Copper Sulphate Crystallisation Plants at Remote Ore Locations

Darren Megaw, Johan Moolman, Priscillia Muzadi* and Tanja Marcus

ProProcess Engineering (Pty) Ltd, Johannesburg, South Africa

**Corresponding author: priscillia.muzadi@proprocess.co.za*

Many copper hydrometallurgy refineries have been established in Zambia and the Democratic Republic of the Congo to treat copper-cobalt ore deposits. As the high-grade deposits at primary refinery sites are depleted, new ore deposits are processed. These deposits are often situated some distance from the refineries, thus necessitating upstream mineral processing to produce a concentrate that is transported to the refinery. In this paper, an alternative processing route that produces a copper sulphate ($CuSO_4$) product at the remote ore location is compared with dense media separation (DMS). Similar technology has been successfully implemented in South American plants; however, the applications have targeted $CuSO_4$ as a final product, primarily for consumption in the animal feed additive market. Although the production of feed-grade $CuSO_4$ offers producers a premium on the final product, the market demand is limited. The demand for London Metal Exchange-grade copper metal is orders of magnitude higher than that of feed grade $CuSO_4$. An advantage of satellite $CuSO_4$ production is that copper units can be supplemented to the cathode producer with less secondary processing. The end product is attractive for cathode producers that have unutilised SX and electrowinning capacity available. When added to SX, the sulphate in $CuSO_4$ is recovered as sulphuric acid in the raffinate, supplementing fresh leach acid consumption requirements. The $CuSO_4$ purity is such that it can also be added intermittently to the advance electrolyte circuit; however, care must be taken to maintain the sulphate balance in the electrowinning circuit. The two processing routes are compared.

INTRODUCTION

The run-of-mine (ROM) ore extracted during mining operations usually undergoes primary mineral processing in the vicinity of the mineral resource and reserves generated, as is the case for many copper processing plants established in the African Copperbelt region. In mineral processing, target minerals, liberated from the ROM ore, are often separated from the gangue minerals, hence producing a higher quality product (concentrate) that is further refined to extract the metals of interest.

There exist various mineral processing methods, such as ore sorting, heavy media separation, dense media separation (DMS), froth flotation and magnetic separation. Selection of the mineral processing route generally depends on the characteristics of the ore and economic factors. While all the above-mentioned methods are well-proven, innovation in mineral processing can be very attractive for copper processing plants.

In this work, an alternative to DMS, aimed at producing a copper sulphate concentrate at satellite mining operations, is presented. Similar technology has been successfully implemented in South American operations and, although the final product has been primarily targeted for livestock feed

Hydrometallurgy Conference 2016: Sustainable Hydrometallurgical Extraction of Metals
Cape Town, 1–3 August 2016
Southern African Institute of Mining and Metallurgy

additives, the product is equally attractive for London Metal Exchange (LME)-grade copper cathode producers that have unutilised capacity at their existing metal production facilities. This process alternative is compared with the production of a concentrate via the more conventional DMS processing route.

BACKGROUND

Dense Media Separation

Located in Central Africa, the Copperbelt region is one of the largest and most mineralised copper-hosted geological settings. It stretches a distance of approximately 450 km, from the Northern Copperbelt province of Zambia to the south-eastern Katanga province of the Democratic Republic of Congo (DRC).

During the last commodity cycle upswing (2004–2008), this vast copper-rich region saw an influx of investment in capital mining equipment and metal extraction plants from multinational corporations to exploit its rich copper and cobalt deposits. This meant that primary extraction and refining plants were constructed in the immediate vicinity of mining operations that offered the most lucrative return on product yield and operational cost.

The increased demand for copper and cobalt during the high-commodity-demand period, as well as rapid primary grade depletion, mean that additional secondary resources need to be considered by many of the established operations. These secondary ore resources are often situated some distance from existing refineries, requiring upstream mineral upgrade processing in order to reduce refinery feed transportation costs, in a region characterised by a deficiency in reliable transportation infrastructure. These satellite deposits are often limited in size and do not justify building additional refining infrastructure. It is common practice for low-grade copper ores to be treated at mineral processing plants situated at the satellite sites to produce an upgraded copper concentrate. A preferred method to achieve upgrade is via the DMS process flowsheet route. The concentrate produced is transported by road to a primary operating refinery to produce a higher-quality product. The limited recovery of target copper via DMS results in the generation of large volumes of waste (floats). These floats often contain notable unutilised copper resource, which remains dormant or is omitted from project life-of-mine.

A balance between metal recovery and upgrade via DMS concentrate often results in high transportation costs and high overall production costs per ton of contained copper processed. The degree of ore beneficiation attained in the mineral processing plant plays a significant role, because transportation costs can rapidly escalate and reduce profitability. This, coupled with cyclical fluctuations in commodity prices, may drive away existing and potential investors, ultimately leading to the inefficient utilisation or rejection of satellite copper resources.

Copper Sulphate Crystallisation Plants

An alternative ore-processing route that provides a competitive advantage to other conventional mineral processing technologies is proposed. The processing facility produces copper sulphate pentahydrate crystals via the following process unit operations:

- Crushing and screening of the ROM ore;
- Heap leaching of the screened material;
- Solvent extraction (SX) for the selective extraction of copper from the pregnant leach solution (PLS);
- Crystallisation of copper as copper sulphate pentahydrate (1979).

This process route can offer a total copper recovery from ROM of 65–70% (recoveries primarily dependant on heap leach efficiency). Other advantages include:

- Lower transport costs associated with a high-grade (~24% copper) intermediary product, compared with 10–15% contained copper concentrate for the DMS processing route.
- Savings in processing costs with metal beneficiation at primary refinery. This is due to the supply of a higher-grade copper intermediate that is easily converted into a form that favours good copper mass transfer in SX circuits with minimum aqueous-associated impurity co-transfer.
- Maximum utilisation of existing primary refinery assets. The focus is on reducing operational costs by optimizing copper unit throughputs at an elevated percentage utilisation of installed design capacity.
- Supply of additional copper units to cathode producers. Copper units can be supplemented to cathode-producing operations. The concentrate produced is attractive for copper cathode producers that have unutilised SX and EW capacity available at their existing operations. In SX, the sulphate associated with the copper sulphate is recovered as sulphuric acid in the raffinate and recycled to the leach circuit, thus reducing fresh acid addition to the refinery raffinate solutions. In addition, the copper sulphate concentrate produced can be added intermittently to the EW advance electrolyte circuit (in this case, the sulphate balance needs to be considered as the limiting rate). This is attractive to improve or maintain product cathode quality by maintaining favourable copper plating conditions during periods of reduced front-end minerals processing and leaching throughputs of the primary refinery operation (reduced depletion of copper concentrations of the spent and advance electrolyte).
- Copper sulphate crystallisation has been successfully implemented in South America with the establishment of two plants established by Despromin (2016).
- The modular approach adopted for the construction of copper sulphate crystallisation plants (Figure 1) allows for retrofitting of the system for phased plant capacity expansion. The system components are designed as movable skids, which can be positioned in various process configurations. The skid-mounted approach also means that the units are easily transported.
- Other advantages of modular construction are:
  - Cost savings in terms of civil works: the plant is designed to allow for minimum site preparation.
  - Low operational energy cost requirements allow for off-grid power independence.
  - Optimum utilisation of space layout (reduced plant footprint).
  - Assembly and off-site testing of the various plant modules prior to transport to site, resulting in shorter installation times and minimum site interruption.
  - Lower labour construction costs (reduced site preparation infrastructure requirements).

STUDY METHODOLOGY

Purpose

The purpose of the study was to assess the technical and economic feasibility of implementing a satellite modular copper sulphate crystallisation plant at a production output of 8000 t/a contained copper. (This design nameplate was chosen because it fits the copper sulphate module plant size.) The process is compared with a typical DMS processing route for the same contained copper output. A third comparison is conducted to compare copper sulphate plant and DMS throughputs required to achieve the same final refinery cathode output. Simplified flowsheets of the copper sulphate crystallisation and DMS processing routes are illustrated in Figures 2 and 3, respectively.

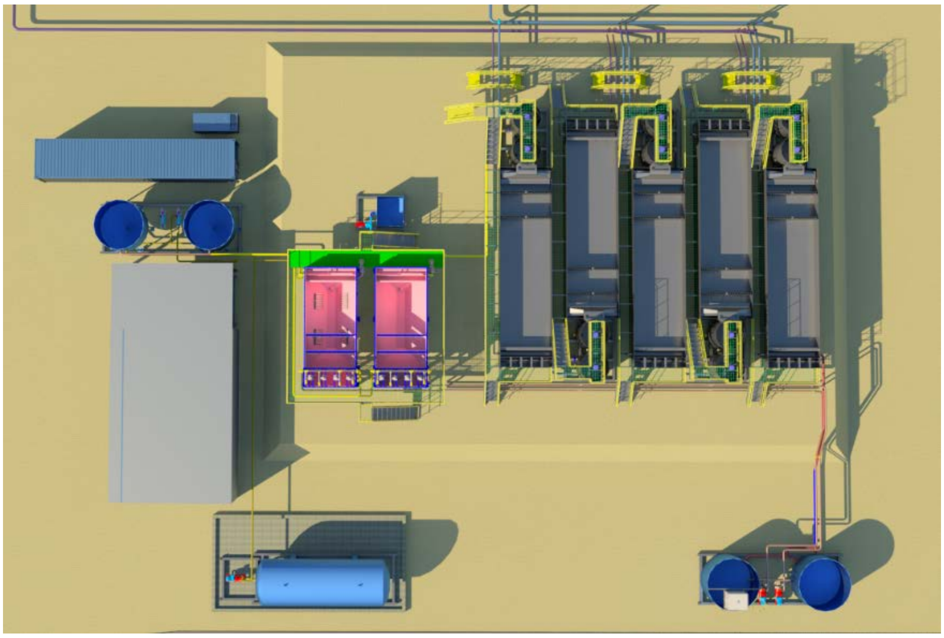

Figure 1. Modular copper sulphate crystallisation plant concept.

Basis of Cost Estimates

For the purpose of this study, only major equipment items were costed as part of the capital cost estimates (CAPEX). The estimate is within an accuracy range of −30% to +50%, in accordance with methodologies of the American Association of Cost Engineers (AACE) International Recommended Practice No. 18R-97.

The estimated costs associated with major plant equipment required for the DMS plant were compared with those for the copper sulphate crystallisation plant. The major plant equipment costs were developed using either an in-house cost database or quotations from equipment suppliers and vendors. Other items that form part of the CAPEX, *i.e.*, structural and civil work, electrical, instrumentation, and others, were excluded from the estimates.

The operating cost estimates (OPEX) were calculated at the order-of-magnitude accuracy level. In-house cost information and reagent consumption were used as the basis for the estimates. The OPEX excluded costs associated with maintenance and repairs. Labour costs were excluded from the comparison because they were assumed to be similar for both process options. A contingency of 20% was applied. The currency used for the capital and operating cost estimates is the United States Dollar (USD).

Battery Limits

The scope of the estimate is concerned with the pre-treatment of the ROM ore for the production of copper sulphate crystals, via crushing and screening, heap leach, SX and crystallisation processes, and the production of a concentrate via crushing and screening, and DMS processes. The estimates include costs related to the transport of the intermediary products, but exclude the additional downstream processing of the copper sulphate crystals or DMS concentrate.

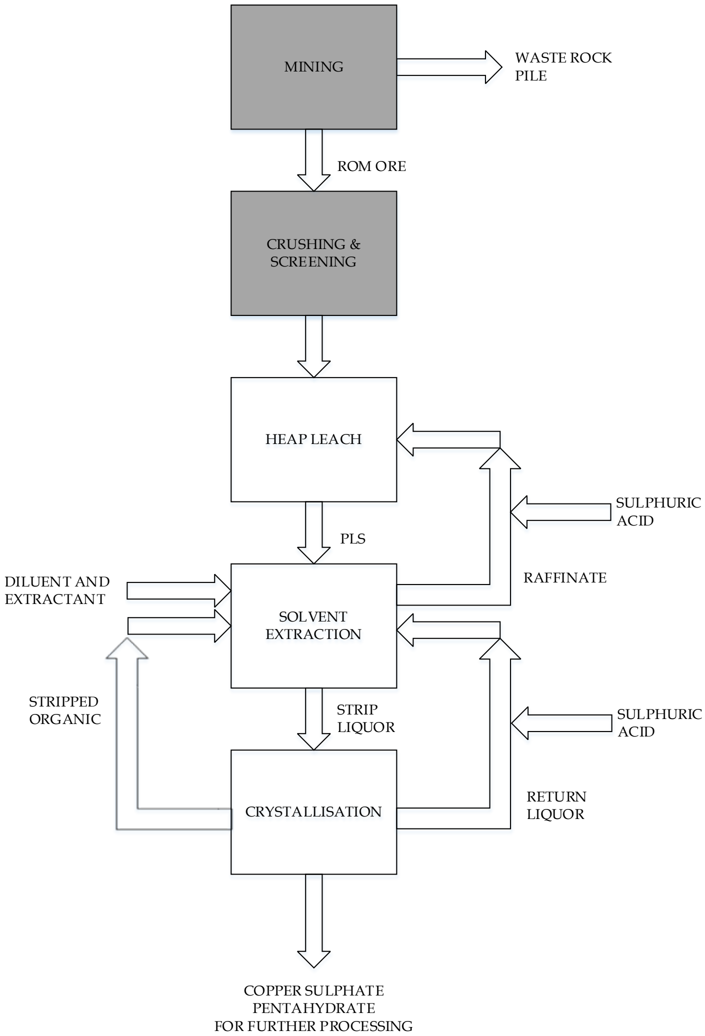

Figure 2. Copper sulphate crystallisation process simplified flowsheet.

COST ESTIMATES

A summary of the costs of major equipment is shown in Table I for the copper sulphate crystallisation and DMS processing routes. It can be concluded that, for an 8000 t/a contained copper design nameplate plant, the estimated equipment cost for the copper sulphate crystallisation processing route is significantly lower than that for the DMS processing route.

The OPEX related to the copper sulphate crystallisation plant in comparison with a DMS plant for the same copper content product (8000 t/a contained copper) in satellite operations are presented in Table II. The power requirement is 500 kW for each processing route. Operational region-specific information was used to estimate the costs tabled.

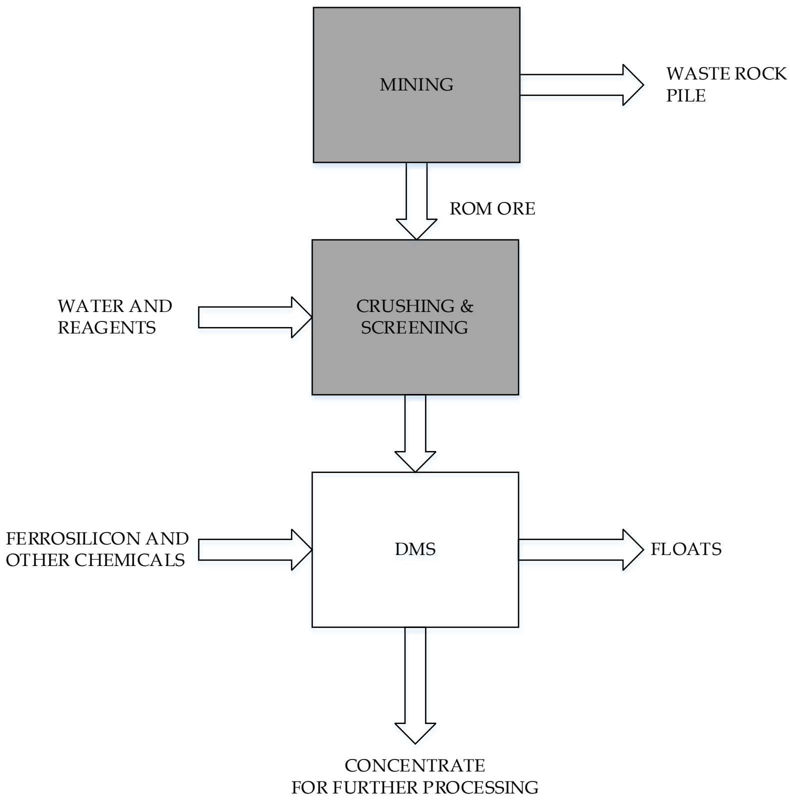

Figure 3. DMS process simplified flowsheet

Table I. Summary of major equipment costs (same contained copper output)[1]

Item	Copper sulphate crystallisation (USD '000)	DMS (USD '000)
Crushing and screening	3,571	3,571
DMS plant	–	6,072
DMS with ancillaries (incl. product handling and sizing)	–	*4,286*
-1 mm beneficiation (spirals or other)	–	*1,786*
Heap leach	213	–
PLS pond construction	*91*	–
Raffinate pond construction	*91*	–
Heap pad construction	*31*	–
SX–crystallisation plant	2,283	–
Sub-total	**6,067**	**9,643**
Contingency (20%)	1,214	1,928
Total	**7,281**	**11,571**

Note 1:

Inclusions
First fill of extractant
First fill of diluent
Handling of final product

Exclusions
Slimes thickening and disposal
Process water distribution
Mobile mining equipment

Table II. Summary of OPEX comparison (same contained copper output)

Item	Copper sulphate crystallisation (USD '000)	DMS (USD '000)
Mining	6,097	7,717
Crushing	1,110	1,405
DMS	–	1,431
Heap leach	5,963	–
SX-crystallisation	2,158	–
Acid transport	809	–
Transport of product	571	1,321
Sub-total	**16,708**	**11,874**
Contingency (20%)	3,342	2,375
Total	**20,050**	**14,249**

When compared on the basis of contained copper content of satellite plant product, the OPEX associated with the copper sulphate crystallisation processing route are significantly higher than those for the DMS processing route, as can be seen from Table II; however, the improvement in copper recovery in the final product, which results in a ~24% contained copper intermediary product, compared with only 0–15% for the DMS copper concentrate, adds to the financial attractiveness of this processing route. A typical copper recovery of 50–55% is obtained in a DMS plant, compared with 65–70% for the copper sulphate crystallisation processing route: equivalent to an increase in copper recovery of 25–30%. Furthermore, the DMS concentrate still requires significant processing because it needs to be introduced at the leach stage of the primary refinery process for further treatment, prior to entering the SX–EW circuit for production of copper metal, whilst the copper sulphate intermediary product can be introduced directly at the SX–EW circuit.

Table III compares the OPEX associated with the amount of DMS feed required to achieve the same final copper units exiting the primary refinery. For this basis of comparison, the OPEX for the DMS processing route are almost double.

Table III. Summary of OPEX comparison (same final refinery output cathode)

Item	Copper sulphate crystallisation (USD '000)	DMS (USD '000)
Mining	6,097	11,290
Crushing	1,110	2,056
DMS	–	2,093
Heap leach	5,963	757
SX	–	988
SX–crystallisation	2,158	–
Acid Transport	809	534
Transport of product	571	1,932
Sub-total	**16,708**	**19,650**
Contingency (20%)	3,342	3,930
Total	**20,050**	**23,580**

Comparing the capital and operating cost estimates, it can be concluded that the copper sulphate crystallisation processing route is economically attractive for copper cathode producers, when compared with the conventional DMS processing route. The copper sulphate processing route offers higher copper recovery, has lower transport costs (per ton of contained copper) associated with the intermediary product, requires fewer process steps for copper metal production, produces copper units (as a copper sulphate product) which are readily available for copper transfer to the refinery SX–

EW circuit under favourable extraction conditions and, lastly, the sulphate content of the product is recovered as sulphuric acid in the raffinate, thus reducing the requirements for fresh acid addition to the primary refining leach circuit.

ADDITIONAL CONSIDERATIONS

Proven Technology

Two copper sulphate processing facilities have been successfully implemented in South America for the production of copper sulphate pentahydrate crystals. One of them, the Chapi copper facility in south-eastern Peru, produced 28 800 t/a copper sulphate pentahydrate crystals (equivalent to 7200 t/a contained copper). Plant views are shown in Figures 4 and 5. During the first year of plant operation, all copper sulphate produced was introduced into an SX–EW circuit belonging to the same copper cathode producer that had spare EW capacity available. This was easily done by dissolving the crystals in the feed liquor. Thereafter, copper sulphate crystals produced at the plant were mainly used as micronutrients in animal feeds. Plant operations have since been suspended owing to depletion of feed stocks.

Figure 4. Photographs of SX area.

Figure 5. Photographs of crystallisation area.

Cost Competitiveness
Offtake of copper sulphate has economic benefits over copper concentrate. These include:

- Higher value copper product based on contained copper per ton of product;
- Reduction in transportation costs and overall production costs per ton of contained copper processed;
- Lower costs of major equipment.

Environmental Impact
The potential environmental impacts of the copper sulphate crystallisation processing route are similar to those of a conventional copper heap leach–SX facility that primarily poses risks of accidental release of process solutions from the heap-leach facility to the surrounding environment and elevated fire and explosion in the SX plant. These impacts are mitigated through environmental legislation to reduce or minimise environmental consequences. When compared with the DMS route, the copper sulphate process may seem to have an elevated environmental risk; however, it should be kept in mind that many DMS concentrates are inevitably processed via a similar downstream hydro-metallurgical route as that of copper sulphate.

Energy Requirement
The extent of copper sulphate crystallisation accelerates with increasing sulphuric acid and copper concentrations in the crystallization solution or decreased solution temperature. In order to accelerate the rate of crystallisation, a heat exchanger could be considered. However, in the copper sulphate crystallisation processing route considered here, the targeted rate of production of copper sulphate crystals is based on the acid concentration needed to maintain a specific rate of crystallisation at an operating temperature that requires little or no additional forced cooling. A lower target operating temperature is achieved by having dual-duty acid make-up and dosing tanks in the circuit. This offers sufficient residence time to cool acid-addition electrolyte prior to dosing into the advance electrolyte for effective crystallization rate.

Labour Requirement
Staffing requirements for the two process plants are similar, as shown in Table IV; however, plant personnel at the copper sulphate crystallisation plant are required to have strong technical skills due to the higher level of associated plant automation and control.

*Table IV. Staffing requirements per shift**

Item	Copper sulphate crystallisation	DMS
Plant operators	4	5
Plant superintendent	1	1
Plant manager	1	1
Total	**6**	**7**

*Includes operations, water services and product handling. Excludes front-end loader driver, forklift driver and ROM loading operators.

CONCLUSIONS

Conventional methods of mineral processing are used today to provide a more concentrated intermediary product that is suitable for treatment in hydrometallurgical facilities. Although mineral processing techniques such as dense media separation are well established, the copper sulphate crystallisation processing route offers a competitive alternative with potential improvement in “first pass ore processing” copper recovery. Based on a comparison of the DMS and copper sulphate process CAPEX estimates for the same final refinery output cathode, the copper sulphate crystallisation processing route offers an estimated 37% reduction in capital requirement. A comparison based on region-specific OPEX, the copper sulphate route offers an approximate 15% reduction when compared with those for DMS.

REFERENCES

Despromin Ltd., Chile (2016). Private communication.

Moyer, H.R., III (1979). Copper sulphate via solvent extraction and crystallisation. *AIME Annual Meeting.* New Orleans, Louisiana.