EXPERIMENTAL AND NUMERICAL STUDY OF THE HYDRO-GEOCHEMICAL BEHAVIOUR OF MONOLAYER COVERS PLACED ON ACID-GENERATING TAILINGS

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Abstract

This study focuses on two acid-generating tailings sites, located in Quebec (Canada). Both are partially oxidized due to extended exposure, so the pore water is already acidic. Monolayer covers, made of a till or with non acid-generating tailings, are being used to try to control the generation of acid on these two sites. The goal of this investigation was to assess the behaviour of the tailings-cover systems, to determine the efficiency of the covers, and, if needed, to provide alternative reclamation methods. Samples were collected in situ (oxidized and non-oxidized tailings, and cover materials) and characterized in the laboratory. Large columns were set up to study the hydrogeological and geochemical behaviour of the sulphidic tailings and covers. Monthly wetting and drying cycles were repeated to simulate natural infiltration. Water content, suction, and oxygen concentration in the columns were monitored during the drainage cycles. The effluent was also regularly sampled for chemical analysis. These results were then used to calibrate and validate numerical models. Some of the key results are summarized in this article.

Introduction

Monolayer covers, often coupled with an elevated water table (e.g. Aubertin et al., 1999; Ouangrawa et al., 2009, 2010), are sometimes used for the reclamation of acid-generating tailings impoundments. The main purpose of such covers, under a humid climate, is to favour infiltration and limit water loss by evaporation when a coarse-grained material is used or, for fine-grained materials, to promote water retention in the cover, due to a capillary barrier effect, which can then act as an oxygen barrier. In this study, column tests were conducted to assess the hydrogeochemical behaviour of the reactive tailings, with and without a monolayer cover. Such kinetic tests are frequently used to study acid mine (rock) drainage, AMD (or ARD), and to evaluate cover efficiency to prevent it from occurring (e.g. Aubertin et al., 1999; Bussière et al., 2004; Ouangrawa et al., 2010). The results provided specific hydrogeological and geochemical data for the development and calibration of numerical models that were used to simulate other conditions and cover scenarios (Pabst, 2011).

Materials and Methods

Four tailings and two cover material samples were collected and characterized (at Polytechnique Montréal and at the Université du Québec en Abitibi-Témiscamingue) for particle size distribution, specific gravity, saturated hydraulic conductivity, water retention curves, and mineralogical composition; the oxygen diffusion and reaction rate coefficients were also determined using the method described by Mbonimpa et al. (2003).
Four large columns (2.3 m high, 15 cm internal diameter) were filled with 1.7 m of reactive tailings and about 40 cm of cover material to follow the hydrogeological and geochemical response of the tailings-cover systems. Saturated materials were put in place and then consolidated. A suction was applied at the base using a porous ceramic plate and a saturated PVC U-shape tube. This column setup was not intended to reproduce natural field conditions, but rather to provide a basis of comparison to study the effect of various influence factors, and also for calibrating numerical models, which were later extended to longer times and larger scales (Pabst, 2011, Pabst et al., 2011a,b). Such large-size column tests have been shown to produce repeatable and reliable results (Demers et al., 2011). A schematic view and a photo of the large column setup are presented in Figure 1. Every 30 days or so, about 10 cm of deionised water were added at the top of each column. Several sensors (TDR and ECH₂O probes, water-filled tensiometers and optical oxygen sensors) were installed in the columns to monitor the hydrogeological behaviour of the tailings and covers. Calibration of the sensors was made prior to, and after the column tests for the specific testing conditions. The position of each sensor is indicated in Figure 1.

An additional sensor monitored the temperature and relative humidity in the laboratory. The pan evaporation rates were also measured. Water outflow rates were measured at the base of each column, and geochemical analyses were conducted on water samples (for pH, electrical conductivity, sulphate, Fe(II) and Fe(tot), K, Mg, Ca, Mn, Al, Zn, Ni, Na, Si, Pb, Cu, Cd, and Co concentrations). Small columns (45 cm high, 10 cm internal diameter) were used to assess the geochemical behaviour of the reactive tailings when left uncovered. More details on the column test methodology are presented in Pabst (2011).

**Results**

The monitored pore water pressures and volumetric water contents during the column tests showed good reproducibility from one cycle to the next, as illustrated in Figure 2; similar trends were obtained with the other instruments installed in the different columns. The numerical simulations, conducted with Vadose/W 2007 (GeoSlope Inc.), accurately reproduced the evolution of the degree of saturation $S_r$ and pore water pressure $u$. In this case, the combined volumetric water content and suction values
measured in the columns have been used to adjust the WRC (previously obtained from Tempe cell tests) used in the simulations of the wetting and drainage cycles. It can also be observed in Figure 2 that full saturation is not achieved at the beginning of each cycle, which indicates hysteresis effects in the cover. Also, evaporation accounts for the largest part of suction.

The geochemical parameters, adapted from the small column tests, were used to simulate the response of the large columns using the Min3P code (a finite volume numerical model developed for simulating 3D reactive transport; Mayer et al., 2002). Figure 3 presents some experimental measurements and simulation results from one of the large column tests.

Experimental measurements show that the large columns all produced acid, despite the monolayer cover. Sulphate and iron concentrations slightly increased during the test. The concentrations of metals in the leachate (including Zn) remained relatively high and constant. The geochemical response appears to have reached a (pseudo) steady state. The experimental and numerical results tend to indicate that the tailings were producing acidity primarily as a result of indirect oxidation due to the abundance of Fe(III) in the leachate and the low pH (< 3.5).

These same parameters were used to simulate some of field conditions and to assess alternate reclamation methods. Figure 4 presents a comparison between the results obtained for monolayer and multilayered covers, for simulations representative of field conditions. Multilayered covers with capillary barrier effects (CCBE) can constitute a very efficient technique to reclaim acid-generating tailings sites (e.g., Aubertin et al., 2006; Bussière et al., 2006), even for pre-oxidized tailings. The layered cover considered here is made of a 1 m thick waste rock layer covered by a 1 m thick layer of (silty) non-acid-generating tailings, with another 0.5 m waste rock layer added on top. Figure 4 shows that the degree of saturation in the monolayer cover decreases by almost 60% during the summer, increasing the risk to generate acid mine drainage (as observed in the column tests). It also shows that in the layered CCBE, both waste rock layers are fully drained, while the moisture retention layer in the middle remains nearly saturated (Sr > 95%). The two capillary break layers create a strong contrast with the fine grained material, that prevents water in the retention layer from flowing down or from moving up due to evaporation. The water retention layer can thus remain nearly saturated and act as an oxygen barrier that limits the flux to the reactive tailings (and ARD generation). For these conditions, a CCBE would appear as a more efficient reclamation method than a monolayer cover.
Figure 4. Simulation results for single- and multi-layer cover systems showing a) the variation of the degree of saturation $S_r$ in the retention layer over one year, and b) $S_r$ (degree of saturation) and c) u (pore water pressure) profiles in the tailings and in the cover; $z = 0$ m is located at the tailings-cover interface; the profiles are drawn for day 200 (during Summer).

Discussion and conclusion

Column tests and numerical simulations indicate that the monolayer covers made with the available materials are inefficient in preventing AMD generation for the conditions assessed here. A water table located 2 m or 1 m below the tailings surface did not sufficiently decrease the oxygen flux, so the tailings continued to oxidize despite the covers. The simulations show that a three-layer CCBE could constitute an alternative method to prevent further oxidation and AMD generation (considering both the oxygen flux decrease and water quality improvement).

References


