Decreasing Operating Costs and Soluble Loss in Copper Hydrometallurgy With Use of Innovative Solvent Extraction Circuits

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ABSTRACT

The largest single operating loss in many hydrometallurgical plants is the poor recovery of leached product in the solids sent to tailings. Any reduction in the concentration of the valuable species in this stream will improve the project economics.

Conventional design, to reduce the soluble loss, is to increase the number of wash stages or the wash/water ratio. This approach is limited in effectiveness as it can only reduce the soluble loss to that dictated by the concentration in the returning solution. For copper plants this concentration is set by the recovery in the solvent extraction (SX) plant. When using a single grade of SX feed a single grade of SX raffinate is produced generally with five to seven per cent of the copper still remaining in solution.

An alternative approach has been developed by Cognis Corporation and implemented on a number of recent projects using engineering input from Miller Metallurgical Services. The SX plant feed is ‘split’ into two different streams: a high-grade stream containing up to 75 per cent of the copper and a low-grade stream with the remaining copper. This Split-Circuit™ concept has significant benefits in terms of both copper recovery and reduction in acid costs.

The high-grade stream has the bulk of the copper removed and the raffinate sent directly back to the leach; to fully re-use the acid that has been generated during extraction in the SX process. The recycling of this higher concentrated acid stream considerably reduces the acid in the raffinate sent to washing steps. It represents a significant saving in acid consumed via the tails stream. The low-grade stream has a significantly lower SX feed grade and hence produces a lower raffinate acid and copper concentration. This lowers the economic species in the wash solution and hence reduces the soluble loss accordingly. Other operating improvements are realised with lower neutralisation costs (with the lower acid in the wash stream) and from a decreased need for in-circuit neutralisation to improve SX performance.

The SX plant itself is also split into a high-grade extraction and a low-grade extraction stream to enable the low-grade raffinate to be produced. A number of circuit alternatives have been utilised that have provided a range of benefits. The circuit concept has been included into both new and existing plant operation. As a result of this experience other methods of incorporating the concept into a circuit have been developed.

INTRODUCTION

The largest single operating loss in many hydrometallurgical plants is the poor recovery of leached product in the solids sent to tailings. Any reduction in the concentration of the valuable species in this stream will improve the project economics.

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DEVELOPMENT OF THE SPLIT-CIRCUIT™ CONCEPT

Nisbett (2002) of Cognis Corporation developed the concept of the split SX circuit concept after experience at two agitation leach-SX-EW projects in Zambia. He was frustrated to see how much acid was costing and how much acid was going out of the circuit (and being neutralised) every day. At one time the larger of the two operations calculated that they were neutralising 125 tpd of acid. The costs of the acid and the neutralisation are very large imposts on the operation.

The thinking at the time was to run the circuits with as dilute a copper concentration as possible. A low toner of copper in the PLS meant that the plant could generate a low toner raffinate with a lower soluble loss. Similarly the acid in the tails solution would be lower from the lower copper extracted from the PLS. There will always be a certain volume of aqueous that needs to be removed from the circuit to maintain the water balance. The trick is to have this volume as low as possible in both copper and acid. A schematic flow sheet of a conventional agitation leach circuit is shown in Figure 1.

Fig 1 - Conventional agitation leach and SX circuit.

An expansion project at an operation in Zambia required the addition of a second SX plant to transfer the increased production. It was realised that having two separate SX circuits opened possibilities for having them configured in alternate ways.

The key to the split circuit concept is the ‘split’ obtained at the first solid/liquid separation stage (without dilution from the washing activity). This washing can be either via filtration or counter-current decantation (CCD). It was thought an initial 70:30 split of volume in the two aqueous streams would be reasonable depending on the equipment in use. Filtration has the potential to increase this if the material filters ‘well’.

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If 70 per cent of the initial leach aqueous is removed and treated in a high-grade circuit, getting a high recovery is not that critical. It is possible to obtain some really high net copper transfer rates in SX if a ‘lower’ recovery is targeted, say 85 per cent recovery. In total the copper extracted from the high-grade SX will be approximately 65 per cent to 70 per cent of the total recovered.

The 30 per cent of the leach aqueous volume that remains after the initial solid/liquid separation is then washed extensively in the ‘second stage’ solid/liquid step (filter wash water or CCD wash solution). From this activity comes a lower grade PLS that will go to the low-grade (LG) SX train. A lower PLS grade will mean a lower raffinate copper (lower soluble loss) and less acid in the soluble loss fraction. It will also allow targeting of a higher copper recovery by use of higher reagent strength. The split circuit flow sheet developed from this is shown in Figure 2.

The split circuit concept’s full benefit is only apparent once a mass balance of both copper and acid is undertaken. The amount of copper to be transferred remains the same; but in theory the overall net transfer on the organic will be better than the conventional route (with two identical PLS streams). The savings in acid can be quite substantial; both recycled to the leach and from lower soluble and tailings losses. When the concept was discussed with the client, there was a certain amount of disbelief. However, the circuit was modelled (by the then engineering design company) and shown to behave as predicted by Nisbett as shown in Table 1.

At this level of acid in the low-grade PLS in-circuit neutralisation is not required to obtain >92 per cent copper extraction. Slightly raised reagent concentrations will compensate for the elevated acid concentration. As a result a refinement of the flow sheet was made to eliminate the neutralisation of the low-grade raffinate recycled to the solid-liquid separation step.

The high-grade stream has the bulk of the copper removed and the raffinate sent directly back to the leach; to fully re-use the acid that has replaced the copper via the SX process. The recycling of this higher concentrated acid stream considerably reduces the acid in the final raffinate sent to the washing steps. It represents a significant saving in acid consumed via the tails stream. The low-grade stream has a much lower SX copper feed grade and hence produces a lower raffinate concentration. This lowers the copper in the wash solution and hence reduces the soluble loss accordingly. Other operating improvements are realised with the lower tails neutralisation cost (with the lower acid tonnage in the wash stream) and from a decreased need for any in-circuit neutralisation to improve SX performance.

The key to implementation of the split circuit concept is to have at least two SX facilities that can treat alternate PLS grades. This allows the low-grade raffinate to be used as wash solution and the high-grade raffinate to be recycled to the leach.

**SPLIT CIRCUIT ECONOMICS**

The economic evaluation of the split circuit economics is based on the significant reduction in operating costs from the lower acid consumption and lower tails neutralisation costs. An interactive mass balance is required (MESTIM®, ASPEN®, or similar combined with Cognis ISOCALC®) that allows modelling of circuit alternatives for economic evaluation. The balance needs to track copper, acid, calcium and total sulfate as a minimum.

The operating cost reductions come from:

- **Increased recycling of high acid tenor, high-grade raffinate directly to the leach.**
- **Production of lower copper tenors in the low-grade raffinate used as wash water, reducing the true copper soluble loss.**
- **Decreased acid tenor in the low-grade raffinate – both from the lower copper in the low-grade feed but also from the reduction in acid recycle load build-up in the closed wash circuit.**
- **Decreased cost of neutralisation of the acid in the solution exiting with the tailings stream.**
- **Decreased acid loss and cost of neutralisation of any excess water from a positive plant water balance – this bleed can be made up from the low-grade raffinate and thereby reduce the acid contained in it.**

**TABLE 1**

Typical conventional and split circuit copper and acid profiles.

<table>
<thead>
<tr>
<th>No</th>
<th>Stream</th>
<th>Conventional circuit aqueous component</th>
<th>Split circuit aqueous component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Flow (m³/hr)</td>
<td>[Cu] g/l</td>
</tr>
<tr>
<td>1</td>
<td>Preleach thickener U/F</td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Leach discharge</td>
<td>180</td>
<td>10.0</td>
</tr>
<tr>
<td>3</td>
<td>First CCD O/F</td>
<td>330</td>
<td>5.6</td>
</tr>
<tr>
<td>4</td>
<td>PLS to SX1</td>
<td>165</td>
<td>5.6</td>
</tr>
<tr>
<td>5</td>
<td>PLS to SX2</td>
<td>165</td>
<td>5.6</td>
</tr>
<tr>
<td>6</td>
<td>SX1 raffinate</td>
<td>165</td>
<td>0.45</td>
</tr>
<tr>
<td>7</td>
<td>SX2 raffinate</td>
<td>165</td>
<td>0.45</td>
</tr>
<tr>
<td>8</td>
<td>Recycle to leach</td>
<td>150</td>
<td>0.45</td>
</tr>
<tr>
<td>9</td>
<td>Recycle to wash</td>
<td>180</td>
<td>0.45</td>
</tr>
<tr>
<td>10</td>
<td>Final CCD U/F</td>
<td>30</td>
<td>0.65</td>
</tr>
<tr>
<td>11</td>
<td>Post leach thickener U/F</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
• Eliminating the need to control the pH in the SX feed circuits. With a single PLS grade the recycled acid via the wash system can increase the PLS acid concentration to a level where achieving +92 per cent recovery in SX is problematical. With the split circuit concept the recycled acid levels are below those that would cause concerns. As a result in-circuit neutralisation is not required to achieve high SX plant recoveries. For the first plant implementation this aspect was significant.

The implementation needs a number of extra capital cost facilities that would not necessarily be required for a single grade SX plant at a new site:

• Two SX plants of similar capability. This aspect can be ignored if there is a plant expansion that includes the construction of the second plant. Similarly for a large capacity plant that needs two SX facilities to treat the full volume flow.

• Two sets of solution clarification, PLS storage and pumping, raffinate storage and pumping, and plant controls and instrumentation.

Recent corporate risk management tools have identified the provision to two SX plants as a prime driver towards reducing the business interruption risk from an SX fire (Miller, 2005). With this aspect also driving the use of at least two SX facilities, the incremental capital cost for the split SX does not necessarily need to cover the provision of the two SX plants. However, the increased facilities for solution clarification and handling will need to be included in the financial analysis.

Commercial analyses have been done on three projects to incorporate such split circuits. In all cases the financial indicators have been extremely positive with payback periods of less than 12 months. None of the financial analyses have been made available for commercial confidentiality reasons.

IMPLEMENTATION STRATEGIES

A number of different implementation strategies have been developed as the level of confidence in the concept has increased. The basic strategy uses two separate SX plants operating independently and producing two raffinate streams. Further refinement has been to use a single SX train for the split circuit; and another to integrate the split circuit flow sheet into a plant to remove copper to ppm levels prior to cobalt hydrometallurgical recovery. All three circuits are described.

Implementation with two SX plants

The block flow sheet for the ‘Standard’ implementation scenario is shown in Figure 3.

In this circuit the two SX plants are physically separate and are only linked through the electrolyte circuit to the electrowinning (EW) plant. It requires the most equipment and facilities; but can be used as part of the project overall risk management planning. The use of in-circuit pH control is no longer required and can be removed (shown dotted in Figure 3).

Two operations using this concept have been installed to date with the assistance of MMS engineering services. The first to be implemented was for a nominal 35 000 tonne per annum copper EW facility, which treated 400 m³/h through each SX train. The second was a new plant with a 60 000 tpa EW facility to treat 800 m³/h through each train (Miller, 2003).

As discussed in a later section, the first plant did not initially achieve the full benefit of the circuit modifications due to a very large positive water balance. Later operation improved to the predicted levels as the water balance was brought closer to neutral. The second plant achieved the full benefits from initial start up as it was in a nett negative water balance. This aspect of the plant design and operation is crucial to attain the full benefit of the split circuit modifications.

Implementation with a single SX train

Having seen the implementation of the first split-circuit SX plant, another existing operation undertook in-house analysis of the potential benefits to them of the split circuit (Grosse, 2004). The plant has four trains of SX each with three extract and two strip stages. The overall solids and water balance was not conductive to using the separate existing trains in the basic split SX plant configuration. However, there was a significant and large soluble loss that could be reduced if the wash water on the CDD circuit could be increased in flow rate. The project was considered in two separate stages:

1. recommission the existing CCD units to largely replace an ageing belt filter plant;
2. increase the wash ratio in the CDD circuit by using the No 3 extraction stage as a parallel unit treating low-grade PLS from CCD No 2, and create a high-grade PLS from CCD No 1 overflow.

This strategy was modelled to ensure that both stages were cost-effective and that the same sorts of benefits would accrue. The plant block flow sheet is shown in Figure 4.

By utilising the capability of the ‘spare’ extraction mixer-settler, the plant PLS flows could be doubled to allow the high-grade and low-grade circuits to maximise the split achieved. The major benefit is in the cost reduction in the acid neutralised in the tails. The plant has an extremely positive water balance and has been consuming prodigious amounts of acid and lime in the excess volumes sent to tails. Again payback for this project was less than one year.
One other project is currently in design using a similar but slightly more optimised arrangement. This project uses the series-parallel concept in a single SX train to provide the two separate streams for operating cost minimisation. However, in this case the 'parallel' section consists of two extraction stages in series. In this way the low-grade raffinate is very low in copper due to the strong extraction from the newly stripped and high reagent concentration organic.

This plant has also taken steps to minimise any adverse effects from a positive water balance. The plant tailings are neutralised so that any un-leached sulfide minerals can be recovered by flotation. It is thus important that the minimum acid is sent to tails as excess gypsum production can interfere with recovery in the flotation plant.

A two-SX plant option was not considered to be required from a risk management perspective as the leach project represents less than ten per cent of the site production and could not support the full capital for separate SX plants. Alternate management steps are being taken to reduce the risk of a fire occurrence and other business interruption risks.

Integration with cobalt production in Zambia

Another use for the split circuit concept has arisen particularly in the central African region (Zambia and DRC). A number of copper-cobalt deposits are suitable for direct leaching and recovery of both copper and cobalt. To date the method employed to recover both metals has been to:

- Leach a concentrate (or roaster calcine) to create a high-grade copper solution (>30 g/L).
- Recovery of the copper by direct electrowinning (EW) and recycle of the depleted EW tails to the leach. This utilises the acid produced and 'preg-builds' the cobalt concentration.
- Part of the EW tails is sent to electro-stripping (ES) to remove the final copper prior to cobalt recovery.
- ES tails are treated in various stages of precipitation, re-leaching and impurity removal to generate an electrolyte for cobalt EW.

The process tends to recover only 65 to 70 per cent of the cobalt and produces an impure copper deposit that must be re-refined to LME ‘A’ quality. A new copper SX-EW plant is being designed to replace an existing EW-ES plant and improve cobalt recoveries. The block flow sheet is shown in Figure 5.

![Diagram](image.png)

**Figure 4 - 'Series-parallel' split circuit flow sheet.**

**Figure 5 - Split circuit for copper SX in cobalt circuit.**

The bulk of the copper is removed in the first HG extraction (at approximately 30 g/L copper). Two-thirds of the raffinate is recycled to the leach to utilise the acid and to preg-build the cobalt. LME ‘A’ metal is produced from the purified and concentrated SX strip solution. The cobalt bleed stream is neutralised and iron precipitated prior to the low-grade parallel SX. Copper extraction is maximised by in-mixer neutralisation of the acid produced. This shifts the isotherm to such an extent that the final copper concentration is <50 ppm in the raffinate.

The ability to use the split circuit concept in this modified arrangement has meant that the benefits of acid recycle to leach are gained as proven for the other circuits. The production of LME metal increases the income stream by up to 20 per cent for the ES copper. The acid lost in iron precipitation is the same as the previous operation but the copper loss has been reduced from 500 ppm to <50 ppm. In total these are considerable economic benefits to the operation.

A similar circuit design has been incorporated in the flow sheet for a copper leach-SX-EW project that will make a cobalt precipitate intermediate product. In this case the purity of the precipitate is not as critical as for on-site metal production.
However, the split circuit concept allows all of the copper to be recovered as LME A and almost all of the acid recycled to the leach. Project economic modelling has shown that the split circuit design of the SX plant is an integral part of an overall cost-effective process.

**OPERATIONAL FACTORS**

A number of operational factors influence the ability of the split circuit configuration to operate at maximum effectiveness. The main one is the overall water balance. If the balance is positive then extra water is bled out of the circuit to maintain the balance. This increases both the soluble loss of copper and the total quantity of acid sent to tails. A negative water balance requires water addition to make up the total lost in tails. This maximises the benefit not only from the split circuit, but also for the conventional SX arrangement.

With a positive water balance, there is an overall reduction in the concentration difference that can be maintained between the high-grade and low-grade SX circuits. The raffinate from the high-grade SX can not be all recycled to the leach; and some of the flow (and copper) is sent to the low-grade circuit. Again this reduces the effectiveness of the split circuit. Only site specific mass balancing will indicate if the loss of effectiveness is significant in the decision to implement a split circuit. To date none of the projects that have considered a split circuit have seen that the down-side risk is high enough to stop implementation.

Some innovative water balance control measures have been implemented on split circuit projects to ensure that the balance approaches neutral (or even negative) as closely as possible:

- **High compression thickening or filtration (if appropriate) for the preleach solids to minimise the water input.**
- **Use of low-grade raffinate for flocculant dilution rather than new water.**
- **Use of low-grade raffinate for slurpy pump gland service – this requires acid resistant gland water pumps and pump gland systems but the extra costs are quite marginal.**
- **Milling in raffinate to remove the need for preleach water removal (Baxter, 2004). This practice needs a stainless steel (or stainless-steel lined) mill with ceramic or pebble grinding media to be fully effective.**

Minimisation of other water inputs by providing systems that do not need extra water for spillage clean up, flocculant make up and delivery, SX plant scrub or wash stages and EW bleed minimisation. These latter aspects are all related to SX entrainment control and are covered in detail by Miller (2003a, 2003b).

It is evident that split circuit SX benefits are directly related to control of the water balance in the plant. As a result the focus in the split circuit designs has also been on the water balance. The result has generally been an improvement in the metallurgical plant response as well as a reduction in the positive water balance. One project has now achieved a negative water balance as a result of this focus. The maximum benefits have been obtained and realised as direct and indirect result of implementing the split circuit.

**FUTURE IMPLEMENTATION**

The applications of the split circuit SX concept seem to be limited only by the imagination of the plant designer and the identification of opportunities. One area that can readily use a split circuit is copper heap leaching. Heap leach management strategies often need two or more streams of leach solution at different acid contents. These could be part of an integrated split circuit SX design where the copper is removed from two parallel streams (PLS and ILS) and the resulting raffinate streams directed to different parts of the leach heaps.

Benefits that would arise from this arrangement would include:

- **Ability to treat high copper streams from early leaching heaps. The high acid stream is returned to the early leach heap to recover higher grade solution.**
- **Treatment of ILS solution with production of lower acid grade raffinate for use on later leaching heaps.**
- **These different acid concentrations can contribute significantly to lowering the gangue acid consumption as part of the overall heap management plan (Miller, 2002).**

Other metal extraction systems are also including heap leaching as part of their recovery. Nickel is a prime case where management of the PLS and raffinate acid levels is required to ensure that the overall acid consumption is minimised both in the heap and the metal recovery process. A split circuit arrangement appears to offer benefits when considered as part of an overall process development.

**CONCLUSIONS**

The split circuit concept has been shown to be economically attractive in all cases considered to date. Financial indicators are always positive with fast payback.

The circuits are readily operated to achieve the projected benefit. Focus on the water balance assists both the split circuit effectiveness and the overall plant management and control. Split circuits have been implemented in three different configurations and SX plant arrangements. Further opportunities are identified in assisting heap leach management plans as well as in other metal extraction operations.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


