DEVELOPMENT OF THE KOLWEZI TAILINGS COPPER/COBALT FLOWSHEET

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SYNOPSIS

This paper overviews the status of the Kolwezi Tailings Copper/Cobalt Project which aims to recover both of these metals from flotation tailings dams at Musono and Kingamyambo. The tailings are located in the Kolwezi district in the Democratic Republic of Congo and represent a world class reserve of cobalt with significant copper credits. Over a four year period America Mineral Fields, in conjunction with its co-owners, has undertaken a major development programme with the objectives of defining and optimising the process flowsheet, piloting this to a definitive level and establishing the fundamental design criteria for a future bankable study.

A fully integrated pilot programme has been undertaken at the Anglo American Research Laboratory (AARL) over a period of some twelve months and over 100 tonnes of tailings has been treated. The development programme has examined numerous copper and cobalt circuit options and the selected flowsheet has been proven to be robust and operable. It is capable of producing high quality cathode (>99.9%) with recoveries to metal of 93% Cu and 76% Co.

The process flowsheet is described in the paper. It incorporates simultaneous leaching of copper and cobalt oxide species followed by solid-liquid separation, copper SX-EW, impurity removal and cobalt SX-EW. The main drivers in terms of flowsheet development have been:

- Maximisation of metal recovery that has necessitated optimisation of the post-leach solid-liquid separation efficiency and minimisation of copper leakage into the cobalt circuit.
- Optimisation of acid consumption in the main leach step.
- Development of a robust and operable impurity removal circuit ahead of final cobalt recovery.

Kolwezi Project Location
1.0 INTRODUCTION

The resource is contained in two tailings reserves at Kingamyambo and Musonoi in the Kolwezi district of the Democratic Republic of Congo. Of these, Kingamyambo is the more accessible being in the form of a conventional tailings dam. The Musonoi tailings are spread along a river course, are more segregated and less accessible in the wet season. Extensive drilling and sampling programmes have established the following tailings resource.

Kingamyambo Tailings Dam

Kingamyambo
- Metres drilled 4,460
- Reserves (Mt) 42.3

Musonoi
- Metres drilled 5,823
- Reserves (Mt) 70.5

Total Resource
- 112.8 Mt
- 1.49% Cu = 3,705 M lb
- 0.32% Co = 796 M lb
- 97% Proven to JORC

The resource is high grade and has the added advantages that there will be no mining costs other than hydraulic transportation and little or no comminution cost. This makes Kolwezi potentially the lowest cost producer of cobalt in the World. The project is aiming to treat 3.0 million tpa of tailings to produce 42,000 tpa Cu and 7,700 tpa Co.

The tailings derive from a previous copper flotation process operated at Kolwezi and the minerals of interest are the non-flotable oxides of cobalt and copper ie:

Copper minerals
- malachite Cu₂(CO₃)(OH)₂
- pseudo malachite Cu₅(PO₄)₂(OH)₄
- tenorite CuO
- cuprite Cu₂O

Cobalt minerals
- heterogenite CoOOH
- kolwezite (Cu, Co)₂(CO₃)(OH)₂

Both the copper and cobalt are amenable to acidic atmospheric leaching in a sulphuric acid medium. Since the majority of cobalt is heterogenite, being in a higher oxidation state, the dissolution is enhanced by leaching in a reducing environment. Sulphur dioxide is conveniently employed to achieve the desired operating Eh.
Copper is recovered relatively easily from the filtered leach liquor using the highly selective hydroxyoxime extractant. The cobalt circuit presents a greater metallurgical challenge because of the need to remove a number of impurities including residual copper from the leachate ahead of cobalt metal recovery. Hence the cobalt circuit has received significant attention in the pilot programme with at least six major flowsheet alternatives being examined. The overall process flowsheet for the tailings leach is presented schematically in Figure 1.

The key steps in the overall flowsheet are common to all of the variants that were piloted and include:

- Monitoring of tailings from the two dams in a manner that targets to achieve a degree of homogeneity with respect to particle size, grade and level of impurities.
- Dewatering of the tailings feed in order to achieve the overall solution balance.
- Acid leaching of tailings in recycled raffinate with addition of fresh sulphuric acid and sulphur dioxide gas.
- Dewatering of leached slurry.
- Recovery of copper from the main leachate by conventional SX-EW.
- Impurity removal from the cobalt circuit feed liquor.
- Recovery of metallic cobalt by SX-EW.

The proposed circuit permits a build-up of the cobalt tenor by recirculation of copper raffinate and, in the case of belt filtration, by taking the final wash filtrate as feed to the cobalt circuit. This minimises the flow of liquor to the cobalt recovery leg thereby minimising the capital and operating costs of this section.

2.0 CIRCUIT DEVELOPMENT

The overall flowsheet for Kolwezi has been developed and refined through a significant number of pilot campaigns coupled with cost-benefit studies.

In 1999 laboratory scale testwork was carried out on auger samples and, based on this work, a flowsheet was defined generally as indicated in Figure 1. Subsequently a decision was taken to pilot the flowsheet and in late November 1999 the first bulk sample was collected from the Kingamyambo dam (50 tonnes) with a smaller sample from the Musonoi river tailings (8 tonnes).
Piloting commenced in February 2000 and was undertaken over three campaigns:

1st Campaign Testing of base case flowsheet. Establishment of overall metal accountability.
2nd Campaign Testing of circuit options and optimisation of operating parameters.
3rd Campaign Testing of the preferred flowsheet. Six week final test campaign to establish the definitive design criteria and establish a process control philosophy.

The first pilot campaign evidenced difficulties in achieving metal accountability. A decision was, therefore, taken to extend the piloting campaign in order to examine process options in greater detail. A further 40 tonnes of representative tailings sample was collected to accommodate the additional runs.

Through the second campaign some sixteen flowsheet combinations were identified with most of these being tested at the pilot level. The key issues with respect to flowsheet selection are conveniently discussed with reference to the two major sections ie the copper recovery circuit and the cobalt recovery circuit.

2.1 Main Leach and Copper Recovery Circuit

CCD versus Additional Copper Solvent Extraction

A key objective of the Kolwezi treatment plant is to maximise the tenor of cobalt and to minimise the concentration of copper in the feed to the cobalt recovery circuit.

The former objective is achieved by bleeding the residue filter wash liquor to the cobalt leg. This results in a build up of cobalt concentration around the copper circuit thereby increasing the concentration of cobalt in the belt filter final wash filtrate to 3 g/l Co.

Minimisation of copper leakage into the cobalt circuit is a desirable goal from the viewpoint of minimising acid consumption, maximising copper recovery and reducing the load on the cobalt circuit impurity removal section.

Two major circuit options were identified for maximising copper recovery are these illustrated in Figure 2.

The first option comprises a single copper SX stage with solid/liquid separation achieved using CCD and belt filtration. The second option utilises only belt filtration for solid/liquid separation and then employs a second copper SX step to increase copper recovery.
The two-stage copper SX option was determined to be the most cost effective in terms of maximising copper recovery and minimising the capital cost of the copper circuit. The secondary copper SX comprises two extract mixer-settlers operating on the cobalt circuit bleed stream. These units are significantly smaller than the mixer-settlers in use in the main copper SX circuit. The stripping of copper is undertaken in two mixer-settler stages that are common to both the main and the secondary SX circuits.

Further, the two-stage copper SX circuit was observed to be more flexible and could be operated as an independent unit. On the other hand, the performance of the CCD train was influenced by the performance of the leach and the main copper SX operations.

**Single versus Two-Stage Leaching**

The two-stage leaching concept was originally aimed at maximising metal recovery by providing a facility for aggressive leaching at high acid concentration under reducing conditions in the second stage. Whereas the bulk of the leaching was expected to occur in the second leach stage the function of the primary leach stage was to neutralise excess acid contained in the raffinate. This primary step would also serve as a pre-conditioning step in generating the PLS feed to the main SX. Early pilot work also indicated that leach pulp settling and filtration problems could arise when the system was operated in a single stage leach configuration.

In the pilot test work the difference in leach efficiency between the single and two-stage leaching was not observed to be significant. However, the two-stage system does provide greater flexibility and reliability without the risks associated with poor settling and filtration characteristics. Engineering cost studies indicated that these advantages outweighed the cost penalties of an additional thickener, pumps and piping.

**Cobalt Circuit Bleed Position**

The feed to the cobalt circuit is bled from the copper circuit and a number of bleed positions are possible. The wash filtrate from the post leach filter is the optimum location in terms of achieving the lowest loss of acid from the leach/copper recovery circuit.

### 2.2 Cobalt Recovery Circuit

A number of circuits are available for cobalt recovery. These largely revolve around the options available for the removal of key impurities from the cobalt bleed stream, the chief ones being Cu, Fe, Cd, Mn, Zn, Al. These species can either cause interference with the main cobalt recovery step or be co-extracted and hence contaminate the cobalt cathode. Figure 3 identifies four of the major circuits that were identified and piloted as part of the Kolwezi development programme. Numerous sub-options and variants were also analysed during the development phase. The following comments are made on the options.

The criteria that were evaluated in comparing cobalt flowsheet alternatives are summarised as:

- Capital costs.
- Operating costs. Particularly those for alkali, solvent extraction reagents and ion exchange resins.
- Cobalt recovery and potential loss points.
- Robustness of the process. A particular concern is the impact of a failure or mal-operation of any of the impurity removal steps.
- Environmental impact of waste streams from the process. The prime focus in this respect is the constitution of the cobalt SX raffinate.
- Circuit complexity and operability.
- Avoidance of cross contamination when employing multiple solvent extraction steps in series.
Option CR1- Traditional Circuit

Whilst this option represents a high capital cost alternative it affords some potential operating cost savings in that lime is substituted for caustic soda in the cobalt extraction step. The circuit has also been operated at a number of other cobalt recovery projects and hence there is a body of available experience.

A major drawback, however, is the build-up of circulating solids and liquor and the greater potential for loss of cobalt. There is also a need to utilise impurity removal steps ahead of cobalt recovery as the prime means of achieving cathode quality. The circuit is therefore complex. The disadvantages outweigh the operating cost savings and the option was therefore not considered further.

Option CR2 – Copper/Zinc Removal by IX

This flowsheet has the advantage that it is relatively simple and probably represents the lowest capital cost of all alternatives examined. In the pilot campaign however, a serious operational issue arose. In the event that the initial iron removal step fails to achieve its specified efficiency then ferric iron is loaded onto the IX resin in the downstream Cu/Zn removal step. Being trivalent this species is extremely difficult to elute from the resin using normal techniques. This deficiency essentially precluded the further development of this flowsheet.

Options CR3- Copper/Zinc/Manganese Removal by SX

This option utilises D2EHPA to remove impurity species downstream of Fe/Al rejection. Again operational difficulties arose in piloting in that iron can also be strongly extracted by D2EHPA if leakage occurs. Further operational and cost issues surround the stripping of the D2EHPA in that the generation of calcium sulphate and hence crud formation problems need to be avoided. This can be avoided by either using hydrochloric acid or very low strength sulphuric acid but at an additional costs.

Option CR4 – Zinc Removal Using SX

This circuit was conceived specifically to add robustness to the impurity removal operation ahead of final cobalt recovery. The circuit employs Cyanex 272 to extract zinc at pH 3.0-3.5. This is followed by an IX scavenging step that has the capacity to remove any copper and zinc that leaks through the system due to mal-operation. The first Cyanex extraction step also has the ability to remove any iron that might slip through the first removal stage. The circuit is judged to be extremely robust in terms of operability, control and ability to cope with process upsets. It represents the definitive cobalt recovery flowsheet for the ongoing project.
3.0 DEFINITIVE PILOT CAMPAIGN

3.1 Circuit Feed and Configuration

The flowsheet tested in the definitive and final campaign is illustrated in Figure 4.0.

The feed for the final campaign was composited to reflect the proposed mining plan for the dry months (9 months of the year). Musonoi and Kingamyambo tailings were therefore blended in a ratio of 4:1. It is noteworthy that the composite was made up of significantly coarser material and it contained elevated concentrations of copper, iron, manganese, zinc and nickel than the mean from the mine plan. Hence the pilot circuit was tested under extreme conditions with respect to abrasiveness and impurity elements.
The feed analysis for the definitive run was:

<table>
<thead>
<tr>
<th>Species</th>
<th>Units</th>
<th>Average</th>
<th>Maximum</th>
<th>Minimum</th>
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<tbody>
<tr>
<td>Cu</td>
<td>%</td>
<td>1.82</td>
<td>2.23</td>
<td>1.34</td>
</tr>
<tr>
<td>Co</td>
<td>%</td>
<td>0.46</td>
<td>0.58</td>
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<td>Fe</td>
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<td>Mg</td>
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<td>500</td>
</tr>
<tr>
<td>Zn</td>
<td>ppm</td>
<td>719</td>
<td>1815</td>
<td>90</td>
</tr>
<tr>
<td>Ni</td>
<td>ppm</td>
<td>52</td>
<td>137</td>
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3.2 Overall Leach Performance

Leaching efficiencies were achieved as follows:

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<thead>
<tr>
<th>Element</th>
<th>Leach Efficiencies%</th>
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<tbody>
<tr>
<td></td>
<td>Primary Leach</td>
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<tr>
<td>Cu</td>
<td>86.9</td>
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<tr>
<td>Co</td>
<td>40.4</td>
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<td>Fe</td>
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<td>Al</td>
<td>3.7</td>
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<tr>
<td>Zn</td>
<td>56.7</td>
</tr>
<tr>
<td>Mn</td>
<td>68.1</td>
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</table>

3.3 Definitive Plotting Achievements

Metal Accountability

A total balance accountability in excess of 95% was achieved in the final runs.

Process Design Criteria Definition

The data from the definitive runs is of a level that will support a definitive or bankable feasibility study. Process design criteria were established for all of the key unit operations. The pilot work was complemented by a number of parallel bench tests aimed primarily at establishing scale-up data.

Key unit operations were:

Cobalt and Zinc SX Tests:

- Settler specific throughput versus dispersion band depths were determined in a deep mixer settler constructed specifically for the purpose.
- Mixer kinetics – Derivation of extract and strip isotherms.

Solid-Liquid Separation Tests

- Filtration of both incoming feed and post leach slurries.
- Thickening.
- Clarification ahead of SX.
Confirmation of Process Chemistry and Overall Metal Recovery

The chemistry of the leaching and the extraction processes for both valuable metal and impurities was determined.

Establishment of a Process Control Philosophy

A key element of the third pilot campaign was the establishment of an operable process control philosophy for the system. The key features of this philosophy in terms of measurement and control points were documented. This is a key factor for a complex hydrometallurgical circuit and an element of piloting that is frequently overlooked.

Documentation of Engineering Design Issues

Engineering design data was obtained from the definitive pilot runs in a number of key areas including:

- Coupon testing of various materials of construction.
- Observation of scale formation at critical points in the circuit.
- Observation and measurement of abrasion rates, particularly in the leach reactors.

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