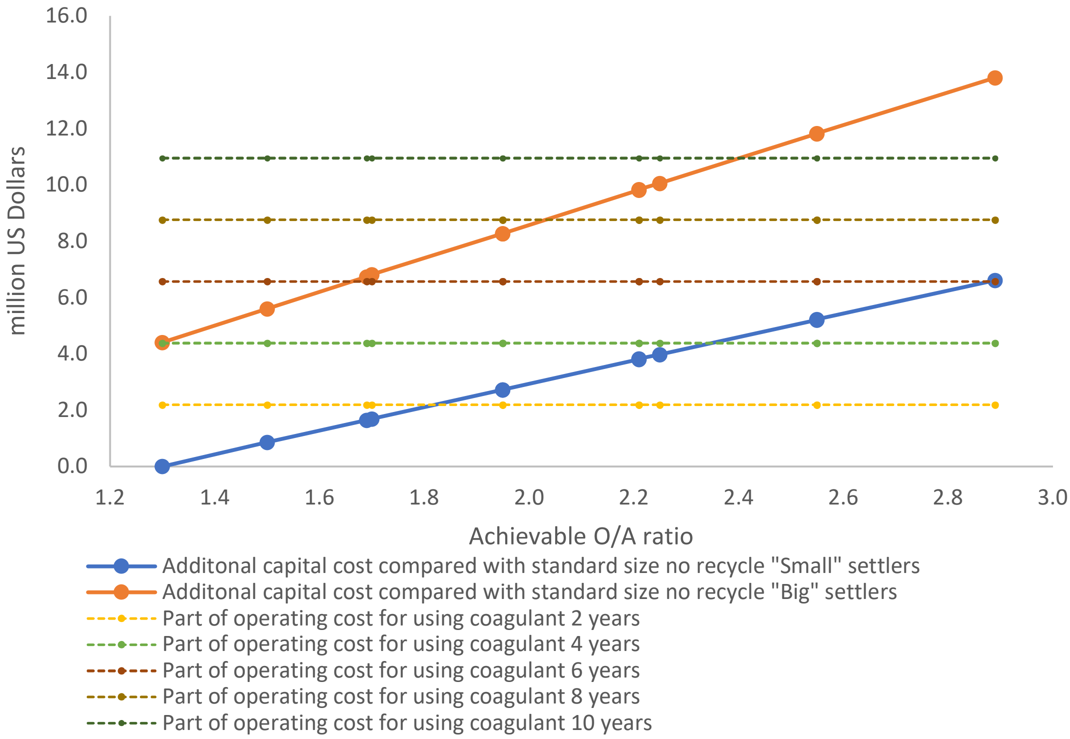

Figure 1: Capital and Operating Costs versus achievable O/A ratio

DRC Colloidal Silica related examples (5), (6)

During the construction of Kinsevere and Ruashi SX plants, sections of pipes giving the option for recycling internally part of the organic of a mixer–settler stage were not installed. Both SX plants experienced colloidal silica related issues, one in 2017 and the other in 2018. On the other hand, Chemaf Usoke and Chemaf Etoile were commissioned with organic recycles and could achieve relatively high mixers O/A ratios when needed, without reducing the flow of PLS. The mitigation of colloidal silica related issues in these 4 SX plants was experienced in the two ways described above.

From December 2018 to May 2019, a Cu production loss caused by crud runs associated with high colloidal silica in the leach solution at MMG Kinsevere was evaluated at 850 tons. To control the stability of mixers in organic continuity in absence of internal recycles of organic it was not possible to increase mixers O/A ratios above the designed value of 1.4 without reducing PLS flow. This was affecting copper production targets. The straightforward solution to the problem was to add a coagulant to reduce silica content in the leach solution. The operation was successful mainly because the coagulant was added to the last leaching tank rather than directly in the leach solution. Earlier attempts to use a coagulant in the DRC were disastrous towards the SX plant.

Owing to problems caused by silica leaching, silica polymerization in the SX circuit and high crud levels, in March 2017, the operability of Ruashi SX plant was dramatically affected for two weeks or so. Over 470 tons of Cu production (and 45 tons of Co) were lost. Mixers could not stay consistently in organic continuity while the SX plant was running within designed parameters. To stabilize mixers operation, it was required to increase the organic flow by 10 to 17% above design values to keep overall production unchanged. This necessitated the addition of diluent to top up the organic inventory. Unfortunately, the higher settlers' specific flows incurred induced relatively high organic in aqueous and aqueous in organic entrainment values, making it difficult to reduce the contamination of the electrolyte.

Chemaf Usoke experienced colloidal silica related issues as early as July 2013 with stripping mixers often flipping from OC to AC, accompanied by "crud runs" where the crud floating within the organic phase of the first stripping settler would start overflowing to the next stripping settler. This would progressively transfer crud and acid to extraction stages, increasing thus the free acid in the extraction aqueous. Extraction mixers would then also flip from OC to AC, generalizing the crud run all over the SX train. But here the problem could be quickly mitigated. To do that, the spent electrolyte had to be turned off completely for 20 minutes or so and restarted with a stepwise flow increase. Since that period, Chemaf Usoke has been typically running with higher than "standard" values of mixers O/A ratios, still achieving production targets quite easily. This is explained by the relatively long mixing time, relatively low settler specific flow. Chemaf Usoke experience was considered in the design of Chemaf Etoile SX plant which was commissioned in 2016. Colloidal silica related issues were also experienced at Chemaf Etoile in 2018 and 2019, but they were easily mitigated by running higher than standard mixers O/A ratios when required.

ORGANIC IN AQUEOUS AND AQUEOUS IN ORGANIC ENTRAINMENT

Introduction

A typical stage of a DRC copper SX train mostly includes one or two mixing boxes where the organic and the aqueous phases exchange copper and protons. An emulsion is generated made of droplets of one phase (mostly the aqueous phase) dispersed within a continuous second phase (mostly the organic phase containing a copper extractant). This type of emulsion is called an "organic continuous" emulsion where the organic is the continuous phase. The reverse applies for an "aqueous continuous" emulsion. The second major equipment of an SX stage is a settler where phase separation takes place. Stages of concern regarding organic in aqueous entrainment include the raffinate stage in extraction and the advance electrolyte stage in stripping. Aqueous in organic entrainment is dreaded in stages producing respectively stripped organic and loaded organic. In theory, relatively higher organic in aqueous entrainment is expected in the aqueous phase when a raffinate stage or a stage providing advance electrolyte are running aqueous continuous. Conversely, higher aqueous in organic entrainment may be expected in loaded or stripped organics running organic continuous. Nevertheless, to control crud at organic/aqueous interface virtually all DRC SX plants run organic continuous in all stages.

Causes of high entrainment depend on SX plant design and operating conditions. These include settler size and internal arrangement, setup of transition of emulsion from mixer to settler, mixer tip speed, O/A ratio, settlers' depth profiles, viscosities of phases involved, presence of surface-active phases contaminants which affect their disengagement rate etc.

Organic in aqueous entrainment may lead mainly to a loss of plant organic, and/or copper cathodes quality. Aqueous in organic entrainment may affect copper recovery and/or electrolyte contamination by manganese and/or silica.

DRC entrainment related examples (7)

Most of the equipment of Chemaf Usoke SX plant (currently shut down) was acquired second hand from an Australian plant. Compared with the rest of the plant equipment upstream and downstream of the SX, mixers and settlers were mostly running "oversized". This offered a major advantage to the operability of the SX plant, especially in conditions of low copper input. Entrainments were relatively low within the range of usual operating parameters. On the other hand, to good control capital cost, the size of Ruashi SX plant was optimised to match the rest of the upstream and downstream equipment. Organic entrainment in raffinates, aqueous entrainment in loaded organics were compared in these two plants over a period of more than one month in 2018 [Mitshabu, 2019].

Comparison of organic entrainment in Chemaf Usoke and Ruashi raffinates in 2018

Averages of organic entrainments in Ruashi and Chemaf Usoke SX raffinates of over one month were plotted versus advance O/A ratios in 2018 (figure 2). It was found that Ruashi had much higher organic entrainment figures with a somehow upward trend relative to the increase of O/A. On the other hand, Chemaf figures were much lower and much stable despite the relatively higher range of advance O/A ratio the plant was running.

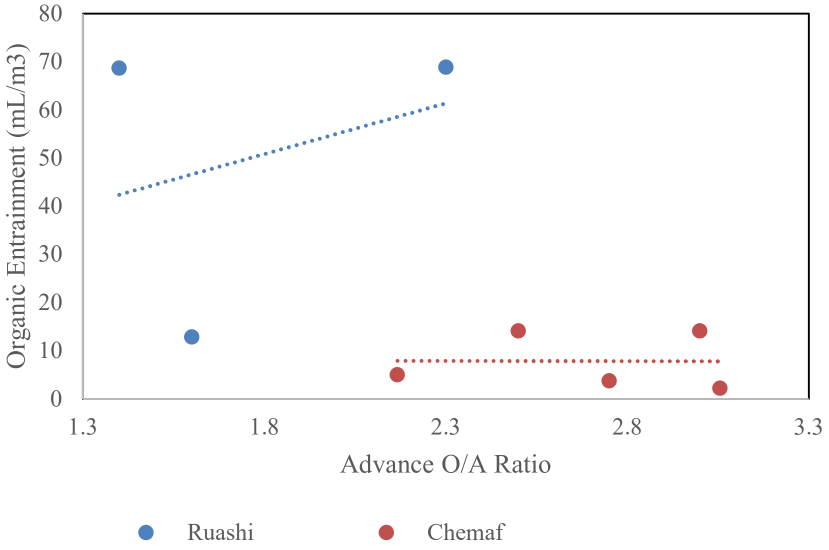

Figure 2: Comparison of organic entrainment between Ruashi and Chemaf

Comparison of aqueous entrainment in Chemaf Usoke and Ruashi loaded organics

Aqueous entrainments were also measured in loaded organics of those two plants during the same period (Figure 3). No measurable quantity of aqueous was ever detected in samples of loaded organic collected at Chemaf Usoke. Conversely, aqueous entrainment in Ruashi loaded organic was relatively high and in an increasing trend relative to the advance O/A ratio. On the other hand, at Chemaf Usoke O/A ratios as high as 3 could be run with a total mixer residence time well above 3 minutes.

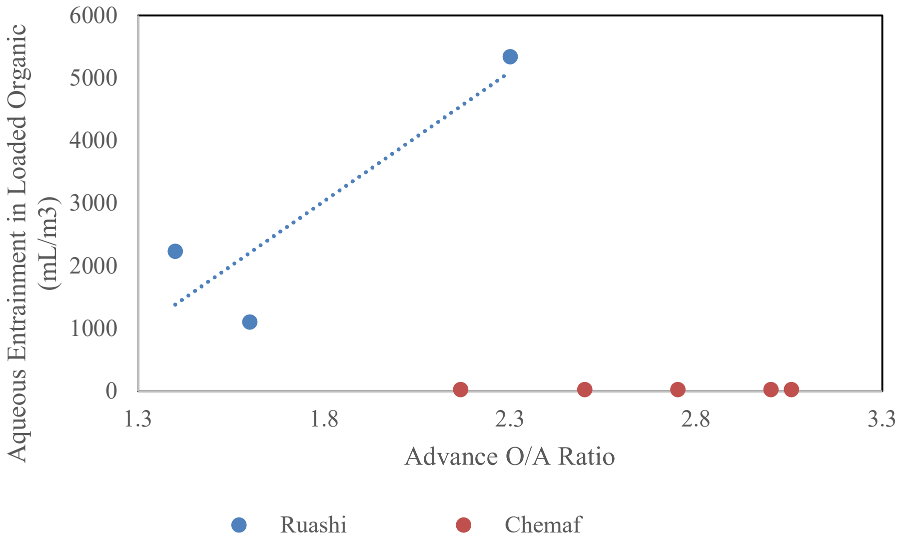

Figure 3: Comparison of aqueous entrainment between Ruashi and Chemaf

Impurities transfer

As far as DRC SX current experience is concerned impurities entrained from the PLS and likely to badly affect the electrowinning process downstream of the SX include manganese and iron ions, and silica. Most of DRC electrolyte contain cobalt ions although it does not require being added to the electrolyte. Virtually all this cobalt in the electrolyte is a balance of the quantity physically entrained from the PLS and the one lost in the electrolyte bleed.

Compared with other DRC SX-EW plants, Ruashi electrolyte inventory is quite high. This does have advantages in terms of buffering due to higher copper storage offered, especially owing to power

restrictions experienced in the area. On the other hand, pollution of the electrolyte takes long to show up, but the disadvantage is the relatively long time and effort it takes to "decontaminate" the electrolyte inventory once polluted. In 2017 crud runs resulted in high transfer of manganese and suspended solids into the electrolyte, with an impact on copper cathode quality, illustrated by nodular copper deposition.
Usually, during the commissioning stage of SX and EW plants, $FeSO4$ is added to the electrolyte up to 1000 ppm at least to control the electrolyte redox. Afterwards, concentrations of Mn and Fe in the electrolyte are adjusted mostly by bleeding
Below say 3 g/L total iron in the PLS, even without a washing stage many DRC SX plants have well managed iron transfer to the electrolyte without the need of bleeding more than 3% of total spent electrolyte flow.

OTHER DRC CHALLENGES

Design related challenges

To "have a hand" on capital expenditure some DRC SX projects were mastered "in house" from the engineering to the construction phases. Earlier SX plants constructed that way had quite a lot of operational issues. In some cases, little consideration was given to safety standards, especially for quite small plants constructed with very limited budget. Over the last 14 years 4 SX plants were designed and constructed at 3 production sites belonging to one DRC group company. It is fortunate that learnings from errors of earlier SX plants were included in the design and construction of more recent ones. Despite this learning, many SX plants, including many designed in China more recently do not include organic recycles at mixers… To increase O/A ratios or/and to mitigate entrainment at critical stages, in some SX plants the flow of spent electrolyte is split between 2 stages, with less aqueous flow sent to the critical stage.

Operational challenges

The presence of relatively high level of suspended solids in DRC leach solutions from agitation leaching is often associated with high interface crud depths and bottom mud in settlers reducing thus their working volumes. In many SX plants crud handling is quite challenging even where crud removal features were considered in the design. Periodic cleaning of bottom mud from settlers is required. This involves putting the stage involved or all the SX plant offline before emptying the settler. Earlier SX designs had no provision for isolating one stage without the need of completely shutting down the SX train. One DRC SX plant running both 1m depth and "open" settlers in a high roof shelter and a more recent design deeper than 1m and covered settlers have noticed substantial savings in the consumption of organic diluent. Settler bottom mud removal with quasi no plant shutdown and manual involvement would be a good future target for SX equipment designers.

To minimize copper losses associated with unexpected spikes in the PLS, most of DRC plants often run with unnecessarily high extractant concentration in their plant organic. It is assumed that incurred organic entrainment losses due to relatively high organic viscosity would not be outweighed by potential copper losses and/or penalties related to copper entrainment in the cobalt containing by product of many DRC copper operations.

High spent electrolyte temperature related issues

A couple of DRC SX plants are confronted with temperatures well above 40 °C, especially in stripping stages. For some reasons, spent electrolyte leaving the EW at more than 45 °C is not cooled enough before returning to the SX. The plant organic is thus exposed to accelerated acid catalyzed hydrolysis of contained oximes. The higher the temperature, the higher the evaporation rate of the diluent, especially in settlers. Safety related risks are also increased.

CONCLUSION

Although SX plant performance depends on many factors, our discussion was mostly based on achievable O/A ratio and settler specific flow. A too high increase of internal recycle of organic will affect mixer efficiency by reducing mixing time. Settlers specific flow will also increase, multiplying the risk inducing higher entrainment values.

High silica and aqueous entrainment related issues were best managed in DRC SX plants designed to handle relatively high throughput O/A without compromising mixer efficiency by a too high reduction of the mixing time. When this is was not possible it was required to add a coagulant well ahead of the

SX plant to reduce the concentration of colloidal silica in the leach solution. Likewise with organic in aqueous and aqueous in organic entrainment.
Capital cost for building “oversized” SX plants is admittedly high but later saving on operating costs would assuredly make it worth, if for example the amount of achievable copper transfer with DRC leach solutions per total settler area was compared with this same ratio in other parts of the world.

If many DRC SX plants could be redesigned, one would recommend:

- Possibility of running with relatively high advance O/A ratio (≥ 2) when needed.
- Compulsory organic recycles.
- Settler’s specific flow ≤ 3.5 m3/m2/h.

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