SURFACE PASTE DISPOSAL OF HIGH-SULFIDE TAILINGS – FIELD CELL MONITORING AND PILOT PLANT TESTING[1]

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Abstract.   Since 2001, Somincor have been investigating the feasibility of changing the tailings deposition method to sub-aerial placement of paste at its Neves Corvo Mine in southern Portugal. The pyritic tailings have a very high acid generation potential and are currently being placed sub-aqueously in a conventional tailings facility. Work completed to date has included a laboratory bench-scale screening program, a three-year field cell monitoring program, and pilot plant testing to investigate deposition techniques, co-disposal with acid-generating waste rock and cover performance. This paper describes the results of the field cell study and provides an introduction to the ongoing pilot plant testing.

Although the field cells exhibited short-circuiting of seepage, the field cell monitoring program has demonstrated that a considerable lag time exists before acidic seepage is generated. This lag time has important consequences in terms of operational placement of paste and closure of a paste deposit. Based on geochemical modeling and observations from the bench-scale testing program, long-term seepage quality may reflect buffering by kaolinite.

A pilot plant paste program has been ongoing since February 2005. This large-scale test (a 1-hectare site containing 35,000 m^3 of paste) provides an exceptional opportunity to investigate paste deposition techniques. In addition, co-mixing with waste rock will be evaluated, as well as the long-term environmental stability of the paste. After paste deposition has been completed, the pilot area will be capped using several trial covers and its geotechnical and environmental performance will be monitored.

Additional Key Words: geochemical modeling, oxidation,

Introduction and Objectives

The disposal on surface of acid generating waste is a common problem for base metal mines around the world. Sociedade Mineira de Neves-Corvo, S.A (Somincor), who own the Neves Corvo Mine and associated tailings facility, have been investigating the possible application of paste technology since 2000 when a feasibility study indicated the potential for major long-term advantages. Given the long remaining mine life (current life-of-mine indicates operations through 2029), the existing sub-aqueous disposal method will require substantial dam raises. In addition, the presence of a water cover in perpetuity as a closure option is a considerable challenge in the very arid and net evaporative climate of southern Portugal.

Understanding the geochemical behavior of the sulfide-rich tailings was paramount as conventional sub-aerial disposal methods can facilitate and promote significant generation of acid rock drainage (ARD) and metal leaching (ML). The first phase of the geochemical characterization of the tailings was conducted in the Somincor laboratory and involved a screening-level assessment of different sub-aerial placement options. This investigation and its findings are described in detail in Verburg et al. (2003).

The study expanded to the field in 2002 with the construction of six field cells to monitor the performance of the sub-aerial placement option. Additional laboratory testing (e.g., kinetic testing) was not conducted due to the desire to rapidly gain experience with preparation and placement of large paste volumes combined with environmental monitoring under ambient site conditions. Wet paste was selected for the field cell trials based on the results of the laboratory testing. Since their construction in September 2002, the cells have been monitored for over two years with weekly collection of seepage and runoff. Significant quantities of data have been generated, and the results of the first year of field cell testing are described in Newman et al. (2004).

This paper presents the most recent results from the field cell program. In addition, predictions of long-term seepage quality are presented based on geochemical modeling and the testing program to date. This paper also reports on the progress of Phase 3 – a 35,000 m^3 pilot paste trial. The trial will last a minimum of several years and will test paste preparation, placement, containment, co-mixing of paste and waste rock and closure options currently under consideration for the implementation of paste at Somincor's active tailings facility.

Methods

Material Characteristics

Based on the results of the bench-scale laboratory testing, wet paste (250-mm slump) was selected for the field cell program as this material demonstrated the lowest rate of sulfide oxidation and acid generation.

The tailings underwent an extensive geochemical characterization as part of the bench-scale and field cell programs. Detail on material characteristics are provided in Verburg et al. (2003). In summary, the tailings are fine grained (60 to 70% minus 20 micron) and highly acid generating, with an acid generating potential (AP) between 700 and 800 kg $CaCO_3$/ton and a neutralizing potential (NP) of approximately 30 kg $CaCO_3$/ton. The dominant mineral is pyrite, which accounts for approximately 40 to 50 wt percent of the paste. Minor sulfides include chalcopyrite, sphalerite, arsenopyrite and tennantite-tetrahedrite. Silicate minerals observed are

quartz, kaolinite and muscovite, for a total of approximately 30 wt percent. Carbonate in the form of calcite, dolomite and siderite is present between approximately 10 and 15 wt percent. Gypsum occurs in trace amounts.

Field Cell Construction

The field cell testing program made use of a robust design that allowed the collection of seepage and runoff. Six cells were constructed and all were filled with 250-mm slump total tailings paste. The paste was prepared at the Somincor paste backfill plant and each cell contained approximately 12 tons of paste with a solids content of 80 percent by weight.

Based on the results of the laboratory testing, three mixtures were selected for field testing:

- Unamended paste;
- Paste amended with a surficial spray of bactericide (Promac®); and,
- Paste amended with 0.5 percent cement by dry weight.

The 0.5 percent cement represented a nominal amount of cement. As identified by the bench-scale testing program, the presence of cement was expected to have little impact on long-term environmental performance of the paste.

Two duplicate sets of three cells were constructed on site according to the design drawing presented as Fig. 1. The "as-built" attributes of the field cells can be summarized as follows:

- an opening at the surface of approximately 3 m by 3 m;
- a depth of approximately 1.3 m and narrowing downwards;
- a basal liner of 1 mm high density polyethylene (HDPE);
- a basal drainage layer of 0.3 m clean silica gravel;
- a non-woven, needle-punched geotextile approximately 2 m by 2 m overlying the gravel;
- Terram 1000 geotextile approximately 2.25 m by 2.25 m overlying the non-woven geotextile;
- 100-mm diameter PVC pipe, perforated in the basal gravel for extraction of leachate samples; and,
- HDPE extending onto the ground surface with a catchment ditch for runoff sampling.

Figure 2 shows the filling of a cell with paste; Figure 3 presents an overview of some completed cells.

Two cells of each 'recipe' were constructed: one was to be irrigated at a rate of approximately 90 liters per week (the approximate equivalent of the amount of annual precipitation over a 1-year application period) and one was to be left to ambient conditions. It was anticipated that the irrigated cells would weather at an accelerated rate relative to the ambient cells due to the continuous wetting and drying as well as the ongoing removal of oxidation products.
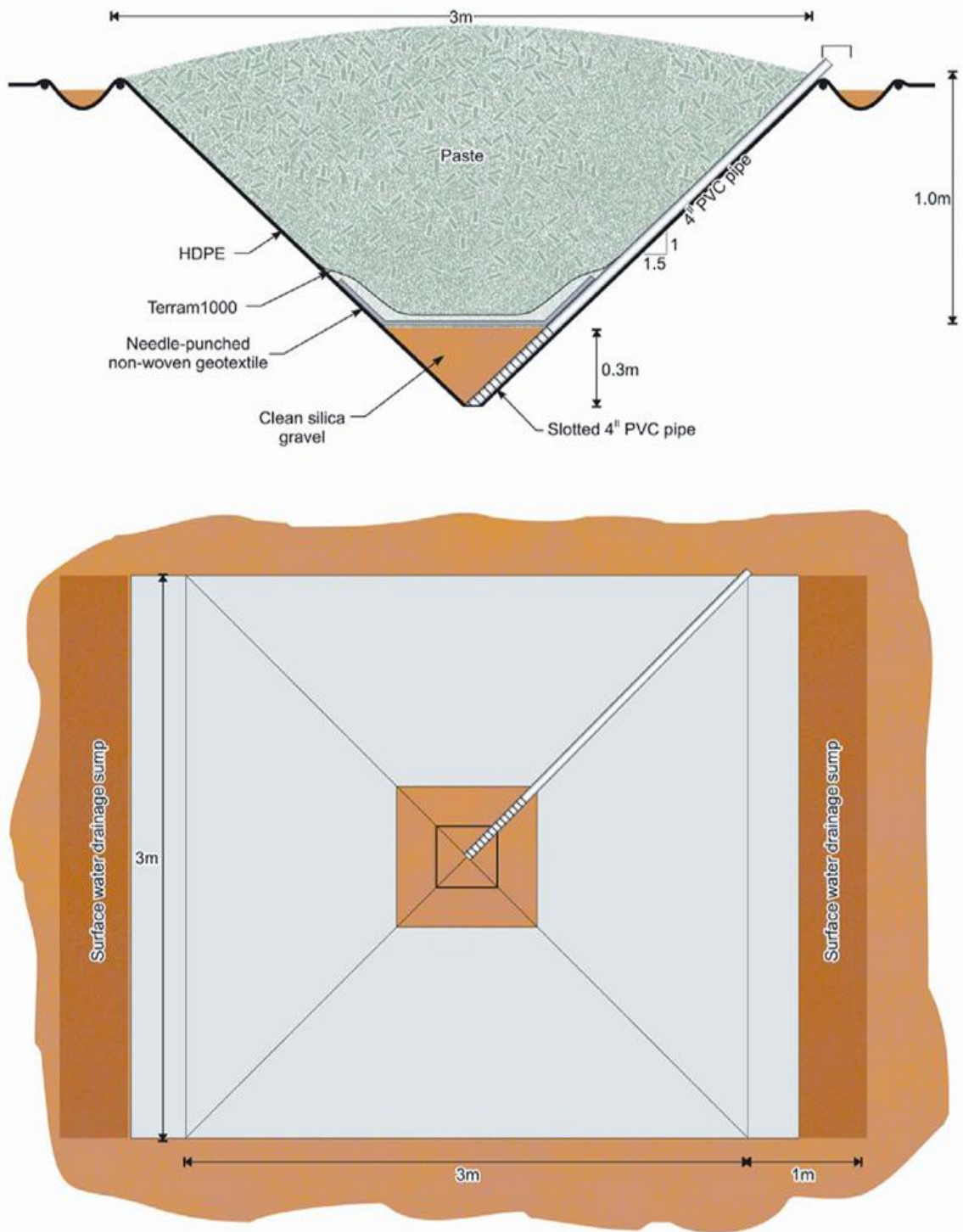
Figure 1. Cross-section and plan view of field cell.

Figure 2. Paste cell filling

Figure 3. Overview of completed cells.

Field Cell Monitoring

The cells were constructed such that seepage (underflow) and runoff (overflow) could be monitored. On-site water quality sampling commenced in September 2002 and has continued since this time. Underflow samples are collected from the PVC pipes, while overflow is collected from the small trenches designed for capture of runoff. On a weekly basis, pH, conductivity, temperature, Fe and SO_4^{-2} are measured. The sample volumes extracted are also recorded. In addition, samples are collected each month for more detailed analysis, with full water chemistry every quarter and selected analysis (conductivity, pH, acidity, alkalinity, Ca, Fe, SO_4^{-2}) the remaining months. The monitoring frequency was reduced after the 2-year anniversary of the cells in September 2004.

On-site climatic conditions are recorded, including measurement of precipitation, evaporation and temperature (maximum and minimum).

In addition to collection of seepage and runoff samples, the cells were cored on approximately the first and second anniversary of the cells (October 2003 and November 2004). Cores were collected using a thin-walled push tube sampler, after which the holes were backfilled with bentonite to prevent preferential ingress of oxygen and water.

In each of the field cells, core was sampled continuously to a depth of approximately 0.8 m. Each sample was extruded onto a plastic tray for photographing and logging. Selection of samples for analysis (four per core) was based on identification of individual strata within each core during the logging process. Samples for geochemical testing were sealed after extraction to prevent interaction with the atmosphere. The geochemical characterization program included acid base accounting (ABA), chemical analysis, mineralogy, paste pH and paste conductivity. Geotechnical investigation (moisture content, solids content, Atterberg limits, particle size distribution, drained shear box, consolidation and hydraulic conductivity testing) was also conducted on the cores collected in November 2004.

It should be noted that, from its inception, the field cell program was considered a prelude to the pilot plant testing, and primarily aimed at gaining practical knowledge regarding long-term paste behavior. As a consequence, it represented a robust program, not designed for detailed monitoring or rigorous quantitative interpretation of monitoring results. The pilot plant test cell has been implemented such and will be monitored such that expected operational conditions are simulated as realistically as practicable, while the geotechnical and geochemical monitoring will be extensive and comprehensive, allowing for quantitative evaluation.

Results and Discussions

Cell Design

Seepage monitoring has progressed weekly for over two years. Cumulative seepage volumes are shown in Fig. 4. For the irrigated cells, they reflect the systematic addition in small, measured doses of additional water. The ambient cells, in contrast, received much of their rainfall in high-intensity storms. Water balance calculations indicate that the majority of the ambient and irrigation water (between 80 and 90%) discharged as runoff.

One of the most important findings of the field cell testing program is that the seepage volumes largely reflect short-circuiting within the cell and preferential flow through cracks and along fissures or the cell wall as well as along the cell-paste interface. This is further supported by examination of time histories of rainfall data with seepage volume data for the six cells. Based on the results from infiltration modeling, it is estimated that water would take approximately 200 days to travel through the paste, assuming a homogenous mass without preferential pathways. However, for both the ambient and irrigated cells, the volume of seepage collected responds rapidly to high-infiltration events without the expected time lag. This indicates that a portion of the rainfall reaches the sump without passing through the paste.

The short-circuiting is caused by to the cell design. With the fine paste above a drainage layer of coarser material (the silica sand), a capillary break will result under unsaturated conditions. This leads to lower net percolation rates through the paste and higher moisture conditions in the paste than otherwise would have occurred without the underlying drainage layer. The higher moisture conditions contribute to the relatively high runoff values, although the significant runoff also can be attributed to the low intrinsic hydraulic conductivity of the paste (approximately 5×10^{-8} m/sec).
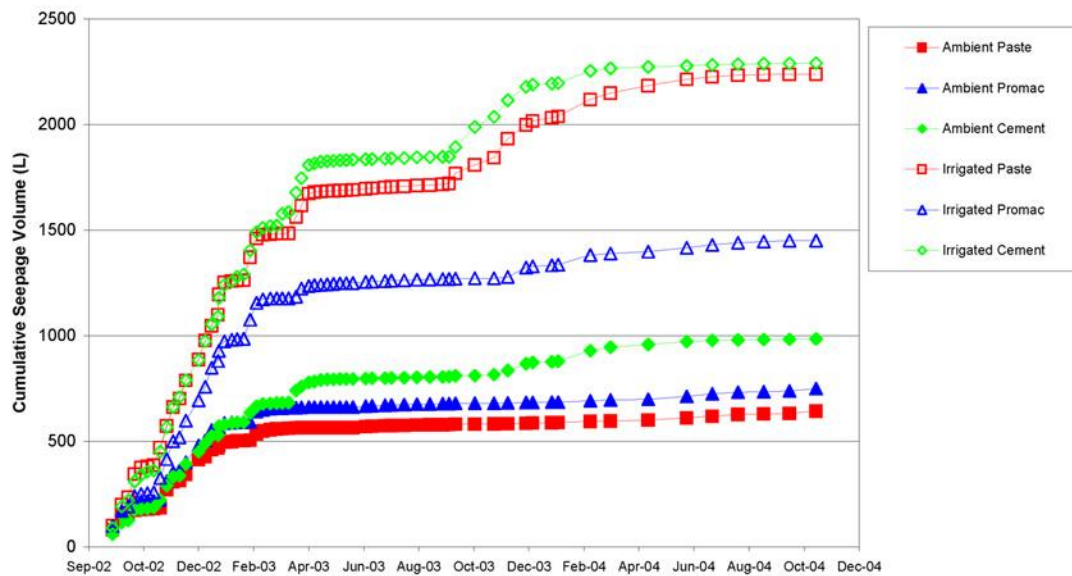
Figure 4. Cumulative seepage volumes.

Despite the apparent deficiency in cell design, they fulfilled their intended purpose, which was to collect runoff and seepage from weathering paste. Without installation of a drainage layer, it likely would not have been possible to obtain seepage samples as the permeability of the paste is too low to produce an adequate volume of drainage. Although a drip surface at zero pressure might have eventually occurred, due to the low permeability of the paste, surface evaporation began to dominate the system before the lower drain condition could form.   In addition, during operational paste placement, a portion of the paste will be deposited on natural ground, which is unsaturated sandy silty gravel. This configuration is in fact simulated by the field cell design. Although the field cells represent a system dominated by crack and by-pass flow, the water quality data derived from the cells provide valuable information that can be used in support of the evaluation of paste placement at Neves Corvo.

Water Quality
Due to the occurrence of by-pass flow, the chemical composition of the seepage does not reflect gradual infiltration through and equilibration with the paste mass. Instead, the chemical evolution of the seepage (most importantly the onset of acidic conditions) is more indicative of the flow regime within the cell. Nevertheless, it is considered that the cells can be used for their intended purposes. In particular, the lag time observed for breakthrough of acidic seepage represents an important observation, which will assist in development of a paste deposition method that prevents the generation and migration of acidic solutions during and after paste placement.

The water quality data indicate that sulfide oxidation proceeds to varying degrees within the six paste cells. Differences in geochemical performance of the cells were more pronounced between irrigated and non-irrigated cells than between the unamended, cemented or Promac® cells, with the irrigated cells being more reactive than the ambient cells.

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As shown in Fig. 5, the irrigated cells reported acidic conditions in the underflow approximately seven months into the trial whereas the ambient cells maintained near-neutral pH conditions throughout the first one-year monitoring period. Underflow in the ambient cells became acidic after approximately 16 months of monitoring, with most recent values for pH being maintained around 2.
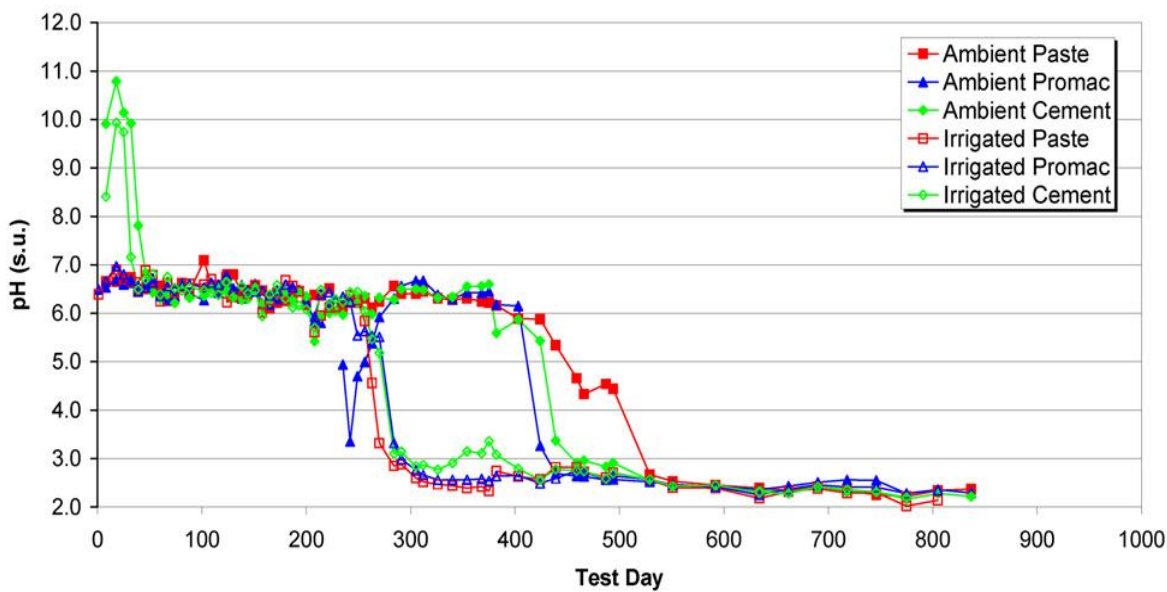

Figure 5. pH trends in underflow.

As expected, SO_4^{-2} and trace metal concentrations increased with increasing acidity. Sulfate concentrations up to approximately 30,000 mg/L have been measured in underflow. Aluminium, Cu, Mn and Zn generally occur in the most elevated concentrations in seepage, reporting peak concentrations between 100 and 1,000 mg/L. Cadmium and Ni levels are lower, reporting peak concentrations between 1 and 10 mg/L. Peak Cr and Pb concentrations reach values between 0.1 and 1 mg/L. Fig. 6 shows an example of the pH-dependency for Cu, with concentrations in runoff and seepage increasing dramatically as the pH declines.

Runoff water quality trends for the individual cells were more erratic, although an overall and rapid trend towards acidity is indicated on Fig. 7. Anecdotal evidence from the personnel collecting the samples indicated that the acidity of the runoff was related to the time interval between collection and the occurrence of previous irrigation and precipitation events. With time, as oxidation penetrated beyond the surface layers, all runoff generated was of poor quality and converged upon a composition similar to that of underflow.
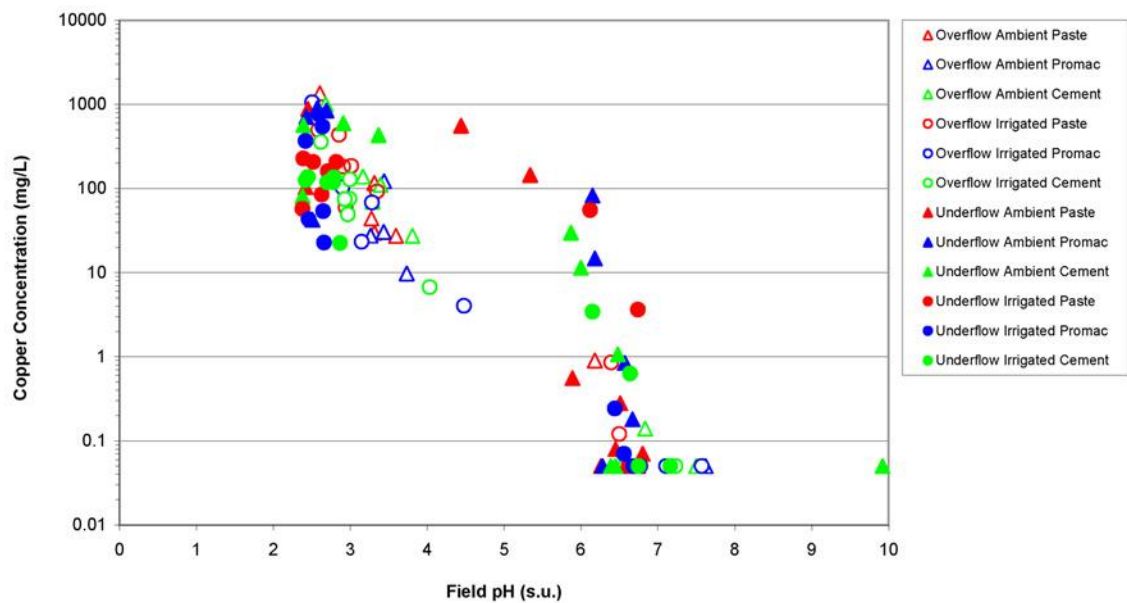
Figure 6. Copper concentration versus pH in underflow and overflow.
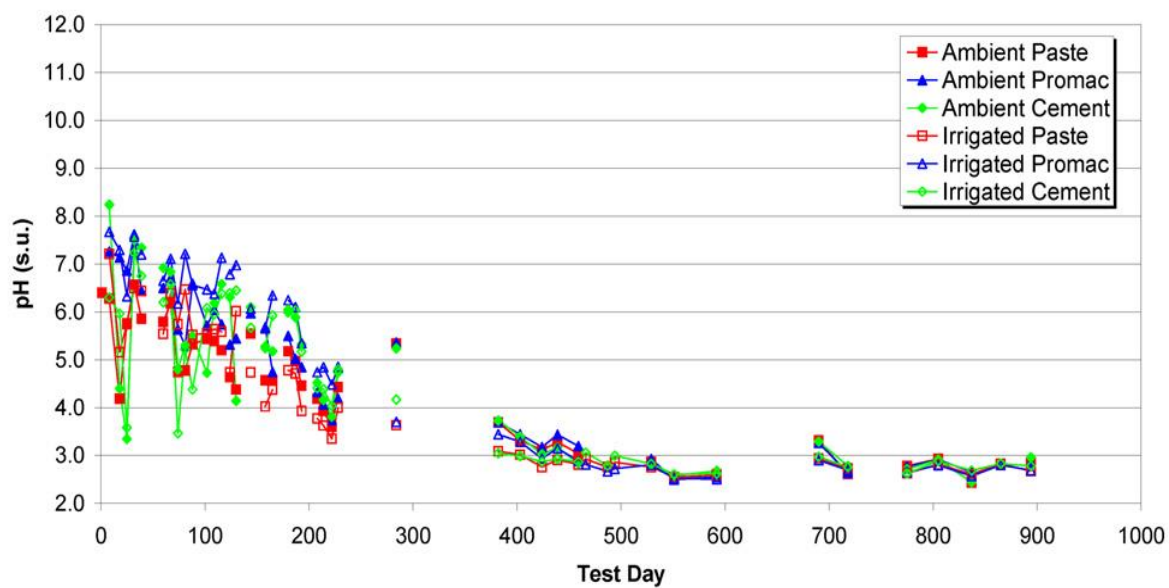

Figure 7. pH trends in overflow.

Solids Quality

Coring of the field cells has taken place twice, at 12 months (October 2003) and 25 months (November 2004) after the initiation of the field cell program. In general, analytical results for both events were similar. Sulfide oxidation trends were evaluated through establishing concentration profiles for ABA parameters (paste pH, sulfur species, neutralization potential), while metal mobility was assessed through evaluation of metal concentration trends.

Surficial samples generally showed lower values for paste pH, depletion of neutralization potential, and higher proportions of SO_4^{-2} sulfur relative to deeper samples, indicative of shallow oxidation. Fig. 8 illustrates these trends by presenting the paste pH profiles with depth for the six cells. Occasional low paste pH values at depth are considered indicative of preferential pathways for low-pH fluids. Such conduits were indeed observed during the coring and manifested themselves as reddish, oxidized fracture traces. In addition, in some instances, paste pH values for 2004 are higher than those in 2003, which is counterintuitive to the notion that, as oxidation proceeds over time, paste pH values should decrease. Although the paste itself was highly homogeneous during placement in the cell, compositional heterogeneity may have developed due to the presence of preferential pathways. This suggests that collection of multiple cores within each cell is required to properly evaluate chemical trends in solids over time. Trace metal trends generally showed significant depletion near the surface with constant concentrations at greater depths.

Geochemical Modeling

Geochemical modeling was conducted to develop a long-term predictive model for paste reactivity that can be applied in support of evaluation of paste management alternatives. The modeling focused on the underflow from the irrigated un-amended paste cell, and made use of the available information on paste hydraulics, seepage chemistry, and chemical and mineralogical trends in the paste solids.

As mentioned in previous sections, the cells short-circuited, and the resulting seepage quality likely reflects partial equilibrium conditions at best. This lack of equilibrium severely limits use of geochemical modeling to accurately and quantitatively simulate conditions in the field cells. Nevertheless, it was considered of interest to use modeling to gain insight into geochemical processes that may be occurring and to test hypotheses regarding major controls on the mobility of selected constituents, provided the modeling was performed "…with an appropriate sensitivity to the inherent limitations and uncertainties of geochemical models and modeling…" (Alpers and Nordstrom, 1999). Therefore, modeling was conducted, but with the understanding that it would be of a speculative nature.

The geochemical modeling program used was PHREEQC Version 2.7 (Parkhurst and Appelo, 1999), an equilibrium speciation and mass-transfer code developed by the United States Geological Survey. This code has the ability to simulate the pertinent processes occurring in the tailings paste, such as precipitation/dissolution of selected solids, redox reactions and atmospheric interaction. The MINTEQA2 database was applied.

The modeling effort focused on the evolution of paste seepage chemistry due to pyrite oxidation. The solid phase composition (i.e., primary mineral phase composition) of the paste was defined using the results of mineralogical analysis of samples collected from the irrigated paste cell. Oxidation of pyrite was simulated as a batch reaction through the addition of oxygen in an arbitrary number of time steps. Despite indications to the contrary, for the purpose of the
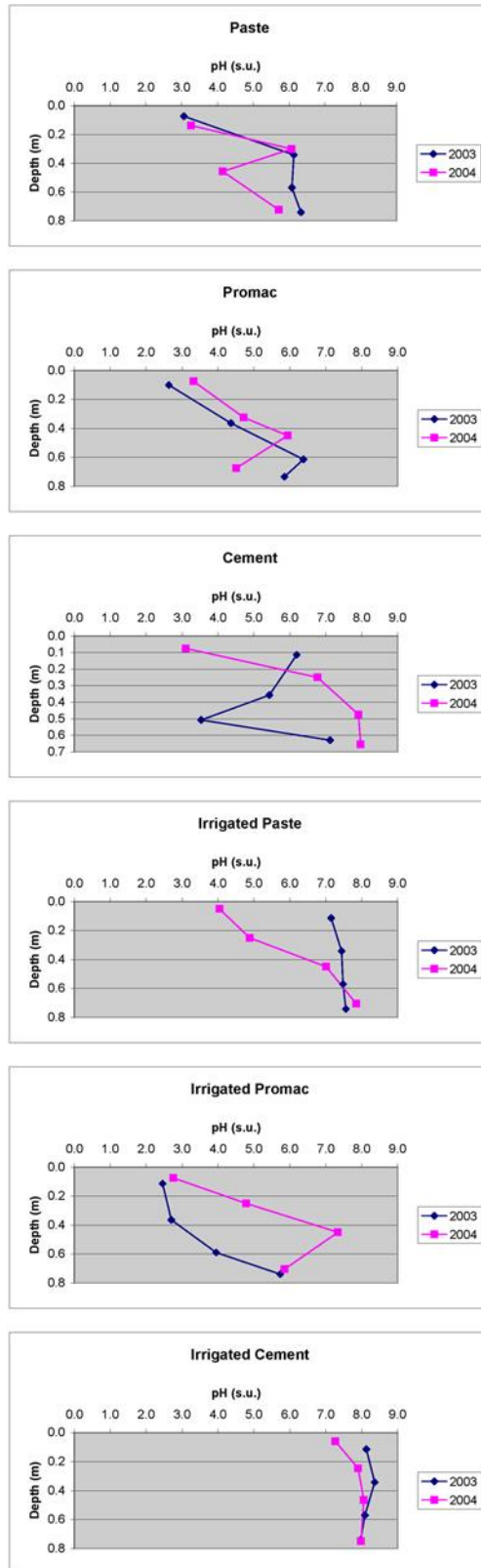
Figure 8. Paste pH trends with depth in the field cells.

modeling, equilibrium was assumed with respect to both primary mineral phases and selected secondary mineral phases. Transport of reactants and reaction products was not considered. Selection of credible secondary mineral phases was based on considerations related to precipitation kinetics, observational evidence at similar sites, results of the speciation modeling and best professional judgment.

Figure 9 shows the modeled paste seepage pH profile. The "time" component along its horizontal axis is dimensionless and does not represent an actual time interval. Rather, it indicates the number of time steps required for a certain condition or trend to develop. Absolute time therefore cannot be determined from this figure, but the number of time steps required for a certain condition to develop and persist can be related to relative duration.
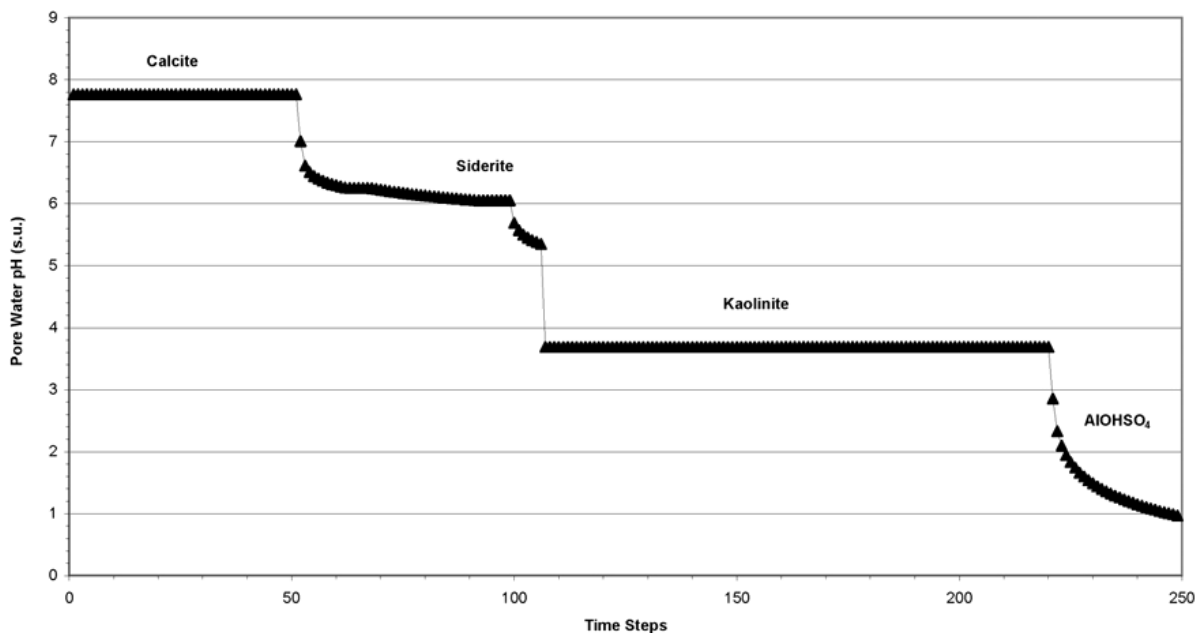

Figure 9. Mineral buffering sequence and pH trend over time.

Pyrite oxidation occurs over the entire model simulation. In the early stages of the model simulation (up to approximately time step 50), solution pH is buffered by the dissolution of calcite. The SO_4^{-2} and Fe released into solution by pyrite oxidation react with the Ca and carbonate released by calcite dissolution to form gypsum and siderite, respectively.

In the latter stages of the model simulation, kaolinite and aluminum hydroxysulfate act as pH buffers (Fig. 9). Following depletion of these minerals, the pH of tailings seepage is predicted to decrease to values lower than those currently observed in the test cell seepage. This sequence is in good agreement with similar observations and modeling results obtained by others for sulfidic tailings (e.g., Jurjovec et al., 2002; Mayer et al., 2002; Molson et al., 2004) who also showed a buffering succession including carbonate and silicate minerals.

Figure 10 compares the model SO_4^{-2} and pH trends to seepage monitoring results from the irrigated paste cell. The water quality monitoring results are plotted versus days of cell operation. The pH was used as a master variable to align the observed trend with the modeled

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trend. The unitless time scale of the model results was adjusted to match the timing of the steep pH decline from quasi-neutral to acidic pH conditions observed in the seepage.

The comparison between modeled and observed pH plateaus shows good agreement between time steps 150 and 250 where siderite is assumed present, but discrepancies are evident in earlier and later time steps. The differences during early time steps may be attributed to the fact that the calcite identified during the mineralogical investigation in fact is an Fe-rich variety similar to siderite. Differences between the actual and predicted pH values during later time steps are considered attributable to reaction kinetics. The PHREEQC simulations assume that equilibrium is achieved in each time step. As such, the approach used does not account for the slower dissolution rates of the silicate versus the carbonate buffering minerals.
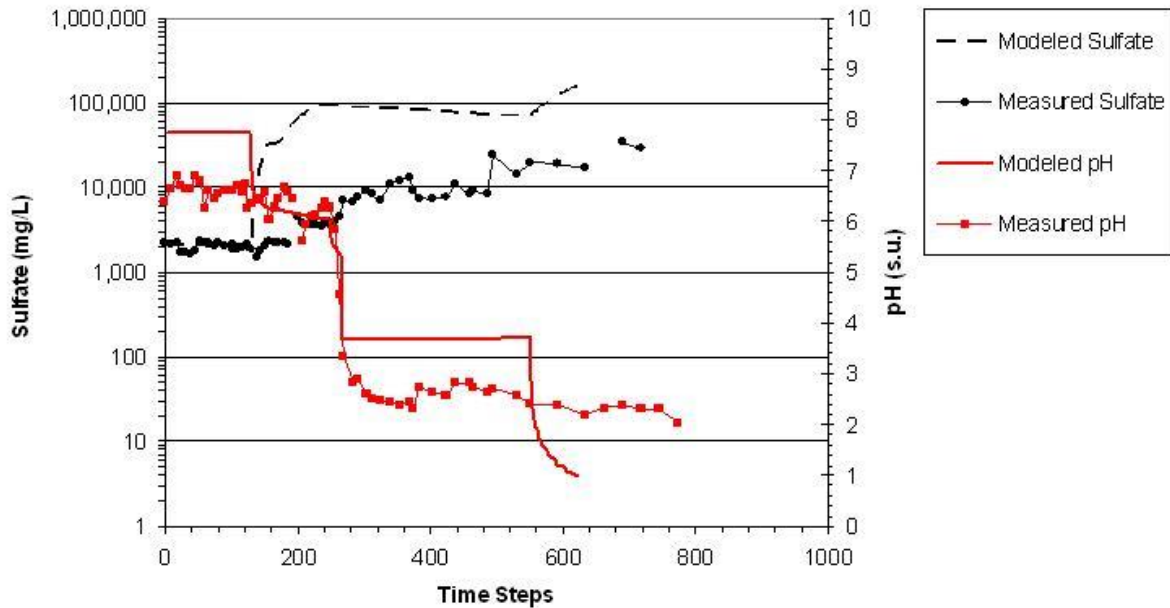

Figure 10. Comparison between modeled and observed pH and SO_4^{-2} trends.

The model predicts a considerable period of kaolinite buffering at a pH of approximately 3.7. In contrast, the field cells have reported an extended period of pH values ranging from 2.0 to 2.6. The cells are known to short-circuit, which leads to accelerated downward transport of infiltration, thereby limiting the contact time between the solution and the slow-dissolving kaolinite in the tailings solids. Speciation modeling indicated that the most recent seepage is near equilibrium with respect to aluminum hydroxysulfate. As a consequence, the observed pH plateau in the seepage may represent combined buffering by $AlOHSO_4$ and kaolinite.

An excellent match between modeled and observed SO_4^{-2} concentrations is found in the early stages of monitoring, when SO_4^{-2} concentrations are modeled to be limited by gypsum solubility. In later stages, the presence of an unknown sulfate-bearing mineral may explain the discrepancy in modeled and observed SO_4^{-2} concentrations. This phase would have to be less soluble than melanterite, which was identified from the geochemical modeling as the control on SO_4^{-2} concentration during the later time steps.

Long-Term Environmental Stability of Paste

The long-term environmental stability of the paste is critical to the feasibility of paste as a disposal option. Clearly, the paste is quite reactive, requiring careful design of operational and post-closure measures to prevent generation of acidic seepage.

To predict the concentrations of key constituents (i.e., pH, SO_4^{-2}, Cu and Zn) under terminal conditions, the results of geochemical modeling, cell water quality monitoring data and geo-environmental models were considered. The latter approach is described in detail in Plumlee et al. (1999) and involves use of mine drainage data from mineral deposits with a similar genesis and environmental setting. For the Neves-Corvo deposit, data from Plumlee et al. (1999) for volcanogenic massive sulfide (VMS) deposits were used to bracket terminal water qualities.

At first glance, geochemical modeling identifies a potential for a further decline in pH in seepage water quality beyond that currently observed in the test cells. The sulfide content of the tailings is very high, and acidity generated by the oxidation of sulfides could eventually exhaust all available buffering mineral phases. This implies that a terminal pH of approximately 1 might be considered reasonable for evaluation of worst-case conditions. In very rare cases, lower values for pH have been observed, for instance at the Iron Mountain VMS deposit in California (Nordstrom and Alpers, 1999). However, these extreme conditions reflect an unusual combination of several factors, including complete lack of interaction between mine water and acid-consuming wallrock minerals, high temperatures in the mine stopes (up to 70°C) and intense evapoconcentration due to arid conditions (Plumlee et al., 1999). Sulfate concentrations in tailings seepage could peak at approximately 100,000 mg/L based on the current modeling. Plumlee et al. (1999) summarize water quality data from a number of VMS deposits. These data support an upper SO_4^{-2} concentration of approximately 100,000 mg/L at a terminal pH of 1.

Based on supporting evidence from the bench-scale testing program, it is considered that it may be possible to avoid generation of such poor-quality seepage when paste disposal and closure of the tailings impoundment are conducted in accordance with best management practices. Implicit in this assumption is that, during placement, paste layers are covered by overlying paste material (or the final cover) before significant oxidation occurs, infiltration through the impoundment is minimal, and any seepage has sufficient time to equilibrate with the tailings solids.

Figure 9 suggests that buffering by kaolinite is likely to be initiated after a substantial time period, and then persist for a significant duration. Therefore, the buffering plateau represented by kaolinite may be representative of expected conditions over the long term provided the requirements for proper paste placement and impoundment closure are met. This plateau corresponds to a pH value of approximately 3.7.

The pH trends for the irrigated paste cell do not include values around 3.7. Instead, as shown in Figure 5, for reasons discussed earlier, a rapid transition occurs from a pH slightly above 6 to a pH of approximately 2.5. Therefore, direct use of field cell data to derive an expected water quality is not considered appropriate. However, another set of tests was conducted that resulted in several solutions with a pH of approximately 3.7. These experiments were the tailings batch tests, which took place in the Somincor laboratory in 2002, and are discussed in detail in Verburg et al. (2003).

The tailings batch tests were part of a screening program aimed at evaluating the environmental performance of a variety of tailings materials as well as amendments. Various

paste slumps and admixtures were tested for a period of 209 days, during which temperature, paste pH and paste conductivity were measured at a regular frequency. The samples were misted with deionized water and any excess water was removed as necessary. At the termination of this program, supernatants were generated for each sample and analyzed for a comprehensive suite of parameters. These supernatants represent long-term water quality associated with paste tailings that have undergone long-term, extensive exposure and weathering under moist conditions.

The analytical results indicated that the supernatants from the three unamended, undisturbed samples all have pH values very similar to the predicted 3.7 (between 3.5 and 3.8). The pH of the supernatant from the agitated filter cake sample was slightly lower at 2.7 as this sample was actively mixed throughout the testing period. The good agreement with the modeling results supports the notion that the kaolinite buffer may indeed be present and govern pH for a very long time under exposed conditions.

As a further check, the supernatant water quality was compared against concentration trends observed in the field cells. This was accomplished by deriving trend lines of pH versus metal concentration using underflow monitoring results from the field cells such as presented in Fig. 6. The resulting equations were then solved for a solution with a pH of 3.8. Although actual field cell data for pH 3.8 do not exist, the agreement between predicted concentrations from the field cell trend lines and supernatant composition generally is good. Consequently, it is currently considered that the supernatant from the 250-mm slump paste may be a reasonable representation of expected long-term water quality from tailings paste, provided that paste disposal and closure of the tailings impoundment are conducted in accordance with best management practices developed for the tailings facility. These assumptions regarding long-term seepage quality and operational constraints will be subjected to further scrutiny in the pilot plant program.

Ongoing Work

Although monitoring of the field cells will continue, the current focus of the paste investigation is on operation of a pilot plant. This plant, commissioned in February 2005, provides an exceptional opportunity to investigate deposition techniques. In addition, co-mixing with waste rock will be evaluated, as well as the long-term environmental stability of the paste through use of monitoring points. After paste deposition, the pilot area will be capped and its geotechnical as well as environmental performance monitored.

The pilot plant is designed to produce 20 m^3/hr of paste developed from total tailings or cyclone overflow tailings (when paste backfill is being utilized underground, the tailings are cycloned and the mine uses the underflow). The plant is simple and incorporates an 8-m diameter deep cone thickener (DCT®) from Dorr Oliver Eimco. The underflow is pumped into the facility using a traditional centrifugal pump. Process control within the plant maintains the flocculent addition rate and the bed height within the paste thickener.

The pilot plant pumps paste into a small inlet in the southeastern corner of the Barragem Cerro do Lobo (BCL) tailings facility which has a surface area of approximately 1 hectare. A containment berm has been constructed using waste rock, and after paste placement, the area will be capped and closed using a number of different capping methods. Figure 11 presents an overview of the pilot plant and active paste deposition in the pilot cell.

Figure 11. Overview of paste plant and pilot cell.

Towards the end of paste placement, a number of monitoring points will be installed into the body of the paste. The monitoring points will include suction lysimeters and piezometers, which will allow the collection of seepage water, and access pipes for neutron probe determination of moisture content with depth. Unlike the field cells, these monitoring points will not suffer any effects associated with the short-circuiting and preferential pathways observed in the field cell. Hence, the quality of water removed from these in-situ monitoring points can be carefully monitored and will be representative of seepage slowly having infiltrated through the paste mass itself. Collection and monitoring of runoff will be conducted as well in support of cover design.

Based on the results of the field cells, it is hypothesized that the quantity of water removed from the monitoring points will fall rapidly. It is these physical properties of paste - low hydraulic conductivity and maintenance of near-saturation conditions - which are so important in the long-term geotechnical and environmental performance of a paste disposal system, in particular for tailings that contain reactive sulfides.

Summary

The field cell testing program has provided important additional information regarding the use of tailings paste as a viable disposal alternative. The results from the field cell testing program have shown that, despite the presence of short-circuiting in the cells, a significant lag time occurs before acidic seepage is generated. This lag time may provide a window for operational placement of paste as well as closure of paste cells. In addition, due to its low hydraulic conductivity, the large majority of contact water discharges as runoff from the paste surface. Based on geochemical modeling and observations from the bench-scale testing program, long-term seepage quality may reflect buffering by kaolinite.

In the ongoing pilot trial, placement design and management will be subjected to detailed investigation to optimize the beneficial properties of paste with the objective of significantly reducing the potential long-term environmental impact of high-sulfide tailings disposal in the BCL.

The paste production process allows for development of an engineered material which can be designed such that environmental impacts can be minimized. This provides increased flexibility in facility siting, disposal and reclamation strategy. In combination with a properly-designed cover, the reduced leachate generation will lessen potential impacts on the environment and receptors. Furthermore, the potential for co-mixing with waste rock and the elimination of a water cover in perpetuity may have significant economic benefits.

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