http://dx.doi.org/10.17159/2411-9717/2017/v117n8a8

Copper sulphate crystallization plants at remote locations

by D. Megaw*, J. Moolman*, P. Muzadi*, and T. Marcus*

Synopsis

The Central African Copperbelt is well known for its high-grade copper-cobalt deposits. Many hydrometallurgical copper refineries have been established in northern Zambia and in the Haut-Katanga and Lualaba provinces in the Democratic Republic of Congo to treat such orebodies. As the high-grade deposits at primary refinery sites become depleted, new ore deposits are exploited. These new deposits are often situated some distance from the refineries, thus necessitating upstream mineral processing in order to produce a concentrate that is then transported to the refinery, usually by road. In this paper a processing route that produces a copper sulphate product at the remote ore location is presented as a possible alternative to the production of a concentrate by dense media separation (DMS). The alternative process comprises crushing and screening of the ore, heap leaching, solvent extraction, and copper sulphate crystallization. Similar technology has been successfully implemented in South America; however, these plants have targeted copper sulphate as a final product, primarily for the animal feed additive market. Although the production of feed-grade copper sulphate offers producers a premium on the final product, the market demand is limited. The demand for LME-grade copper metal is orders of magnitude higher than that for feed-grade copper sulphate. An advantage of satellite copper sulphate production is that copper units supplied to the refinery for cathode production require less secondary processing than a DMS concentrate. The end product is attractive for copper cathode producers that have un-utilized solvent extraction (SX) and electrowinning (EW) capacity. When added to SX, the sulphate associated with the copper sulphate is recovered as sulphuric acid in the raffinate, supplementing the fresh acid requirements for leaching. The copper sulphate purity is such that it can also be added intermittently to the EW strong/advance electrolyte circuit, although care must be taken to maintain the sulphate balance in the EW circuit. The advantages and disadvantages of the two processing routes are compared.

Keywords
copper, copperbelt, solvent extraction, mineral processing, crystallization.

Introduction

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

There are 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, innovative mineral processing methods can be very advantageous for copper processing plants.

In this paper, 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 additives, it is equally attractive for LME-grade copper cathode producers that have un-utilized 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

The Central African Copperbelt is one of the world's largest and most mineralized copper-bearing geological settings. It stretches a distance of approximately 450 km from the northern Copperbelt Province of Zambia to the southeastern Haut-Katanga and Lualaba provinces of the Democratic Republic of Congo (DRC).

* *ProProcess Engineering (Pty) Ltd., South Africa.*
© *The Southern African Institute of Mining and Metallurgy, 2017. ISSN 2225-6253. This paper was first presented at the* Hydrometallurgy Conference 2016 'Sustainable Hydrometallurgical Extraction of Metals', *1–3 August 2016, Belmont Mount Nelson Hotel, Cape Town.*

Copper sulphate crystallization plants at remote locations

During the last upswing in the commodity cycle (2004–2008), this vast copper-rich region saw a growing influx of capital investment from multinational corporations to exploit its rich copper and cobalt deposits. Primary extraction and refining plants were constructed in the immediate vicinity of mining operations that offered the most lucrative returns.

Owing to the increased demand for copper and cobalt during this period, as well as the rapid depletion of the high-grade deposits, additional secondary resources needed to be considered by many of the established operations. These secondary resources are often situated some distance from existing refineries, and on-site upgrading of the ROM material is necessary to reduce the cost of transport to the refinery, particularly in view of the poor transportation infrastructure in the region. These satellite deposits are often of limited size and do not justify building additional refining capacity. It is common practice to treat copper ores, especially low-grade ores, at mineral processing plants situated at the satellite sites to produce an upgraded copper concentrate. This is frequently accomplished via the DMS process, and the concentrate produced is transported by road to a primary refinery for further beneficiation. The poor recovery of copper minerals via the DMS route results in large volumes of waste (floats) being generated, which often contain notable copper resources that remain unutilized.

A balance between metal recovery and concentrate upgrade via DMS often results in high transportation costs, and high overall production costs per ton of contained copper. The degree of beneficiation attained in the mineral processing plant plays a significant role, as 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 utilization or rejection of satellite copper resources.

Copper sulphate crystallization

An alternative processing route that provides a competitive advantage compared with other conventional mineral processing technologies is proposed, in which copper sulphate pentahydrate crystals are produced via the following 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)
- ➤ Crystallization of copper as copper sulphate pentahydrate.

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

- ➤ Lower transport costs due to the high grade (approx. 24% copper) of the intermediate product, compared with 10–15% for DMS
- ➤ Lower processing costs at the 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 co-transfer of soluble impurities
- ➤ Maximum utilization of existing refinery assets
- ➤ Supply of additional copper units to cathode producers. The copper sulphate pentahydrate produced is attractive for cathode producers that have unutilized SX and EW capacity. 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 requirements. In addition, the copper sulphate concentrate produced can be added intermittently to the EW strong/advance electrolyte circuit (in this case, the sulphate balance needs to be considered as the limiting rate). This will improve/maintain product cathode quality by maintaining favourable copper plating conditions during periods of reduced front-end minerals processing and leaching throughputs (less depletion of copper concentration in the spent and advance electrolyte)
- ➤ The modular approach adopted for the construction of copper sulphate crystallization plants (Figure 1) allows for retrofitting of the system for phased capacity expansions. The system components are built on movable skids, which can be positioned in a number of 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 so that minimum site preparation is required
    - Low operational energy cost requirements, allows for off-grid power independence
    - Optimum utilization of space (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 disruption
    - Lower labour costs during construction (reduced site preparation and infrastructure requirements).

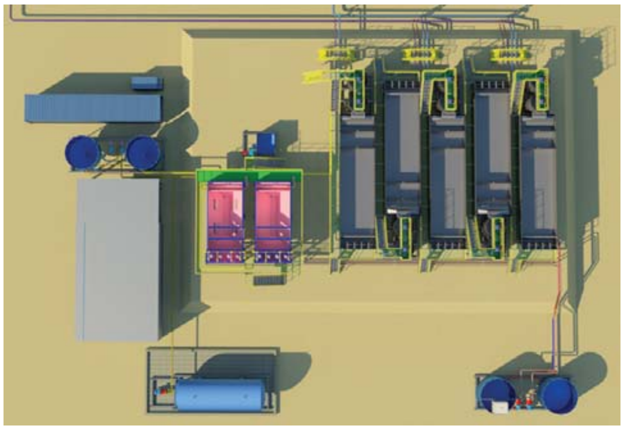

Figure 1—Modular copper sulphate crystallization plant concept

Copper sulphate crystallization has been successfully implemented in South America with the establishment of two plants by Despromin.

Study methodology

The purpose of the study was to assess the technical and economic feasibility of implementing a satellite modular copper sulphate crystallization plant with an output of 8 kt/a contained copper. This nameplate capacity was chosen as it fits the copper sulphate module plant size. The process is compared to a typical DMS processing route for the same contained copper output. A further comparison is conducted to compare copper sulphate plant and DMS throughputs required to achieve the same final cathode output from the refinery. Simplified flow sheets of the copper sulphate crystallization processing route and DMS processing route are illustrated in Figure 2 and Figure 3, respectively.

Basis of cost estimates

For the purpose of this study, only major equipment items were costed as part of the capital cost (CAPEX) estimates. 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.

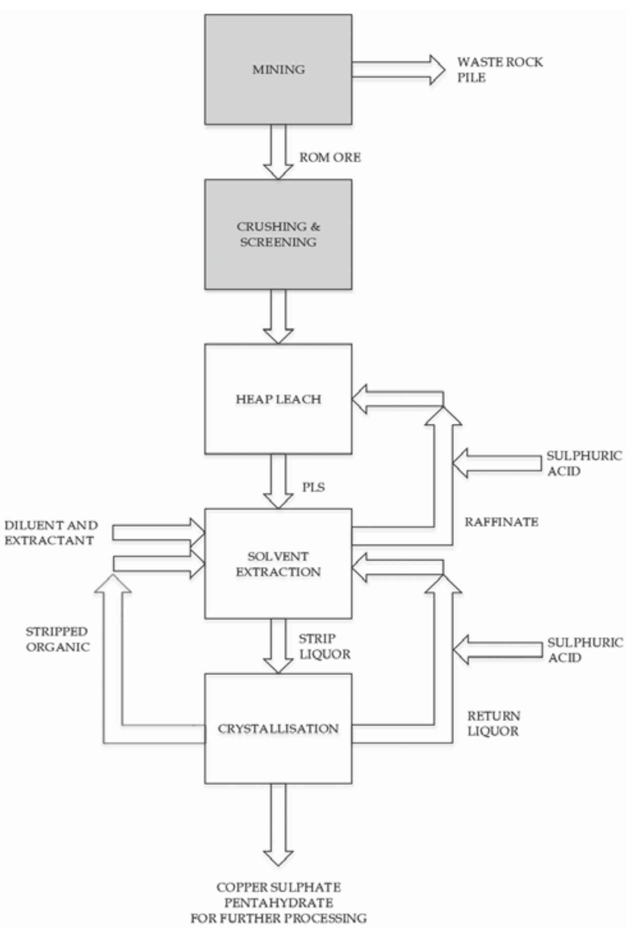

Figure 2—Simplified flow sheet of the copper sulphate crystallization process

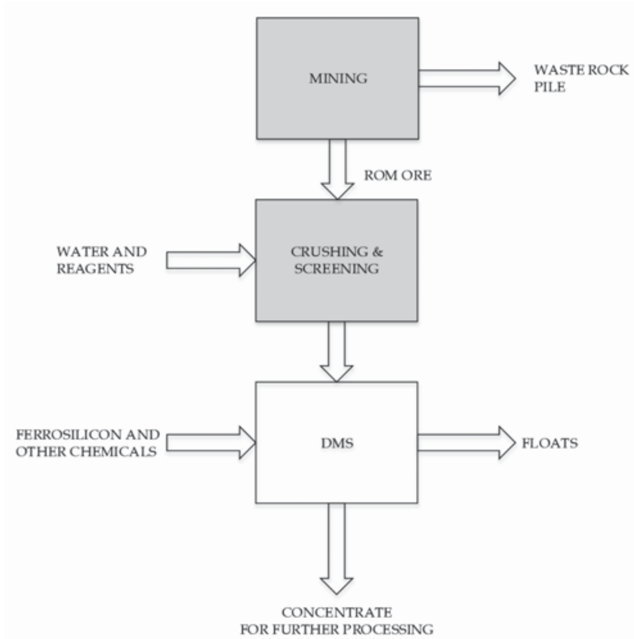

Figure 3—Simplified flow sheet of the DMS process

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

The operating cost (OPEX) estimates were calculated at the order-of-magnitude accuracy level. In-house cost information and reagent consumptions were used as a basis for the estimates. The operating costs excluded costs associated with maintenance and repairs. Labour costs were excluded from the comparison as 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 US dollars.

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 leaching, solvent extraction, and crystallization, and the production of a concentrate via crushing, screening, and dense media separation. The estimates include costs related to the transport of the intermediary products, and exclude the additional downstream processing of the copper sulphate crystals or the DMS concentrate.

Cost estimates

A summary of the costs of major equipment for the copper sulphate crystallisation processing route and the DMS processing route is shown in Table I.

Table I

Summary of major equipment costs (8 kt/a contained copper output)1

Item	Copper sulphate crystallization (US$)	DMS (US$)
Crushing and screening	3 571 428.57	3 571 428.57
DMS plant	-	6 071 428.57
DMS with ancillaries (incl. product handling and sizing)	-	*285 714.29*
-1 mm beneficiation (spirals or other)	-	*1 785 714.29*
Heap leach	213 618.52	-
PLS pond construction	*91 452.12*	-
Raffinate pond construction	*91 452.12*	-
Heap pad construction	*30 714.29*	-
SX-crystallisation plant	2 282 858.14	-
SUBTOTAL	**6 067 905.23**	**9 642 857.14**
Contingency (20%)	1 213 581.05	1 1928 571.43
TOTAL	**7 281 486.28**	**11 571 428.57**

Note 1:

Inclusions	Exclusions
First fill of extractant	Slimes thickening and disposal
First fill of diluent	Process water distribution
Handling of final product	Mobile mining equipment

Table II

Summary of OME OPEX (8 kt/a contained copper output)

Item	Copper sulphate crystallization (US$)	DMS (US$)
Mining	6 096 526.23	7 717 193.06
Crushing	1 110 134.81	1 405 246.91
DMS	-	1 430 566.67
Heap leach	5 963 224.14	-
SX-crystallization	2 157 602.00	-
Acid transport	809 598.71	-
Transport of product	570 846.92	1 320 780.18
SUBTOTAL	**16 707 932.80**	**11 873 786.82**
Contingency (20%)	3 341 586.56	2 374 757.36
TOTAL	**20 049 519.36**	**14 248 544.19**

It can be seen that for a plant with a nameplate capacity of 8 kt/a contained copper, the estimated equipment cost for the copper sulphate crystallization route is significantly lower than that for the DMS processing route.

The operating costs of the two processes are presented in Table II. The power requirement is 500 kW for each processing route. Similar production outputs of 8 kt/a contained copper were targeted for comparison purposes. Region-specific information was used to estimate the costs tabled.

As can be seen from Table II, the operating costs associated with the copper sulphate crystallization processing route are significantly higher than those for the DMS process. However, the improvement in copper recovery to the final product, which results in an intermediate product with a copper content of approximately 24%, compared to only 10–15% for DMS, adds to the financial attractiveness of this processing route. A typical copper recovery of 50–55% is obtained in a DMS plant, compared to 65–70% for the copper sulphate crystallization route; which is equivalent to an increase in copper recovery of 25–30%.

Furthermore, the DMS concentrate needs to be introduced at the leach stage of the refining process, while the copper sulphate intermediary product can be introduced directly into the SX-EW circuit.

Table III compares the operating costs of the two processes based on the throughputs required to achieve the same final refined copper output. On this basis, the operating costs for the DMS processing route have almost doubled.

Table III

Summary of OPEX based on throughput for the same final cathode output from refinery

ITEM	Copper sulphate crystallization (US$)	DMS (US$)
Mining	6 096 526.23	11 289 874.67
Crushing	1 110 134.81	2 055 807.26
DMS	-	2 092 848.83
Heap leach	5 963 224.14	757 418.70
SX	-	987 649.90
SX-crystallixation	2 157 602.00	-
Acid transport	809 598.71	534 255.80
Transport of product	570 846.92	1 932 236.57
SUBTOTAL	**16 707 932.80**	**19 650 091.72**
Contingency (20%)	3 341 586.56	3 930 018.34
TOTAL	**20 049 519.36**	**23 580 110.06**

Comparing the capital and operating cost estimates, it can be concluded that the copper sulphate crystallization route is economically attractive for copper cathode producers. The copper sulphate route offers higher copper recoveries, has lower transport costs (per ton of contained copper) for the intermediary product, requires fewer process steps for copper metal production, produces copper units (as copper sulphate) that are readily available for copper mass transfer to the refinery SX-EW circuit under favourable extraction conditions, and lastly, the sulphate content of the copper sulphate product is recovered as sulphuric acid in the raffinate from SX, thus reducing the requirements for fresh acid addition to the refinery leach circuit.

Additional considerations

Proven technology

Two copper sulphate processing projects have been successfully implemented in South America for the production of copper sulphate pentahydrate crystals. One of them, at the Chapi copper mine in southeastern Peru, produces 28.8 kt/a of copper sulphate pentahydrate crystals (equivalent to 7.2 kt/a contained copper). Plant views are shown in Figures 4 and 5.

During the first year of operation, all copper sulphate produced was introduced into the SX-EW circuit of the Chapi copper cathode producer, which had spare EW capacity. This was done easily by dissolving the crystals in the feed liquor. Thereafter, copper sulphate crystals produced at the plant were used mainly as micronutrients in animal feeds. The plant operations have since been suspended due to depletion of feedstocks.

Cost competitiveness

Offtake of copper sulphate has economic benefits over copper concentrate:

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

Figure 4—SX area of the Chapi plant , Peru

Figure 5—Crystallization area of the Chapi plant, Peru

Environmental impact

The potential environmental impacts of the copper sulphate crystallization processing route are similar to a conventional copper heap leach and SX facility which primarily poses a risk of accidental release of process solutions from the heap leach facility to the environment, and elevated fire and explosion risk in the SX plant. These impacts are mitigated through adhering to environmental legislation put in place to reduce or minimize environmental consequences.

The copper sulphate crystallization process may seem to have an elevated environmental risk when compared directly with DMS. However, it should be kept in mind that many DMS concentrates are processed via a similar downstream hydrometallurgy route as that for producing copper sulphate.

Energy requirement

The rate of copper sulphate crystallization increases with increasing sulphuric acid and copper concentrations in the crystallization solution and with decreasing solution temperature. In order to increase the rate of crystallization a heat exchanger could be incorporated in the circuit. However, in the crystallization route considered here, the targeted rate of copper sulphate production is based on the acid concentration needed to maintain a specific rate of crystallization at an operating temperature that requires little or no additional forced cooling. The target lower crystallization 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 pregnant advance SX electrolyte for an effective crystallization rate.

Labour requirement

The staffing requirements for a DMS processing plant and a copper sulphate crystallization plant are similar, as shown in Table IV. However, personnel at the copper sulphate plant are required to have strong technical skills due to the higher level of plant automation and control employed.

Table IV

Staffing requirements per shift

Item[(1)]	Copper sulphate crystallization	DMS
Plant operators	4	5
Plant superintendent	1	1
Plant manager	1	1
TOTAL	6	7

[(1)]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 to provide a more concentrated intermediate product that is suitable for treatment in hydrometallurgical facilities. Although techniques such as dense media separation are well established, the copper sulphate crystallization processing route offers a competitive alternative with potential improvement in 'first-pass ore processing' copper recovery.

Compared to the DMS process, for the same final cathode output at the refinery, the copper sulphate crystallization processing route offers an estimated 37% reduction in capital requirement. Based on typical OPEX rates for the specific operating region, the copper sulphate route offers an approximate 15% reduction in operating costs compared with DMS.

References

DESPROMIN LTD., CHILE. 2016. Private communications. March 2016.

MOYER, H.R., III. 1979. Copper sulphate via solvent extraction and crystallisation. *Proceedings of the AIME Annual Meeting*, New Orleans, Louisiana, 18–22 February. ◆