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Deep well rinsing of a copper oxide heap

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ABSTRACT

A subsurface irrigation test, using a series of four rinse wells, was conducted on a copper oxide heap leach pad over a three week period. The pad has been significantly underperforming due to difficult drainage conditions imposed by a high degree of fine-grained material. The test was to determine whether it would be feasible to conduct the directed leaching method across the entire pad assuming that enough copper is liberated to pay for the upscaled well field installation. The rinse wells were connected directly to an existing raffinate line. Validation of the test included 1) hydraulic monitoring to ensure sufficient solution flow and coverage in the formation and 2) metallurgical monitoring of solution samples extracted from nearby monitoring wells to ensure copper liberation. The results showed that the mean flow rates to each rinse well exceeded expectations by a factor of at least 1.5 for an extended period of time, that radial solution coverage for optimal operating conditions was approximately 17 m, and copper grade was upwards of three times the anticipated grade. The test was then extended for an additional two months on a single well, where the copper grade remained approximately two times higher than that from surface irrigation. By the end of the testing, it was calculated that at least 191,000 kg of copper was liberated. The upscaled program is to include 170 additional wells spaced 31 m apart and the potential for 12 wells to be rinsed simultaneously, which would allow the program to be completed in less than three years.

1. Introduction

It appears rather clear that processing of low grade metallic ore in a surface-irrigated heap leach facility is a mature technology (Schmuhl et al., 2011), owing to the many works dedicated to the topic (see Watling, 2013 and references therein) and the large number of mining facilities worldwide that have adopted it (Ghorbani et al., 2011). At a high level, applying solution to a large rock pile and collecting the liquor at the outlet would give the impression of a simple system. Heap leaching, however, is deceptively complex, and Dixon and Petersen (2003) distinguish a range of different processes occurring from the macroscale of the entire heap (e.g., solution flow, heat balance, gas advection) down to the mineral grain-scale (solid surface processes, reactive constituents, redox chemistry). Much of the early research in heap leaching went to conceptually understanding these processes and developing mathematical models to predict behavior (Roman et al., 1974; Shafer et al., 1979; Letowski, 1980; Bartlett, 1992; Dixon and Hendrix, 1993). With these efforts have come large-scale spatiotemporal phenomenological models that can track moisture, metal recovery and remaining inventory, temperature, air movement, and cyanide or free acid consumption (Cross et al., 2006; McBride et al., 2012).

More recently, a significant focus has been on improving or optimizing the heap leach process, with a mindful eye towards economic forces that include market prices, recovery time, and expenses, balanced with mining constraints as related to heap height, particle size, irrigation rate, curing, and other factors (Padilla et al., 2008). Operationally, Mellado et al. (2011) and Trujillo et al. (2014) examined optimal heap leach design criteria in maximizing a mine's metal recovery and hence income. Besides ore grade, other important factors included heap height, cycle time, and the number of simultaneously operating heaps as major factors to consider in designing a profitable facility. At a microscale and without considering economics, Petersen and Dixon (2007) optimized zinc recovery by adjusting heap height, irrigation rate, acid concentration, and solution temperature. Deveci et al. (2003) investigated optimum temperatures, pH, oxygen demand, and nutrient loads for bioleaching of sulfidic minerals. Other examples of optimized parameterization of leaching processes include those works by Bouffard and West-Sells (2009), Garcia et al. (2010), and Mellado et al. (2010).

Despite all of the best efforts to optimize engineering parameters at the onset of heap design and to make adjustments to the process through implementation, there is still a great potential for metal to be left behind. Using a simple example of a 0.25% acid soluble copper grade in a 50 million-ton stockpile, for every percentage of unrecovered metal there are 2.5 million pounds of copper internally distributed and potentially available for continued leaching. Extracting this last bit of material from the stockpile, however, can be challenging unless the nature of the solution delivery system is drastically changed. As many have discussed so far, preferential flow of leach solution (e.g., Orr and Vesselinov, 2002; Wu et al., 2007, 2009) will inhibit uniform wetting and drainage through all pore space. These flow channels cannot easily be broken unless the pore pressure is redistributed in favor of flow towards underleached areas (by substantially reducing the irrigation

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rate for an extended period of time) or through hydraulic alteration of the pore structure. The latter can be achieved through pressurized delivery of leach solution via injection wells (e.g., Seal et al., 2012), where the wash-out of fines has been hypothesized to increase the hydraulic conductivity and expose new surfaces to barren leachate (Winterton and Rucker, 2013).

While the hydraulics of this new pressurized solution delivery method has been investigated in some detail (Rucker et al., 2014), the potential for metal liberation has not. In Seal et al. (2011) the PLS grade in the reclaim pond was used to estimate additional gold recovery above a hypothetical baseline and it was suggested that upwards of 4500 troy ounces was recovered as a result of the injections. Unfortunately, there were many parts of the heap leach pad reporting solution arrival at the reclaim pond, thus providing a level of unquantifiable uncertainty associated with that recovery estimate. In this work, a great deal of effort was expended to quantify the real liberation at the point of delivery using both rinse and solution monitoring wells. A distinction is made here between injection wells used in previous works and rinse wells, where rinse wells are connected to existing irrigation piping without the use of external booster pumps and apparatus to segregate individual zones along the well. The demonstration of rinse wells is conducted on a copper oxide run-of-mine stockpile and the solution coverage, metallurgical parameters, and hydraulic alteration are quantified to allow for upscaling the operation pad wide.

2. Ore description

Copper extraction from the leach pad has consistently fallen short of forecasts due to the difficult drainage conditions imposed by fine grained material. It is estimated that copper recovery is near 40% for the 40 million ton heap with average acid soluble copper grades of 0.25%. After an extensive drilling campaign to characterize the pad, it was discovered that fines, as defined by those particle sizes passing the 200 mesh (0.075 mm), ranged from 5 to 26%, were evenly distributed throughout the depth profile but were stratified within individual lifts, and the assayed parameters of particle size distribution and total residual copper exhibited high spatial variability. These observations lead back to the specific type of ore and host deposit, which is a dual-centered landslide breccia deposit comprising mainly of schist with supergene mineralization sometime from the Eocene to late Miocene. The deposit is covered by dacite and a relatively well cemented tuff, where mineralization has also occurred. A major fault lies between the two breccia-host mineral centers and is itself hosted in brecciated diabase.

Chrysocolla generally fills the clay-rich matrix of the brecciated deposit, the fault, and open fractures within the schist and diabase immediately in the footwall zone of the fault, dacite, and larger clasts of the breccia. Malachite is locally abundant in the deposit and sporadically along the fault. Chalcocite is the only significant copper sulfide mineral present and is restricted to the lower parts of the deposit. Chalcocite is commonly found rimming or partially to totally replacing pyrite, which is often found as veinlets or individual grains within breccia clasts.

Acid consumption is the highest for material within the fault zones, and particularly from the low lying fault which establishes the bottom of the pit area. Here, precipitation of elements such as calcium, magnesium, zinc, aluminum, etc. during the formative events of copper mineralization, give rise to sulfuric consumption on the order of 50 kg/tonne according to 24-hour bottle roll tests. This value is steady over the depth of extracted samples, except for the bottom of each drill hole tested (representing the bottom bench of the pit).

After blasting, the ore is trucked to the heap for placement and surface leaching. Surface leaching occurs at an approximate rate of 6 L/h/m^2. Early in the heap's development, the trucks dumped their load to be spread by dozer, and there was significant traffic on the heap. Lift heights were upwards of 10 m. Approximately three years ago, small conveyance stackers were introduced to reduce the compactive forces from haul trucks and lifts were reduced to 5 m. Interlift drains have also been placed along a few lifts to help move the pregnant leach solution out of the heap more expediently and to reduce build-up of hydraulic head at the interface between the truck dump and conveyance stacker portions of the heap.

3. Methodology

Given the low recovery, a secondary recovery method using subsurface irrigation was chosen. This type of solution delivery can be applied in a number of ways that include adjusting variables associated with application pressure, number of injection zones per well, consideration of extraction wells, drilling method, well casing, and well screening materials. For the injection examples presented for gold mines (Seal et al., 2011, 2012; Winterton and Rucker, 2013), the drilling method was dual rotary that advanced the steel casing during drilling to ensure tight contact between with the formation, which minimizes the potential for blowout of the well. The wells were perforated in-situ at multiple zones and a high pressure booster pump was employed to maximize the solution coverage for each zone. The high pressure allowed for well

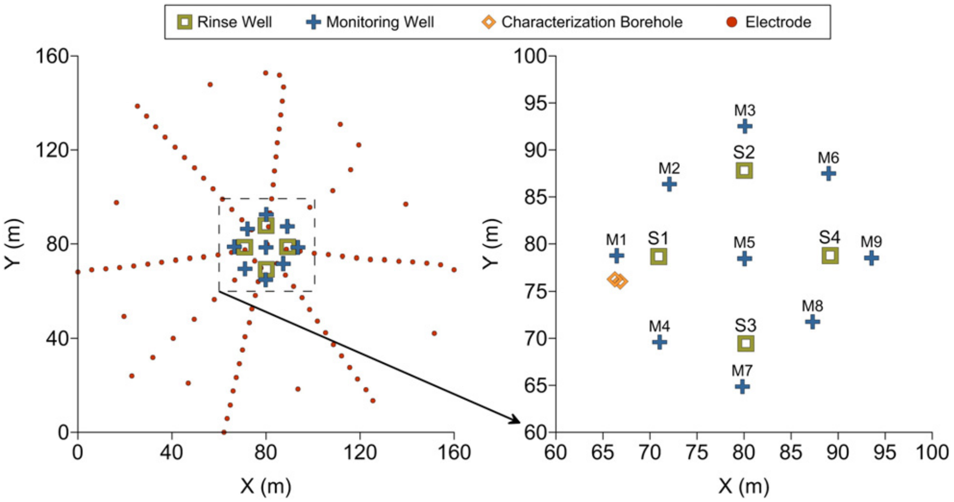

Fig. 1. Layout of the rinse and monitoring wells for secondary recovery of copper. Positions of stainless steel electrodes are also shown, which were used to image the solution propagation using electrical resistivity geophysics.