Profitable copper production from low-grade waste ores

by Patrick I. James and Mark Baker

Global industrial development and economic growth led by the modernization of China and India are propelling a burgeoning demand for copper anticipated to last decades. Concurrent rapid ore depletion is driving an overall declining trend in the average grade of copper ore worldwide and compelling increasing processing costs despite new copper ore discoveries (Mudd, 2009). In response, lower-cost and low-energy heap leach processing using solvent extraction and electrowinning (SX/EW) to produce copper metal has seen expanded adoption; accounting for about 25 percent of global and nearly 50 percent of primary copper production in the United States (Komulainen, 2005 and Dutrizac, 2007). However, even this transformative process is struggling and has, except for a few exceptional cases, generally failed to be economically viable when the heap leach product stream known as the pregnant leach solution (PLS) tenors fall below 0.5 g/L of copper.

Opportunity: As a result, huge amounts of valuable ore assets in the form of marginal or difficult to leach ores like low-grade chalcopyrite (Fig. 1) are lying fallow – physically accessible but economically out of reach (Davenport and Schlesinger, 2002 and Singer et al., 2008). Numerous methods to economically utilize this ore such as bioleaching, PLS strengthening via reverse osmosis (R/O) and ion exchange (IE), and direct metal removal from weak PLS or waste streams by electrowinning (EMEW — Electrometals Technologies Ltd. and Freeport-McMoRan’s flow through electrowinning cell) and selective precipitation (BioSulphide process – BioTeQ) have been explored. Despite strenuous and costly efforts, a broadly effective and dominant solution to this critical problem has not yet emerged. Blue Planet Strategies (BPS) developed DeMet approach offers new hope by cost effectively concentrating weak PLS to enable profitable and immediate copper production with existing infrastructure from the vast fallow ore resources currently considered waste.

DeMet overview

What: The patented DEMET approach uses electricity to capture and release the target metals in a two-step process to transform unusable weak PLS into normal tenor product suitable for direct use in SX/EW copper recovery trains. Specifically, (Step 1) target metals are removed from input solution (loaded), separated from the input stream, and are then (Step 2) released into a product stream (stripped) in a cleaned and desired concentrated form (summarized in Fig. 2 in a simplified fashion as one steps through discrete time points (Frames B-F)). The target metal (copper) is effectively separated from the PLS input stream and then deposited into the product stream. Keeping the product stream volume smaller than the input stream achieves a higher metal (copper) concentration in the product stream as dictated by mass balance. The process can be readily tailored through electrical control and is extremely versatile. Proprietary approaches and equipment enable the steps to be accomplished efficiently, practically, and in continuous fashion even at input PLS tenors well below traditional economical processing limits.

DeMet employs a unique
DeMet copper concentrating overview – illustrated in a step-wise batch treat fashion B-F (in practice, DeMet employs a continuous process for better practicality).

- **A. Summary of the net electrolytic process.**
- **B. Initial conditions before treatment.**
- **C. Early stage of treatment.**
- **D. Later stage of treatment.**
- **E. End of treatment.**
- **F. Switch electrodes (reset) and repeat process.**

The novel approach leverages well-established and scalable processes with several new twists to circumvent traditional limits to practicality while maintaining key electrolytic technology benefits. These system and process benefits include: robust and compact systems widely used across a broad spectrum of industries with a long history of success and modest CAPEX costs plus processing that is easily tailored through operating parameters, selective and well-understood theoretically. The resulting powerful and versatile proprietary integrated solution is extremely adaptable, readily amenable to a tremendous range of chemistries, and can be used alone or as a drop-in solution to augment the capabilities of existing conventional process trains and open powerful new opportunities which are intrinsically unavailable to traditional electrowinning technologies.

Although DeMet can target powder metal product, this more radical departure from existing SX/EW operations is more challenging and tends to be more attractive in scenarios where existing SX/EW is not readily available. Here, the primary focus is augmenting production and extending mine life at operations with existing SX/EW. Thus, the discussion is restricted to generating concentrated product streams of the solubilized metal as a feedstock for existing conventional SX/EW operations.

When augmenting SX/EW facilities, the target metal (copper) effectively gets plated twice.
Although this is counterintuitive, this is done to improve overall process practicality by reducing fluid transfer (pumping—particularly problematic and low Input metal concentrations), mixing and product harvesting costs while also leveraging existing SX/EW strengths. It can be considered a necessary cost to avoid other higher costs key to the total augmented SX/EW production process. Blue Planet Strategies’ DeMet process assembles a recipe of processes and materials to create a flexible platform technology enabling practical and continuous target metal (copper) plating and stripping to generate concentrated PLS like product for conventional SX/EW final processing into metal. This leverages the mature existing technologies in their areas of strength and focuses on augmenting them to effectively extend their range of utility.

How does DeMet provide improved performance and functionality?

Electrowinning (Step 1) is the main hurdle to the DeMet process utility for weak PLS treatment. Numerous electrowinning approaches have been studied for reclaiming metals in a compact, pure and directly salable form from aqueous streams as summarized in Fig. 4 and all try to improve target species mass transfer to the cathode (plating) electrode surface to improve performance at lower concentrations (6 a-z). All have failed to find successful large scale practical application for the targeted direct weak PLS treatment below conventional SX viability (≤ 0.5 g/L copper) due to a variety of intrinsic fatal flaws.

Briefly: Plate and frame or rotating barrel configurations (are only practical at ≥ 3.0 g/L) (7), packed bed cells (work efficiently but experience occlusion and problematic dendrite formation), fluidized bed cells (work efficiently but suffer impractical electrolyte pumping costs at the low target concentrations). In the target regime (≤ 0.5 g/L copper), the candidate EMEW technology is impaired by (limited electrode surface and high electrolyte pumping costs) (8), while the Freeport-McMoRan flow-through cell (struggles with powdered production generation leading to difficulty harvesting product metal).

Spouted electrode technology (SET) takes a step in the right direction and embodies the best features of packed and fluidized beds (9). Work by Evans’ group at Berkeley throughout the 1980s and 1990s demonstrated low-cost planar forms of SET conducive to scale up and low-cost, compact stacked cell designs while also extending the range of viability to below 1 g/L in acidic media (9d-9i). Other investigations include a range of pH 2-12 and design adaptations for individual applications while Calo’s work at Brown University developed a predictive model for point source metal recovery with SET reactors (9j-9n, 10a, 10b). Recent work by author James and his colleagues removing Cu and Zn from pH 1 simulated acid mine drainage (AMD) demonstrated excellent copper removal from 1 g/L down to <0.010 g/L with an average plating efficiency of >60 percent (Fig. 5)(6t, 10c). Comprised of a slowly moving, high-surface area particulate bed cathode, SET resists occlusion and dendrites while requiring significantly reduced fluid pumping yet affording improved mass transfer supporting efficient plating at high rates and stable operation for long periods of time. Spouted electrode designs rely on an electrolyte jet to churn the particulate electrode bed which links spouting and electrolyte flow and severely limits operation parameter flexibility. This requires a high electrolyte flow rate while causing considerable fluid bypass of the treatment zone resulting in low per pass removal rates necessitating batch mode operation and excessive energy demands for pumping. Traditionally, these SET problems have not been overly important for more concentrated solutions (≥ 5 g/L) as the higher operation current densities supported dilute the impact of the pumping demands. However, below 2 g/L these fatal flaws precluding...
large-scale practical SET application are glaringly apparent. Industrially, SET has proved useful for dilute metal recovery (< 3 g/L) but endures unacceptable efficiency roll-off and excessive fluid pumping costs below 2 g/L at practical plating rates along with intrinsic product harvesting impracticalities (6t,10).

For example, the SET results noted in Fig. 5 indicate that the average electrical energy cost for EW from 0.5 g/L copper solution is a reasonable 1.4 kWhr/lb or 11 cents/lb at $0.08/kWhr (FE ~ 80 percent at 0.5 g/L, cell potential =~ 3 Vdc). However, to obtain this result the fluid pumping power required was ~4X that of the plating cost or another 44 cents/lb. By the time product harvesting, O&M, and other necessary costs are included, the end-to-end cost for this stage of the process is prohibitive. At yet lower solution concentrations (< 0.50 g/L), the situation gets rapidly worse, as one faces trades between lowering the plating rate (increasing equipment size and CAPEX), operating at lower plating efficiency, or increasing the fluid pumping rate to improve mixing – all of which increase process cost (OPEX) appreciably and further hamper practical utility.

The BPS DeMet solution: BPS’s new patented DeMet technology was specifically developed to overcome these vexing challenges and represents the next evolution in moving bed particle electrode technology cells. DeMet is covered by three issued and several additional pending patents that BPS holds. By decoupling the particle electrode motion from the electrolyte fluid motion, a range of new operational flexibility and control is gained. Independent optimization of previously coupled operational parameters to specific situational chemistry needs improves EW performance and lowers overall process energy requirements and costs while maintaining the benefits of SET. Also, fluid electrolyte flow patterns and rates through the treatment zone can be readily defined and controlled for more complete cathode bed utilization to enable much higher treatment system unit target metal per pass removal and input stream treatment rates. Due to these innovations, DeMet retains SET’s benefits yet avoids its pitfalls to retain practical viability for the target weak PLS treatment.

For example, the results for Step 1 (the hard step: controls cell performance) of the DeMet process (EW) seen in Fig. 5 indicate that the average electrical energy cost for EW from actual weak PLS is an excellent 0.56 kWhr/lb or 5 cents/lb at $0.08/kWhr (FE ~ 86 percent across the span 0.7 g/L down to 0.07 g/L, cell potential =~ 1.25 Vdc). Including fluid pumping (~3X the plating cost) adds 14 cents/lb giving a total that is only 35 percent of SET electrical costs. Additional DeMet improvements reduce product harvesting, O&M, and other necessary costs keeping the end-to-end cost for this stage of the process viable.

To complete the PLS treatment, the new decoupling and control achieved by DeMet allows the particulate cathode to be separated from the treated input stream and returned to the cell as the anode in a controlled fashion. This
enables stripping of the plated target metal (Step 2 – the easy step) into a smaller volume product stream to create the concentrated product while retaining the above noted EW benefits and performance improvements. Copper sulfate product solution (≥ 2 g/L) is created, which can then be fed into conventional SX/EW facilities to transform the DEMET product into copper leveraging their optimized production capabilities. This eliminates significant costs and complications for faced by conventional SET and direct PLS EW for product harvesting. Additionally, significantly greater cell design flexibility is realized and several costly cell elements are eliminated. The result is both lower CAPEX and OPEX with improved versatility and overall practicality.

Future directions: Applicable to a variety of metals (copper, iron, nickel, zinc, gold, silver and others) and feed stream chemistries (acid and alkaline), DeMet can benefit a number of areas as summarized in Fig. 6. It can augment production or recover metals from a range of metal laden streams mining and manufacturing process streams and generate a variety of useful and valuable products to meet feed stream specific chemistry needs and client desires. It can also improve waste water treatment by providing a plug-in capacity ahead of conventional waste water treatment plants (WTP) to recover valuable metals/metal products prior to traditional lime precipitation treatment. This creates a new revenue stream defraying costs or even generating new profits while also lessening WTP metal and acid loads, which can shrink conventional WTP processing costs. BPS is continuously seeking additional application opportunities and welcomes inquiries to explore how DeMet could enhance your processes.

Conclusions

Average worldwide copper ore grades used are falling and driving increased reliance on low-cost heap leaching and SX/EW as a dominant lower-grade ores processing method. Unfortunately, this technique generally fails to be economically viable for leach product (pregnant leach solution – PLS) below 0.5 g/L of copper and readily leachable ores are running out. Abundant low-grade chalcopyrite could supply copper for many decades but is difficult to leach and fails to produce strong enough PLS for commercial production by traditional means despite vigorous research to generate stronger PLS. Alternatives to cost-effectively strengthen as generated PLS for subsequent SX/EW processing or directly produce copper from the weak PLS have also failed. DeMet provides a powerful new option for wresting new value out of existing brownfield operations and unlocking the huge potential of fallow assets that can now be economically harvested. Its two-step process can cost-effectively process unusable weak PLS (down to ~0.05 g/L copper) and concentrate it to ≥2 g/L for use in conventional SX/EW copper recovery trains. This can provide new opportunities that have traditionally been considered nonviable and significantly extend mine lives while improving GM during implementation and transition to leaching of ores currently considered waste.

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