Kinetic Tests of Non-Amended and Cemented Paste Tailings Geochemistry in Subaqueous and Subaerial Settings

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Abstract Addition of cement to paste tailings is increasingly used for tailings management. Enviromin investigated the geochemistry of various tailings management scenarios, using untreated and cemented paste tailings in standard and modified procedures. Kinetic geochemical tests included subaerial weathering of cemented paste tailings cylinders in modified humidity cell tests (HCTs, with 4% or 2% binders) and a saturated diffusion test (4% binders). Untreated tailings were weathered in conventional and saturated (modified) HCTs. Chemistries from these tests were used to predict operational and post-closure water quality, and clearly illustrate the benefit of reducing oxygen exposure and reactive surface area with cemented paste.

Key words paste tailings management, ASTM C1308, humidity cell test, Black Butte Copper Project

Introduction

Designing an economically and environmentally feasible tailings management facility is important to the permitting and financial success of mining operations. These facilities traditionally include tailings ponds, dry-stacked tailings, or subsurface placement of paste tailings as backfill. The addition of cement to paste tailings significantly reduces the reactive surface area of sulfidic minerals, thereby decreasing oxidation related impacts. While placement of paste tailings underground as backfill is common, application of this technology to create a non-flowable deposit with reduced reactivity in surface facilities is of increasing interest. Predicting the potential environmental impacts of these facilities remains a challenge due to continuing evolution of this technology and relevant testing methods. Although numerous publications address the use of cemented paste tailings as backfill (e.g., Aldea and Cornelius 2010; Yilmaz et al. 2003), less has been published about the application of geochemical characterization methods in predictions of water quality (MEND 2006; Moran 2013), particularly in surface facilities. Here we describe how multiple methods of geochemical characterization (ASTM D5744-13, both unsaturated and saturated, and ASTM C1308) have been applied to assessment of these materials for management of sulfidic tailings.

Tintina Montana, Inc. proposes to mine and mill copper from two massive sulfide zones in underground workings at its Black Butte Copper Project (Project) in central Montana, USA. Approximately 45% of tailings will be placed as 4% cemented paste backfill for ground control in mined out stopes. Tintina has proposed a novel solution to management of the remaining 55% of its tailings, involving placement of 0.5 to 2% cemented paste with non-flowable characteristics in lifts within a double lined Cement Tailing Facility (CTF). This paste will weather subaerially when exposed to direct precipitation and runoff. All affected water will pass through a waste rock drain and receive reverse osmosis water treatment; no water will be stored on the facility. Subsequent lifts of paste will be placed regularly, within a matter of days to weeks, over previous lifts. At the end of mine-life, Tintina will increase the percent of binder in the paste mixture to approximately 4%, thereby creating a more stable surface layer which will then be covered with a liner (welded to the lower liner) and reclaimed with topsoil, returning the land to its current use for livestock grazing.

To evaluate the stability of this material and its potential to affect water quality, Enviromin tested both untreated and cemented paste tailings using standard and modified ASTM methods to evaluate the geochemical activity of sulfidic tailings under a variety of tailings management scenarios.

Methods

Tintina proposes to float finely ground ore, producing tailings with 95% passing 75 microns. Tailings samples obtained from metallurgical bench testing were sulfide-rich, ranging in content between 17-30% sulfide (Knight Piesold 2016). The net neutralization potential of these samples ranges from -493 to -934 $tCaCO_3$/kton rock, with NP/AP ratios between 0.01 and 0.1. The two proposed methods for tailings management for the Project include underground placement of cemented paste tailings (with 4% binder), and surface disposal of cemented paste tailings (with 0.5 to 2% binder) in the CTF. Cement was added to change the strength of paste for use as backfill (4%) and to reduce flowability in paste to be placed at the surface (0.5 to 2%), but does not appreciably change acid generation potential based on static ABA data for the tailings. Cemented paste cylinders used in geochemical testing were provided by AMEC paste testing laboratory (AMEC 2015). Alternatives likely to be considered during environmental review include sub-aqueous storage of non-amended tailings in a traditional tailings pond and dry stacking of non-amended tailings. All four of these management options were addressed using a cross-section of test methods.

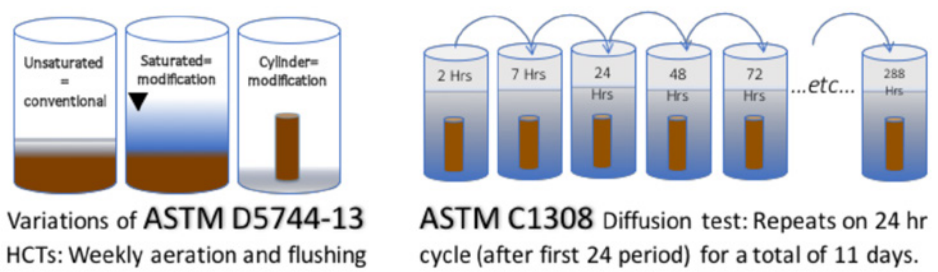

Figure 1 *Schematics of various test methods applied to evaluation of tailings management alternatives.*

Backfilled paste tailings will weather subaerially underground during mining operations followed by submergence when groundwater rebounds at closure. To best represent these conditions, 4% cemented paste was weathered subaerially in a modified humidity cell test (HCT; ASTM 2013), which allows weekly submergence and rinsing of the 3-in diameter, 6-in tall cylinder in place of conventional sub-3/8-in crushed material. The cemented paste was also leached in a saturated diffusion test (ASTM 2008) to evaluate post-closure solute release. The diffusion test is conducted for a set time frame of 288 hours, and the HCT was conducted for 28 weeks.

A 3-in diameter, 6-in tall cylinder of the 2% cemented paste cylinder was also weathered in a modified HCT, which was intended to represent surface weathering of material placed in the CTF. This HCT was terminated after 28 weeks of testing.

Alternative scenarios dry stack and subaqueous tailing placement were addressed with non-amended tailings weathered in a conventional HCT, and in a saturated (modified) HCT, where leaching proceeds under a standing head of water that was drained weekly, respectively. These tests were terminated after 48 weeks of testing.

Results

Results of these tests, which are presented in Figure 2 and Table 1, clearly illustrate the benefit of reducing oxygen exposure and reactive surface area with cemented paste in management of sulfidic tailings. Furthermore, submersion of the paste tailings in the diffusion test resulted in even greater improvements to predicted water quality.

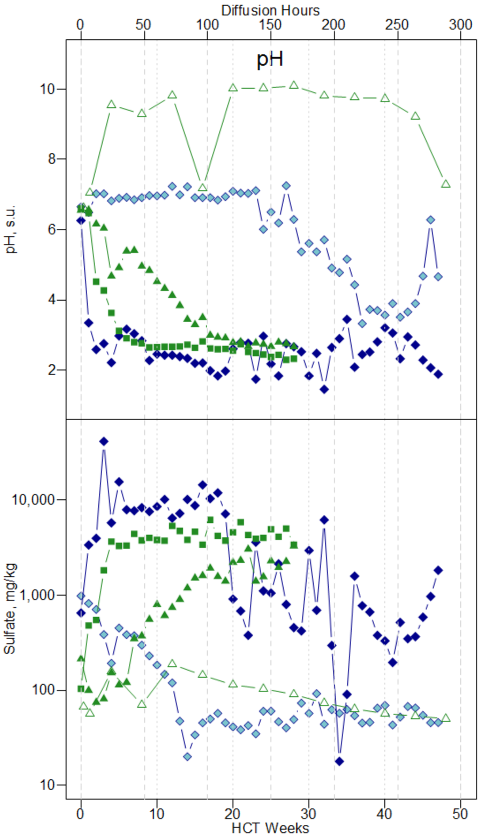

***Figure 2** Sulfate release and pH in kinetic tests of tailings*

The 4% diffusion test maintained a variable, but overall neutral, pH between 6.5 and 9.5, with available alkalinity, and produced less sulfate than the HCTs of paste tailings. The HCT results demonstrate that the paste-amended treatments have lower potential for acid, sulfate and metal release than HCTs of non-amended tailings as a result of lower reactive surface area. Initially, the saturated non-amended tailings HCT exhibited the lowest sulfate, acid and metal release, but following depletion of available alkalinity after 25 weeks, many constituents demonstrated a steady increase in release. Rates of metal release were significantly lower in diffusion tests of cemented paste tailings than in HCTs. Only the groundwater standard for As was exceeded in the 4% diffusion test, which exceeded fewer overall groundwater standards than the 2% cemented paste HCT (Table 1). Furthermore, the 4% cemented paste HCT began to release increasing concentrations of sulfate and metals of, e.g. Cu and Ni, after 7 weeks of weathering, while the 2% HCT began producing high concentrations of metals much sooner, in proportion to its higher rate of disaggregation in the column test. This difference is important when considering the short-term weathering potential of interim lifts of cement pasted tails.HCT results for paste cylinder samples provide an interesting contrast to the HCTs of non-amended tailings. The unsaturated, sub-aerial HCT exhibited distinctly higher sulfide oxidation rates than all other kinetic tests of tailings, with a cumulative sulfate production of more than 200,000 mg/kg and pH consistently below 3. Conversely, suboxic conditions in the saturated HCT significantly limited acid and metal production until alkalinity was depleted after week 35.

Furthermore, the non-amended tailings sample tested in the conventional, subaerial kinetic test demonstrated correspondingly high potential to generate several metals at low pH. Effluent from this test routinely exceeded groundwater standards for Sb, As, Be, Cd, Cr, Cu, Pb, Ni, Tl, and Zn. In contrast, the saturated kinetic test of non-amended tailings showed much lower sulfide oxidation and release of metals, and maintained a circum-neutral pH for most of the test. After 30 weeks of testing, following depletion of available alkalinity, this material also produced acidic leachate. At the lower oxidation rate in the saturated HCT, fewer metals exceeded relevant groundwater quality standards. Specifically, in nearly all weeks of testing, relevant groundwater standards for As, Ni, and Tl were exceeded in the saturated tailings HCT effluent, with isolated groundwater standard exceedances for Pb and Cu.

Table 1 *Exceedances in Kinetic Tests of Paste and Non-Amended Tailings*

Facility represented	Test Name	Test Length	Final pH	Constituents >MT DEQ GW Standards [1]
Backfilled 4% paste	4% Diff.	11 d	7.15	**As**
Paste Tailings in CTF	4% HCT	28 w	2.67	*As, Be, Cr,* **Cu**, **Ni**, *Tl*
Paste Tailings in CTF	2% HCT	28 w	2.87	*Sb*, **As**, Be, **Cr**, **Cu**, F, **Ni**, *Tl*, U, Zn
Tailings pond	Sat. HCT	47 w	4.66	**As**, *Cu*, *Pb*, **Ni**, **Tl**
Dry stack	Unsat. HCT	47 w	1.89	**Sb**, **As**, *Be*, **Cr**, *Cd*, **Cu**, **Pb**, **Ni**, **Tl**, *U, Zn*

[1] (MT DEQ 2012):
Regular font indicates exceedance(s) once or more in initial time points only (weeks 0-2 or days 0-2)
Italicized font indicates single or isolated exceedance(s) in later time points (week 8 or later or day 3) in paste HCTs, and earlier weeks (before week 12) in non-amended tailings HCTs
Bold font indicates exceedances in all or nearly all time points of testing

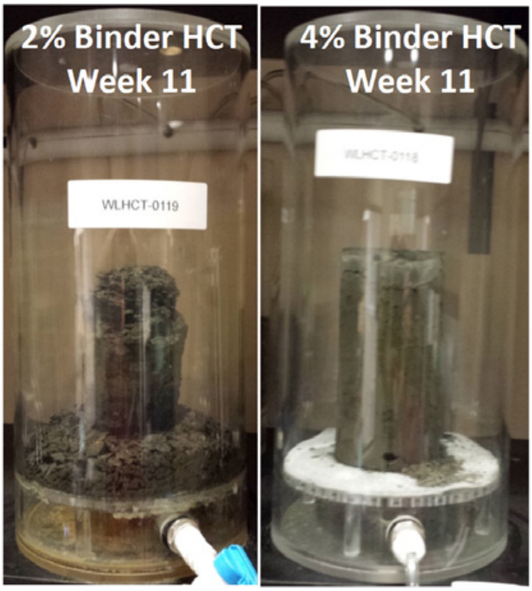

Figure 3 *Photos of 2% (left) and 4% (right) HCTs of cemented paste tailings cylinders at 11 weeks of testing.*

The addition of binders to these fine, sulfidic tailings substantially reduced the observed production of sulfate and acidity in HCTs. Disaggregation of the cylinders (beginning in weeks 3 and 10 for 2% and 4% HCTs, respectively, Figure 3) led to increased reactive surface area and reduced the difference between the untreated tailings and paste tailings HCTs. Because the test weathered small cylinders of cemented paste under laterally unconfined conditions, the extent of disaggregation is expected to be much less significant along lifts of cement in the CTF.

Conclusions

Recent application of the ASTM method C1308 has provided a basis for evaluating backfilled cemented paste tailings. The results indicate that the alternative scenarios using untreated tailings considered in this study pose greater environmental concern than the proposed placement of paste tailings as backfill and at the surface in the CTF.

While the information gathered from the diffusion test and the modified HCTs of paste tailings provided useful inputs to geochemical models, there is room to improve these tests to gain more applicable data. Development of methods targeting subaerial weathering of these materials that can address reactive surface area at scales appropriate to field conditions would greatly improve environmental geochemical predictions for this type of tailing storage facility.

These results have been used to modify tailings management plans and to predict water quality and treatment requirements for the Black Butte Copper Project.

Acknowledgements

The authors appreciate Tintina's permission to report these data and their continued commitment to creating a world class facility. We also thank AMEC and Knight Piesold for their support of this testing program. We also appreciate the contributions of McClelland Laboratories and Western Environmental Testing Laboratory (Sparks, Nevada, USA) in conducting these tests and providing guidance.

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