Optimizing acid utilization and metal recovery in African Cu/Co flowsheets

M. REOLON*, T. GAZIS*, and S. AMOS*

*GRD Minproc Pty (Ltd), South Africa

Recent global demand for copper and cobalt has resulted in renewed interest in developing the copper and cobalt deposits in the DRC. In addition, recent dramatic increase in sulphur and sulphuric acid prices, as well as the copper and cobalt prices, has led to the creation of innovative ways to increase the utilization of reagents and recovery of metals.

As a result of the potential in saving in operating costs, and the possibility of increased recovery of metal, a series of trade-off studies was performed to determine the cost benefits to several copper/cobalt studies for projects in the DRC. The purpose of these trade-off studies was to determine the feasibility of implementing any of the alternate flowsheet options into the next phase of these projects.

This paper presents the base case and the various trade-off options and includes a brief description of the flowsheets considered. Special considerations specific to the base case are identified as these may influence the benefits of the options for individual projects. The major advantages and disadvantages are listed in order of importance to indicate where capital, operating or latent risk costs are affected by the options. High-level cost estimate ranges for capital, operating and annualized risk are given for the various options. Where applicable, comments on sensitivity to any identified parameters are discussed.

In order to compare the various options to each other, both process and economic summary tables comparing the options are shown. Discussion on the interaction of more than one of the options will complete the comparisons.

Democratic Republic of the Congo

Introduction

The Democratic Republic of the Congo was initially established as the Belgian Congo in 1908. It subsequently gained independence in 1960. The early years of independence were marked by social and political turmoil.
In a coup in 1965, an army colonel, Joseph Mobutu seized power, renaming himself Mobutu Sese Seko and the country Zaire. Under his presidency, social and economic conditions in the country deteriorated further. In 1997, Mobuto was toppled by a rebel leader, Laurent Kabila. Kabila restored the name of Congo in the form of the Democratic Republic of the Congo (DRC). He, in turn faced a rebel movement backed by Rwanda and Uganda. Troops from a number of African allies were flown into the country and the rebellion was put down and a ceasefire signed in 1999. Kabila himself was assassinated in early 2001, and his son, Joseph Kabila, was installed as president of the Republic.

Joseph Kabila subsequently negotiated the removal of Rwandan forces, and a peace agreement was signed in South Africa in 2002. A transitional government was formed with the objective of eventually holding democratic elections in the country. These elections were held in July 2006, and resulted in the leading two presidential contenders each receiving less than 50% of the vote, although Joseph Kabila did gain a significant majority over his leading rivals. In the terms of the election rules, a run-off between the last two took place in November 2006 with Kabila gaining an outright majority.

The United Nations were invited to install a peacekeeping force in the country at the end of last century, and this force has contributed to a general improvement in the internal security of the country, although, even today, there is continuing insecurity in the north-east of the country. This area is quite remote from the main copper and cobalt mining province of Katanga, where conditions have remained calm.

Economy

Since 2001, when Joseph Kabila became president, the economic policy of the country has aimed at stabilization. Since about that date, there is little doubt that the mining and construction sectors are improving, albeit from a low base. Gross national income is US$120 per capita, but since 2002, the economy has shown signs of expansion with a GDP growth in 2002 of 3.5%, 2003: 5.7%, 2004: 6.8%, 2005: 6.5%. The latter two figures are provisional.

The independent central bank has bought inflation under control in recent years, again indicating a normalizing of the economic and social situation within the country.

The corporate tax and investment codes are being revised to continue to liberalize the domestic business environment and attract foreign investment, and an increasing number of foreign companies are establishing themselves in the country.

Gecamines

Prior to the departure of the Belgians from the Congo in 1960, the copper industry in the Katanga area was owned and operated by Union Miniere de Haut Katanga (UMHK), a company dating from 1906. After independence, nationalization of the copper industry was inevitable, and UMHK were eventually dispossessed of their ownership of the industry, and a state owned company, initially Generale Congolaise des Minerals and later La Generale des Carriers et des Mines (Gecamines) took over as owners and operators of all the copper mines in Katanga. Gecamines initially prospered throughout the 1970s and 1980s, but since the late 1980s, the company went through a series of increasing crises, until finally, by the late 1990s, copper production was only 35,000 t of copper and 3,940 t of cobalt, compared to 437,000 t of copper in 1987, plus 11,900 t of cobalt in the same year.

As a result of this poor performance, the Government started to seek ways of improving the situation both within Gecamines and within the copper industry as a whole. As a result of these initiatives, foreign private industry has been encouraged to enter into agreements with Gecamines in an attempt to restore the industry. After some stumbling, these initiatives are now beginning to bear fruit.
**Code Minier**

A Code Minier has been introduced by the Government and provides a transparent legal framework for investors in mining. The code has been gazetted in the French and English, making it easier for foreign Anglophone companies to review the legislation.

**Copper cobalt process—the base case**

A typical hydrometallurgical copper cobalt flowsheet as used in southern Africa is shown in Figure 1. This flowsheet is used as a base case against which the various options are compared.

A predominantly oxide ore is crushed and milled to expose the copper and cobalt minerals for leaching. The milling step is the main entry point for water in the process.

The milled slurry then undergoes a solid/liquid separation stage in a thickener in order to reduce the water entering the leach circuit. The separated water is recycled back to the mill.

The thickened slurry is sent to the leach reactors, where acid rich raffinate (from solvent extraction) and makeup acid is blended with the slurry. Copper and other elements are leached by the acid. The leach reaction is also performed under reducing conditions using sulphur dioxide in order for the cobalt to be effectively leached.

After leaching the slurry is washed in a 6 stage counter current decantation (CCD) wash circuit using slightly acidified process water. This step removes most of the metal containing solutions from the leached solids. The washed solids are discharged to the tailings neutralization step, and the metal containing solution is sent to the solvent extraction (SX) step as pregnant leach solution (PLS).

The washed solids from the underflow of the last CCD thickener are pumped to the tailings neutralization circuit. Iron/manganese precipitate is also neutralized in this step. Slaked lime is used to control the pH at above 8. The neutralized tails are then pumped to the tailings disposal site. Some of the water is decanted from the tailings dam and recycled to the process water pond. The balance of the water remains in the tails. This is an exit point for water.

---

**Figure 1. Base case process flowsheet**

OPTIMIZING ACID UTILIZATION AND METAL RECOVERY IN AFRICAN Cu/Co FLOWSHEETS
The PLS is fed to the SX circuit where copper ions are selectively exchanged for acid (or hydrogen ions) using a liquid organic solvent extraction medium. The discharge solution (copper lean but acid rich) is discharged from the SX circuit as raffinate, which is recycled and used in the leach step (see above). In order to maintain a water balance, and to bleed cobalt and other metals out of this recycle stream, some of the raffinate is bled off and sent to the cobalt production circuit.

The copper extracted by the SX organic is stripped with a strongly acidic electrolyte, where the copper ions are exchanged for acid. The copper rich electrolyte is sent to the copper tank house where the copper is electroplated, harvested and prepared for market. The electrowinning (EW) process produces acid while plating copper metal.

The raffinate bleed that is sent to the cobalt production circuit is depleted of copper, but rich in acid (from leach plus SX) and other accumulated metals. The cobalt circuit consists of a series of stage-wise neutralization/precipitation reactions and solid/liquid separation steps.

The first stage is to remove primarily iron, manganese, aluminium and phosphates as precipitates. This is done using limestone as a neutralizing agent controlled to pH of 3–3.5, and a mix of SO₂/air as an oxidizing agent for iron and manganese. The precipitate is thickened, filtered, washed and transferred to tailings neutralization (see above).

The next stage is to precipitate residual copper at pH 5–5.5 using slaked lime. The precipitate is thickened and pumped to the leach circuit for recycle of the copper and some co-precipitated cobalt.

The final stage is to precipitate cobalt as an impure hydroxide at pH 8 using slaked lime. This cobalt product is thickened, filtered, dried and bagged for market.

The remaining solution from the cobalt circuit is sent to the process water pond for recycle in the plant. Excess water is treated at this point for disposal.

**Alternative flowsheets for the optimization of reagent utilization and copper/cobalt recovery**

The focus of the trade-off studies has primarily been on the reduction of acid consumption, and the subsequent need to neutralize the acid with limestone, lime and other acid neutralizing reagents. This drive for acid consumption minimization was particularly powerful during the recent sulphur price increase during 2007 and 2008. Even though the sulphur price has returned to the levels prior to this increase, there remains a significant cost to transport the sulphur into the DRC, therefore one can always expect sulphur costs at substantially above coastal sulphur costs.

The following list of options has been considered in recent projects, initially as trade-off studies as well as inclusions in the feasibility studies and EPCM.

- Split SX
- Milling in raffinate
- Pre-leach filtration
- Acid tailings
- Post-leach filtration instead of CCD.

The projects evaluated during mid 2007 to mid 2008 are located in the DRC and range in size as follows:

- ROM throughput — 1 300 000 to 4 500 000 t/a
- Copper production — 30 000 to 80 000 t/a. the base case is centred around 40 000 t/a
- Cobalt production — 1 500 to 7 000 t/a.
Capital and operating costs are based on the costs received during the period given above. It must be noted that these costs did vary significantly during this period. For this reason the results given in this report are indicative only. An evaluation of this nature will need to be performed on specific projects to obtain relevant data specific to the project under evaluation.

Split SX

Description

The base case flowsheets and design criteria have proposed that the leach product be washed in a series of six CCD thickeners before passing the PLS (CCD1 overflow) to copper SX/EW. At this point, this is the only place in the circuit where copper is removed.

By introducing the split SX option, the first CCD thickener will assume the function of a post-leach thickener as well as a point of separation for the high grade and low grade PLS streams. The high grade PLS stream will pass directly through the high grade copper SX/EW stage where copper is removed. The resulting raffinate solution is recycled to the leach feed. The low grade PLS stream will be passed through the remaining five CCD thickeners, undergoing washing before being sent to the low grade copper SX/EW stage. The resulting low grade raffinate is sent to the cobalt removal circuit.

The amount of Copper produced increases slightly in comparison with the Base Case, as well as a slight increase in the production of Cobalt, resulting too in less Cu/Co settling out in the tailings dam. (Figure 2.)

Analysis for splitting the SX stream into high grade and low grade streams

In comparing the mass balances for both the base case and for the split SX alternative, it is observed that both the copper and cobalt production increase slightly (having fewer losses to the tailings dam), with a significant decrease in total acid consumption. Due to splitting the PLS and redirecting a portion of it to the high grade SXEW stage, the acid content of the CCD

Figure 2. Split SX flowsheet

OPTIMIZING ACID UTILIZATION AND METAL RECOVERY IN AFRICAN Cu/Co FLOWSHEETS
underflow to the tailings neutralization decreases as well as the acid content of the cobalt bleed stream; therefore limestone required to neutralize this acid decreases. These changes are used to determine the change of operating cost and revenue earned.

Advantages and disadvantages

Below is a list of advantages and disadvantages of the split SX option in relation to the base case.

Advantages

Capital
- Reduced lime plant
- Reduced acid plant

Operating and revenue
- Reduced acid costs
- Reduced Co bleed and tails neutralization
- Cu production increase
- Co production increase

Risk
- SX plant redundancy
- Potential for additional SX throughput
- Potential to continue partial operation on SX fire destroying one train

Disadvantages

Capital
- Additional SX stream
- Additional PLS pond
- Additional raffinate pond

Operating and revenue
- Additional plant operation (labour)

Risk
- Operational complexity

Capital estimate

The capital cost changes for the implementation of the split SX option is based on the following.
- Reduction in limestone plant size
- Reduction in acid plant size
- Addition of a secondary copper SX/EW circuit as well as associated ponds.

Operating cost estimate

The operating cost changes for the implementation of the split SX option is based on the following.
- Reduction in the consumption of limestone and acid
- Increase in copper production
- Increase in cobalt production.

Risk estimate

Annualized risk equivalent costs have been determined based on the following significant risks.
• SX train redundancy
• Partial production after a fire event.

Results
The summarized results for the split SX estimated capital costs, operating costs and revenues earned, and annualized risk assessment is given in Table I.

The implementation of the split SX option will negatively affect capital, where the addition of an extra PLS and raffinate pond capacity as well as supplementary SX costs will load the capital expenditure by an additional $2 000 000. Capital advantage for reduced acid and lime plant is also allowed.

An operating cost advantage of $4 200 000 is realized, however, in the split SX option. This emanates greatly from the increased copper and cobalt revenue, as well as a reduction in the consumption of both acid and limestone.

The costs associated with risk are advantageous in excess of $300 000 /a.

Recommendation
The split SX option offers both risk as well as operating and revenue advantages and is recommended to be considered in any future hydrometallurgical copper cobalt projects.

Milling in raffinate

Description
The base case flowsheets and design criteria have proposed that the mill circuit uses process water recycled from the downstream preleach thickener overflow and makeup process water. This results in the addition of water into the leach circuit due to the slurrying of the relatively dry ROM. Any water that passes into the leach circuit will need to be removed from the process. The water trapped in the settled tailing is the only substantial outlet for water in the plant. Any further water accumulation will have to be treated in the raffinate bleed.

By introducing the milling in raffinate option, recycled raffinate is used to slurry the crushed ROM, thus reducing the water input into the process. This will have the net effect of reducing or eliminating excess water accumulation in the plant, therefore reducing the raffinate bleed to the cobalt plant.

Other benefits include better leaching and the elimination of the preleach thickener step, reduced acid and limestone consumption. (Figure 3.)

Table I
Cost advantage summaries for the split SX option

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost advantage</td>
<td>-$2 000 000</td>
</tr>
<tr>
<td>Operating/revenue cost</td>
<td>$4 200 000</td>
</tr>
<tr>
<td>advantage</td>
<td></td>
</tr>
<tr>
<td>Annualized risk advantage</td>
<td>$300 000</td>
</tr>
<tr>
<td>Net annual advantage</td>
<td>$4 500 000</td>
</tr>
<tr>
<td>Payback</td>
<td>0.45 years</td>
</tr>
</tbody>
</table>

Positive cost values imply savings or financial gain to the project.
Negative cost values imply expenses or financial loss to the project.
Data indicative of 40 000 t/a copper production.
Analysis of milling in raffinate compared to milling in water (base case)

In comparing the mass balances for both the base case and for the milling in raffinate alternative it is observed that the acid consumption decreases. The acid content of the raffinate bleed also decreases, therefore limestone to neutralize this acid decreases. Due to the reduced size of the cobalt bleed, the tenor of cobalt will increase in the raffinate returning to leach. This in turn will cause the cobalt loss to CCD underflow to increase, resulting in cobalt production decrease. These changes are used to determine the change of operating cost and revenue earned.

Advantages and disadvantages

Below is a list of advantages and disadvantages of the milling in raffinate option in relation to the base case.

Advantages

Capital
- Cobalt plant feed and capital reduced
- Acid plant size reduced
- Limestone plant size reduced
- No pre-leach thickener required.

Operating and revenue
- Cobalt plant operating cost reduced
- Acid consumption reduced
- Limestone consumption reduced
- No preleach op costs required
- Reduced maintenance on acid and lime plants.

Risk
- Co tenor therefore product purity increase.
Disadvantages

Capital
• Acid resistant mill required
• Acid resistant mill area required.

Operating and revenue
• Co production decrease
• Additional mill maintenance.

Risk
• Risk of mill and area corrosion
• Added mill delivery schedule of approximately 20 weeks
• HSE risk.

Capital estimate

The capital cost changes for the implementation of the milling in raffinate facility are based on the following.
• Reduction in the size of the cobalt plant
• Reduction in the size of the acid plant
• Complete removal of the preleach thickener area
• Reduction in the size of the limestone plant
• Additional cost for an acid resistant mill, stainless steel chute and plate work and protected structural steel and concrete.

Operating cost estimate

The operating cost changes for the implementation of the milling in raffinate facility are based on the following.
• Reduction in the consumption of acid and limestone
• Reduced power, maintenance and consumable in the cobalt plant
• Remove preleach thickener operating costs
• Reduced operating cost in the acid and limestone plants
• Additional mill operating costs
• Reduced cobalt production.

Risk estimate

Annualized risk equivalent costs have been determined based on the following significant risks:
• Additional delay in delivery of the mill causing delayed revenue. This risk is highly variable, and could be mitigated by earlier procurement, if such timing is available
• Downtime and replacement of corroded mill shell
• Increased HSE risk in the area.

Results

The summarized results for the milling in raffinate estimated capital costs, operating costs and revenues earned, and annualized risk assessment is given in Table II.

The implementation of the milling in raffinate option will have an overall capital advantage where the reduction of process and reagent plant capital more than offsets the additional cost of the milling area. The reduction in the cobalt plant and acid plant result in the major capital reduction.
An operating cost advantage of $5 000 000 is realized in the milling in raffinate option. The largest contributor is from the reduction in sulphur and limestone reagent requirements.

The costs associated with risk have been shown to be about $1 000 000/a if the added delay of production start-up can be avoided. If however the added delay can not be mitigated, then the total annualized risk climbs to $5 000 000 /a.

**Recommendation**

In comparing milling in raffinate to milling in water, the result established that milling in raffinate is potentially a high risk option, both technically as well as commercially. Delivery times are high, and the need for expensive spares (mill shell), or prolonged shutdown are typically unacceptable. Risk mitigation strategies may well swing this option positively. The alternative option of preleach filtration vs. thickening offers similar benefits while eliminating the high risk factor of milling in raffinate and is preferred where filtration is feasible.

**Preleach filter**

**Description**

The base case flowsheets and design criteria have proposed that the feed to leach be dewatered in a thickener, thus allowing process water to be recycled back to the mill. Any water in the underflow of this thickener will result in the addition of water into the leach circuit. Any water that passes into the leach circuit will need to be removed from the process. The water trapped in the settled tailing is the only substantial outlet for water in the plant. Any further water accumulation will have to be treated in the raffinate bleed, resulting in the neutralization (loss) of acid using limestone.

By using the preleach filtration option, the water content of the slurry to leach is reduced from 50–60% to an estimated 20–25%, thus reducing the quantity of water into the process. This will have the net effect of reducing excess water accumulation in the plant, therefore reducing the raffinate bleed to the cobalt plant and increasing raffinate utilization in the leach. This will result in reduced acid and limestone consumption. (Figure 4.)

**Analysis of preleach filtration as compared to the base case of preleach thickening**

In comparing the mass balances for both the base case and for the preleach filtration alternative it is observed that the acid consumption decreases. The acid content of the raffinate bleed also decreases, therefore limestone to neutralize this acid decreases. Cobalt production decreased due to increased tenor in the raffinate, resulting in increased losses to tails. These changes are used to determine the change of operating cost and revenue earned.
Advantages and disadvantages

Below is a list of advantages and disadvantages of the preleach filtration option in relation to the base case.

Advantages

Capital
- Reduce cobalt plant size
- Reduce acid plant size
- Eliminate preleach thickener
- Reduce limestone plant size.

Operating and revenue
- Reduce acid consumption
- Reduce limestone consumption
- Reduce cobalt plant operating cost
- Eliminate preleach thickener operating cost.

Risk advantage
- Increased cobalt possibly increased product concentration.

Disadvantages

Capital
- Require a preleach belt filter

Operating and revenue
- Increased complexity of preleach filter—operation and maintenance
- Lower cobalt recovery.

Risk
- Risk of increased operational shutdown.
**Capital estimate**
The capital cost changes for the implementation of the pre-leach filter facility are based on the following:
- Reduction in the size of the cobalt plant
- Reduction in the size of the acid plant
- Complete removal of the preleach thickener area
- Reduction in the size of the limestone plant
- Addition of the preleach filter unit(s).

**Operating cost estimate**
The operating cost changes for the implementation of the preleach filter is are based on the following:
- Reduction in the consumption of acid and limestone
- Reduced power, maintenance and consumable in the cobalt plant
- Reduced operating cost in the acid and limestone plants
- Greater operating costs for filtration than thickener
- Reduced cobalt production
- Removal of the thickener operating costs.

**Risk estimate**
Annualized risk equivalent costs have been determined based on an estimated likelihood of unplanned days shutdown of the filter plant.

**Results**
The summarized results for the preleach filtration estimated capital costs, operating costs and revenues earned, and annualized risk assessment are given in Table III below.

The implementation of the preleach filter option will have an overall capital advantage of about $5 000 000 where the reduction of process and reagent plant capital more than offsets the additional cost of preleach belt filters. The reduction in the cobalt plant and acid plant result in the major capital reduction.

An operating cost advantage of estimated $4 500 000 is realised in the preleach filtration option. The largest contributor is from the reduction in acid and limestone reagent requirements. Unfortunately a reduction of cobalt has been observed resulting in substantial revenue losses, but this factor is outweighed by the other savings in operational costs.

<table>
<thead>
<tr>
<th>Table III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost advantage summaries for the pre-leach filtration option</td>
</tr>
<tr>
<td>Capital cost dvantage</td>
</tr>
<tr>
<td>Operating/revenue cost advantage</td>
</tr>
<tr>
<td>Annualized risk advantage</td>
</tr>
<tr>
<td>Net annual advantage</td>
</tr>
<tr>
<td>Payback</td>
</tr>
</tbody>
</table>

Positive cost values imply savings or financial gain to the project.
Negative cost values imply expenses or financial loss to the project.
Data indicative of 40 000 t/a copper production.
The cost associated with risk is based on an approximately 5 days of production throughput, and is calculated at $2 000 000 /a.

**Recommendation**

Where filtration is reasonably possible, the preleach filtration option offers both capital and operational cost savings, which offset any additional risk. It is therefore recommended to implement the preleach filtration option into hydrometallurgical copper cobalt projects. Recent results on a project have, however, shown that a preleach thickener underflow density in excess of 65% solids was observed, thus the thickener option was retained.

**Acid tails**

**Description**

The base case flowsheets and design criteria have proposed that the CCD underflow slurry stream be mixed with an iron and manganese impurity slurry, and then neutralized with lime prior to being pumped to the tailings facility. The alternate proposal is to pump the CCD underflow slurry directly to a modified tails facility. This will result in a tails facility operating at approximately a pH of 3. The iron and manganese impurities stream will have to be placed in a separate compartment of the tailings facility in order to prevent releaching of the impurities into the acidic water in the acid tailings facility.

The major changes to the plant equipment are the lining of the tails facility, the creation of a separate compartment in the tails facility for the impurities slurry, and the removal of the neutralization circuit.

The conversion to an acid tails facility is expected to increase the utilization of acid, increase the production of copper and cobalt, and possibly increase the leaching of copper and cobalt in the acidic environment of the tails. These benefits are achieved by the recovery of the clarified acidic water that is decanted off the top of the tails facility. This water, containing the acid, copper and cobalt, is recycled to the plant as CCD wash water, where the acid and metals have an opportunity to be extracted in downstream processes.

To enhance the recovery of tails leached material, it is suggested that a means of removing recycle acidic water from the bottom of the tails pond is implemented; else most of the leached copper will remain trapped in the tails sediment. (Figure 5.)

**Analysis for the implementation of an acid tails facility**

In comparing the mass balances for both the base case and for the acid tails alternative, it is observed that the copper and cobalt production increases, while the acid consumption decreased by a small amount. The acid content of the raffinate bleed also increases by a small amount; thus more limestone is needed in the cobalt plant. These changes are used to determine the change of operating cost and revenue earned.

**Advantages and disadvantages**

Below is a list of advantages and disadvantages of the acid tails facility in relation to the base case of neutralized tails.

**Advantages**

**Capital**

- Remove tailings neutralization capital
Operating/revenue
- Reduced tails neutralization costs
- Recover some soluble copper and cobalt from CCD underflow
- Reduce acid costs
- Potential to continue leaching on tails pond.

Disadvantages
Capital
- Acid tails lining costs
- Require a separate compartment for Fe/Mn tails in pond
- Tailings facility closure costs
Operating
- Increased limestone consumption for Co plant
- Storm water capacity.
Risk
- HSE Risk if liner is breached in tailings.

Capital estimate
The capital cost changes for the implementation of the acid tailings facility are based on the following:
- The tails neutralization plant can be removed completely
- The acid tails facility needs a lining to prevent the acid from entering the groundwater
- The acid tails facility needs to be compartmentalized to keep the impurities separate from the CCD underflow tails
- Mine closure costs for the acid tails pond have not been included, but need to be considered in evaluating this option.
Operating cost and revenue income estimate

The operating cost changes for the implementation of the acid tailings facility are based on the following:

- An increase in the revenue from copper and cobalt due to better recoveries
- Elimination of neutralization operating costs
- Reduced acid consumption
- A small increase in limestone consumption in the cobalt plant
- Possibly none, but potentially some revenue from the continued leaching of copper and cobalt in the acid tailings facility. The benefit from this source would have to be tested in a laboratory or pilot plant for each project in order to confidently assign any benefits from increased revenue.

Risk estimate

The main risk identified is that the liner of the acid tailings facility could be compromised during the life of the mine. A significant outflow into the soil and groundwater system below the tailings facility will result in environmental discharge requiring remedial actions to be put in place.

An estimate for the scenario of liner failure has been made. The estimate is based on the probability of a liner installations failing, an assumed cost to repair the failure, and determining the annualized loss of revenue for such remediation actions.

Results

The result for implementation of the acid tails facility is presented in Table IV.

Operating cost and revenue earned values represent the annualized net gain including an estimated income for the extended leaching advantage.

If the advantage of extended leaching is ignored, then the payoff of the capital occurs in more than 10 years. These conclusions are based on current cost analysis only and may differ considerably once further investigation of the cost of lining and lining maintenance of an acid pond is taken into account. Furthermore, the cost of mine closure will further reduce the performance of this option.

Recommendation

Further investigation into actual costs of constructing, lining and maintaining an acid proof pond is required for specific projects considered, as no clear trend has been observed.

Table IV

Cost advantage summaries for acid tails option

<table>
<thead>
<tr>
<th>Cost Advantage</th>
<th>Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost advantage</td>
<td>-$6 500 000</td>
</tr>
<tr>
<td>Operating/revenue cost advantage</td>
<td>$2 900 000</td>
</tr>
<tr>
<td>Annualized risk advantage</td>
<td>-$1 500 000</td>
</tr>
<tr>
<td>Net annual advantage</td>
<td>$1 400 000</td>
</tr>
<tr>
<td>Payback</td>
<td>4.6 years</td>
</tr>
</tbody>
</table>

Positive cost values imply savings or financial gain to the project.
Negative cost values imply expenses or financial loss to the project.
Data indicative of 40,000 t/a copper production.
Furthermore, the risk evaluation for tailings dam integrity is often subjective and therefore difficult to determine. The specific findings of such an investigation significantly alter the cost advantage summary.

**Filtration vs. CCD**

**Description**

The base case flowsheets and design criteria have proposed that the solids in the leached stream be separated from the solution using a conventional CCD circuit operating with a wash ratio of 1.26. This results in the addition of large quantity of water into the PLS stream.

By introducing the post-leach filtration option (which required an initial thickener to pre-concentrate the filter feed), a lower wash water ratio of 0.8 is used, thus adding less water to the PLS. Furthermore, it is anticipated that the recovery of copper, cobalt and acid through the filter is improved due to more efficient washing and the production of a filter cake containing less moisture than the CCD underflow to tailings. A smaller PLS stream also implies that the raffinate bleed, hence the cobalt plant can be reduced in size, with subsequent savings on acid and limestone. (Figure 6.)

**Analysis of post-leach filtration compared to CCD (base case)**

In comparing mass balances for both the base case and for the post-leach filtration alternative-it is observed that the acid consumption has increased, together with the raffinate bleed stream. This is mainly due to increased copper production, causing an increased acid production in the raffinate. Since a significant portion of this raffinate is neutralized, acid consumption is increased. Copper and cobalt production has, however, increased due to better recoveries from the tails. These changes are used to determine the change of operating cost and revenue earned.

Figure 6. Postleach filtration flow sheet
**Advantages and disadvantages**

Below is a list of advantages and disadvantages of the post-leach filtration option in relation to the base case.

**Advantages**

**Capital**
- Remove CCD capital.

**Operating and revenue**
- Remove CCD operating costs
- Additional Cu production
- Additional Co production.

**Disadvantages**

**Capital**
- Add post-leach thickening and filter capital
- Larger cobalt plant
- Larger acid plant
- Larger limestone plant.

**Operating and revenue**
- Add thickener operating cost
- Add filter operating costs
- Additional acid consumption
- Additional limestone consumption.

**Risk**
- Loss of filter.

**Capital estimate**

The capital cost changes for the implementation of the post-leach filtration facility are based on the following:
- Remove the CCD, adding pre-filter thickener and filters
- Increasing the cobalt plant
- Increasing the acid plant
- Increasing the limestone plant.

**Operating cost estimate**

The operating cost changes for the implementation of the post-leach filtration facility are based on the following:
- Remove CCD operating costs but adding the pre-filter thickener and filters operating costs
- Adding copper and cobalt revenue
- Increased acid and limestone consumption.

**Risk estimate**

- Since a spare filter has been allowed for, the risk due to filter shutdown is considered to be negligible.


**Results**

The summarized results for the post-leach filtration estimated capital costs, operating costs and revenues earned, and annualized risk assessment is given in Table V.

The implementation of the post-leach filtration option will have an overall capital cost of $15 000 000. The cost of the filters represents the major capital increase.

An operating cost advantage of only $400 000 is insufficient to justify the extra capital expense.

**Recommendation**

In comparing post-leach filtration to conventional CCD, the result established that post-leach filtration is not a viable option as the capital costs far outweigh the operating cost advantages. Improvement in the filtration properties may reduce the capital, but to date this appears unlikely to make this option viable.

**Overall summary of results**

Table VI shows the averaged costing summaries for the various options considered in this paper.

From the analysis of recent copper cobalt hydrometallurgical plants, it is clear that the split SX and pre-leach filtration options offer a definite advantage in enhancing the performance of the process plant. The milling in raffinate option can potentially offer advantage, however, the risk is high, and thus there has been a tendency not to select this option. The acid tail and post-leach filtration options are costly to implement, with limited returns, as reflected in the payback periods.

The implementation of multiple options has been considered and analysed in individual studies; however, no analysis has been attempted here.

**Table V**

Cost advantage summaries for the post leach filtration option

<table>
<thead>
<tr>
<th></th>
<th>Split SX</th>
<th>Mill in raffinate</th>
<th>Pre leach filtration</th>
<th>Acid tails</th>
<th>Post-leach filtration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost advantage</td>
<td>$2.0</td>
<td>$2.0</td>
<td>$5.0</td>
<td>$6.5</td>
<td>$15.0</td>
</tr>
<tr>
<td>Operating/revenue cost advantage</td>
<td>$4.2</td>
<td>$5.0</td>
<td>$4.5</td>
<td>$2.9</td>
<td>$0.4</td>
</tr>
<tr>
<td>Annualized risk advantage</td>
<td>$0.3</td>
<td>Increased 5.0</td>
<td>$2.0</td>
<td>$1.5</td>
<td>0</td>
</tr>
<tr>
<td>Net annual advantage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payback</td>
<td>0.45</td>
<td>N/A</td>
<td>N/A</td>
<td>4.6</td>
<td>37</td>
</tr>
</tbody>
</table>

Positive cost values imply savings or financial gain to the project.

Negative cost values imply expenses or financial loss to the project.

Data indicative of 40 000 t/a copper production.

**Table VI**

Averaged costing summaries

<table>
<thead>
<tr>
<th></th>
<th>Split SX</th>
<th>Mill in raffinate</th>
<th>Pre leach filtration</th>
<th>Acid tails</th>
<th>Post-leach filtration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital million US$</td>
<td>Cost 2.0</td>
<td>Save 2.0</td>
<td>Save 5.0</td>
<td>Cost 6.5</td>
<td>Cost 15.0</td>
</tr>
<tr>
<td>Operating and revenue million US$/a</td>
<td>Save 4.2</td>
<td>Save 5.0</td>
<td>Save 4.5</td>
<td>Save 2.9</td>
<td>Save 0.4</td>
</tr>
<tr>
<td>Annualized risk million US$/a</td>
<td>Reduced 0.3</td>
<td>Increased 5.0</td>
<td>Increased 2.0</td>
<td>Increased 1.5</td>
<td>0</td>
</tr>
<tr>
<td>Payback, years</td>
<td>0.45</td>
<td>N/A</td>
<td>N/A</td>
<td>4.6</td>
<td>37</td>
</tr>
</tbody>
</table>

The data presented is indicative of 40,000 t/a copper production facility

382 HYDROMETALLURGY CONFERENCE 2009
Marco Reolon  
*Principal Process Engineering, GRD Minproc, South Africa*

Marco has extensive hydrometallurgical experience over a broad range of metals. This includes: pressure leaching of nickel, cobalt and gold, copper leach SX/EW, PGM refining and nickel/cobalt separation.

**Experience**

Principal Process Engineer, GRD Minproc (Pty) Ltd, December 2007 to present

As principal process engineer he is responsible for various projects and studies, and for the development of the process engineering group focusing on copper/cobalt projects and studies in Southern Africa. Project achievements to date include:

- Platmin Congo, Deziwa Copper/Cobalt Definitive Feasibility Study, Democratic Republic of the Congo, (2008 - present)

Senior Process Engineer, Fluor Canada Ltd, January 2006 to November 2007

As a senior process engineer in the Mining and Metals business unit he is responsible for the process aspects of predominately hydro-metallurgical and mineral processes. His major project achievements as Senior Process Engineer and Process Lead are:

- Barrick, Pueblo Viejo Feasibility Project, Gold Pressure Oxidation Leach and Base Metals Recovery, Dominican Republic (2007 - Present)
- Phelps Dodge, Safford Leach Project, Heap leach, Solvent Extraction and Electrowinning. Safford, Arizona, USA (2006-2007)

Solaris Management Consultants Inc, Canada, September 2002 to December 2005

- Coordinating process engineers and process activities within the company.
- Process engineering including Studies, Flow sheets, P&ID, equipment sizing and specification.
- Gas field development for energy companies.
- Developing standards, procedures and forms for process engineering activities.
- Developing Data Books, Operating Manuals and start-up assistance for new facilities.

Major project achievements as process engineer, construction or field engineer and commissioning engineer include:


Flour Daniel Wright Ltd - Vancouver BC Canada, Melbourne and Perth Australia, Calgary and Ft McMurray AB Canada, December 1995 to August 2002

As a senior process engineer in the Mining and Metals business unit he was responsible for the process aspects of predominately hydro-metallurgical and mineral processes.

Major project achievements as process and Lead process engineer are:

- Albion Sands, Muskeg River Oil Sands Project, Fort McMurray, Alberta, Canada (2000–2002)
- Miramar Con Mine Re-commissioning, Yellowknife, NWT, Canada (1999)
- Murrin Murrin Nickel Cobalt Project, Western Australia (1997–1999)
- Lomas Bayas Copper Heap Leach, Solvent Extraction and Electrowinning Project, Chile (1996–1997)
- Several pre-feasibility and feasibility studies.

**Process engineer**

B.M.I Division of E.L Bateman, February 1994 to November 1995


The process utilized a hydrochloric acid process environment to ensure the solubility and appropriate chemistry of the platinum group metals.

**Optimizing Acid Utilization and Metal Recovery in African Cu/Co Flow Sheets**
Extraction and separation process includes Molecular recognition technologies, Ion Exchange, Distillation and solid liquid separation.

Sastech—Division of Sasol Ltd, January 1991 to February 1994

As a process engineer in the petrochemical, oil and gas business he was responsible for the process and business development aspects of the new ventures group.

**Worked on the following projects:**

- Acetic Acid Pilot Plant Commissioning, Secunda, South Africa (1994)
- Hydrogen Sulfide Emission Reduction Study (1993)
- Alpha Olefins Pilot Plant Re-commissioning, Sasolberg, South Africa (1993)
- Alpha Olefins Pilot Plant Conversion, Sasolburg, South Africa (1992)
- Refinery Feed Stream Simulation (1992)
- Alpha Olefins Pilot Plant Commissioning, Sasolburg, South Africa (1991)
- Cresylics Acid Plant Commissioning; Sasolburg, South Africa.

Impala Platinum Ltd, Projects Department, Refineries, January 1988 to December 1990

As a chemical engineer in the projects department he was responsible for the process design and implementation of new projects.

**Worked on the following projects.**

- Selenium/Tellurium Removal Plant Project (1990), as project engineer.
- Chlorine Hydrochloric Matte Leach Upgrade Project (1990), as project engineer.
- Bulk Chemicals Handling Facilities (1990), as project engineer.
- Platinum Metals Refinery Pilot Plant Design (1990), as area engineer.
- Pressurized Oxygen Nickel Leach Autoclave commissioning (1989–1990), as commissioning engineer.
- Rhodium/Iridium/Base Metals Separation Pilot Plant Design (1988), as assistant project engineer.
- Rhodium/Iridium/Base Metals Separation Research and Development (1988), as research engineer.

**Overall experience**

**Tasks:**

- During his career he gained experience in the following work processes or project and operating activities.
- Research and Development (literature surveys, laboratory and pilot test program, outsourcing test work, data analysis, analytical technique development, flow sheet development, new product business development)
- Pre-feasibility studies (estimation of deliverables).
- Proposal (for studies, including schedules and execution plan)
- Feasibility studies (design criteria, flow sheet, pilot plant data evaluation, process simulation, mass balance, process description, equipment list and sizing, piping and instrumentation diagrams (P&ID), equipment and piping layouts, equipment costing, operation costing)
- Detailed engineering projects (as above, operating philosophy, process control and variables, instrument and equipment data sheets, design and equipment reviews, batch operating schedule, HAZOP and PHA studies, functional specifications, operating manuals)
- Pre-commissioning (including construction completion and tracking, equipment inspection, water testing system turnover.)
- Commissioning and Process Optimization (pre-start-up piping and equipment checks, cold commissioning, hot commissioning, equipment performance tests, operator training, optimization, data recovery, high rate trails, equipment evaluation and plant data recovery.)
- Plant Training (operations, trouble shooting and plant optimization, commissioning, production utilities and maintenance scheduling, safety and loss control, plant supervisory training)

**Technologies:**

- Platinum group metals hydrometallurgical processes
- Nickel/Cobalt hydrometallurgical processes
- Copper/Cobalt hydrometallurgical processes
- Zinc hydrometallurgical processes
- Oil Sands processes
- Molecular Recognition Technology.
- Synthol technology
- Sulfur recovery technology
- Plant Utilities (water treatment, steam and condensate, cooling water, air, vacuum, bulk storage)
- Autoclave Leach Reactors (Pressure oxidation, acid and Chlorine/hydrochloric)
- Heap Leach (acid)