C.2 The Use of CCBE to Control ARD: From Laboratory to Field Applications

Michel Aubertin

École Polytechnique

plus

B. Bussière, M. Aubertin and R.P. Chapuis. 2000. The Use of Hydraulic Breaks to Limit Desaturation of Inclined Capillary Barriers. Proc. 53rd Canadian Geotechnical Conference, Montréal

B. Bussière, M. Aubertin, M. Aachib and R.P. Chapuis. 2000. The Use of Low Sulphide Tailings as the Moisture Retaining Layer in Engineered Cover Systems to Prevent AMD. Proc. CSCE 2000 Annual Conference, London, Ontario

THE USE OF CCBE TO CONTROL ARD: FROM LABORATORY TO FIELD APPLICATIONS

Michel Aubertin, Professor
Department of Civil, Geological and Mining Engineering,
École Polytechnique de Montréal, Québec, Canada

A presentation prepared for the
7th Annual BC Metal Leaching/ARD Workshop,
Simon Fraser University, Vancouver, BC
November 29 and 30, 2000

ABSTRACT

This short presentation gives an overview of the work that has been performed, over the last 10 years or so, on covers with capillary barrier effects (CCBE) at École Polytechnique de Montréal. The presentation includes a brief review of the main concepts, results from physical and numerical models in the laboratory for 1D and 2D conditions, a description of in situ test cells constructed at the Manitou site, and data gathered from large scale applications at the LTA and Lorraine sites in Québec. Some preliminary results from a new project at the Goldstrike site in Nevada will also be introduced. The main issues related to the role and efficiency of covers, construction precautions and difficulties, instrumentation and interpretation of data, and long term performance of CCBE are included in the presentation.

CONTENT

INTRODUCTION

The environment can be affected by mining operations in different and interactive ways.

AMD (or ARD) is recognized as a multi-factor pollutant; the main factors are acidity, metal toxicity, suspended solids and salinization.

Different approaches have been proposed to limit the generation of AMD from sulphidic waste rock or mine tailings.

Most techniques try to eliminate one (or more) of the three main components of the oxidation reactions: oxygen, water and sulphide minerals.

Creating an oxygen barrier is considered to be the best option in many cases (for humid climate).

There are different types of oxygen barriers that can be used: water cover, oxygen consuming cover, cover made of geosynthetics (ex. GCL) or of different types of soils (using capillary barrier effects).

In many cases, a cover with capillary barrier effects (CCBE) may be the only viable option, despite the relatively high cost involved for their construction.

To reduce the construction costs of such a CCBE cover, one can use locally available (silty) soils or non-reactive tailings (i.e. tailings with very low sulphide content that do not generate AMD) as the fine material layer in the CCBE.

Material often found in abundance in mining areas close to problematic sites.

In 1990, an extensive laboratory program was undertaken to evaluate the hydro-geotechnical properties of low sulphide tailings (and similar soils) for use in CCBE.

Results have been presented in various MEND reports (Projects 2.22.2 a,b,c, and 2.22.4), and in related publications (see attached papers, and list of references).

It was shown that this type of material can have advantageous characteristics for use as the fine grained moisture retaining layer in a cover with capillary barrier effects.

Laboratory tests, numerical modeling, and *in situ* studies were necessary to confirm the initial findings.

COVERS WITH CAPILLARY BARRIER EFFECTS

The main role of a cover with capillary barrier effects (CCBE), constructed to reduce the production of AMD in a humid climate, is to limit the diffusion of oxygen.

CCBE can also be used to reduce water flow under arid and semi-arid climate.

To limit oxygen flux, the cover must maintain a high degree of saturation in one (or more) of its layers.

The diffusion of gas (oxygen) through a nearly saturated soil can be very low (e.g. Rasmuson and Erikson 1986; Nicholson et *al.* 1989; Aachib et *al.* 1993).

The effectiveness of this type of cover is dependent upon a phenomenon known as the capillary barrier effect, created when a fine-grained material is placed over a coarser one.

The two materials have different hydrogeological properties because of their different textures.

Covers with capillary barrier effects (CCBE) usually contain three to five layers made of different materials; each layer has to play one (or more) specific role(s).

The fine-grained material (low sulphur tailings or silty soil in this study), utilized as the moisture retaining layer, is placed on the coarse layer to create the capillary barrier effect.

Another coarse material is placed upon the fine-grained material layer to prevent water loss by evaporation and help lateral drainage.

LABORATORY INVESTIGATION

Program started with laboratory testing of the hydro-geotechnical characteristics of low sulphur tailings.

Results show that these materials have relatively low hydraulic conductivity ($10^{-6}<k_{sat}<10^{-4}$ cm/s), good water retention characteristics (1.5<AEV<3.5 m of water) and a good resistance to cracking from freeze-thaw cycles (See MEND reports).

Column test description

A series of ten columns were constructed in 1993; used for a testing period of two years; another series of 9 columns used from 1997 to 1999.

Columns were made of plexiglas; and eight of them were 1.7 meters height.

The cover layers, which were placed over a layer of acid generating tailings, include a layer of sand (30 cm in thickness), a low sulphur tailings or silt layer (typically 50 cm in thickness), and a final layer of sand (20 cm in thickness).

Smaller columns were also built with reactive tailings to act as controls.

TDR probes were placed at different locations in the columns to measure volumetric water content in the different layers of the covers.

Can estimate the efficiency of the cover in limiting gas infiltration by using the relationship between volumetric water content (or degree of saturation) and the effective diffusion coefficient of the soil or tailing (see equation)

The sand used in the columns is a typical concrete sand with an air entry value (AEV or ψ_a) of about 25 cm of water and a saturated hydraulic conductivity k_{sat} of 2.1×10^{-2} cm/s.

The different soils and low sulphide tailings used as the moisture retaining layer had an ψ_a typically between 200 and 300 cm of water and k_{sat} between 10^{-4} and 10^{-6} cm/s.

All columns were initially saturated before the bottom valve was opened; water was added from the top periodically (approximately 10 cm of water per month).

The water percolating down was recovered at the bottom of the columns and analyzed for electric conductivity, pH, sulfate and metal contents.

The volumetric water content of the different layers was also measured regularly.

The degree of saturation (S_r) was determined from the volumetric water content (θ) measurements with TDR probes ($S_r=\theta/n$, where n is the porosity).

Degree of saturation profiles were predicted with the numerical model HYDRUS and SEEP/W; information on these calculations are given in Aachib (1997) and Bussière (1999).

These degree of saturation can be used to estimate the effective diffusion coefficient D_e of each soil; often used the Eberling et *al.* (1994) equation :

$$D_e = \tau D_a^0(1-S_r)^\alpha + \tau S_r D_w^0/H$$

D_a^0 is the diffusion coefficient for a pure air phase (1.8×10^{-5} m²/s at 25°C)

D_w^0 is the diffusion coefficient for a pure water phase (2.2×10^{-9} m²/s)

H is the dimensionless modified Henry's law constant (33.9 @ 25°C)

α and τ are fitting parameters (typically: $\tau = 0.273$ and $\alpha = 3.28$).

The validity of this equation was confirmed with various experimental results; other relationships were also used (Millington-Shearer/Collin) and a new one developed for this project.

The coefficient D_e can then be put into Fick's first law to calculate the flux of gas (oxygen in this case) :

$$F(t) = -D_e\frac{\partial C(t)}{\partial z}$$

Using analytical or numerical solutions for this equation allows a calculation of the oxygen flux.

For example: when the degree of saturation is 10% in the upper sand layer, 94% in the moisture retaining layer and 30% in the lower sand layer, the steady-state flux of oxygen through the cover is estimated to be about 0.07 kg of $O_2/m^2/yr$.

Compared to typical values of between 9 and 32 kg of $O_2/m^2/yr$ for uncovered sulphidic tailings.

CCBE would reduce the amount of oxygen available for the oxidation of sulphide minerals by a factor of between 130 to 450.

These results confirm the high efficiency (above 99% reduction) of CCBE for limiting the oxygen flux and AMD generation.

Water quality has been used to evaluate the performance of a CCBE.

Evolution of pH, conductivity, iron and sulfates:

The pH remained close to neutral (the water added at the top had a pH of 5.5 to 6)

The conductivity near 5 mS/cm.

The iron concentration near zero (after the first 100 day period, when residual oxidation byproducts were leached).

The sulfate concentration near 0.4 g/l (also after the first 100 days).

The effectiveness of the CCBE can be evaluated by comparing the water quality results of the covered tailings with those of the control columns.

The pH of the control column dropped from approximately 6 to less than 3 during the experiment.

The conductivity of the water percolating through the control column increased rapidly to values between 10 and 35 mS/cm.

The concentration of iron varied from 5 to 20 g/l and sulfate content increased during the experiment from 10 to 90 g/l.

The water quality of the leachate percolating through the control columns was significantly affected by the oxidation of the sulfide minerals contained in the reactive tailings.

The CCBE placed over the reactive tailings effectively limited the generation of acid mine drainage. More details are given in Aubertin et *al.* (1995, 1997) and in Aachib (1997).

Column tests are useful to make comparative analysis and evaluate the relative performance of different CCBE, but neglect many important factors including lateral water flow.

Constructed an inclined box testing system to evaluate the influence of geometry under 2D conditions.

Show that lateral water flow can reduce the degree of saturation in the upper part along a slope, and increase it in the lower part.

Critical to take this into account to control oxygen flux, or water infiltration (i.e. DDL phenomena).

This has proved to be very important for field applications.

IN SITU TEST CELLS

Following the laboratory studies, *in situ* cells were constructed at the Manitou site (Qc) to evaluate, on a larger scale and under more realistic conditions, the performance of CCBE built with low sulphide tailings and silty soils.

Combined with new column tests with similar configurations.

Three cells with covers made of low sulphide tailings were built during the summer 1995 on ITEC Mineral Inc.'s site, near Val d'Or, Québec, Canada.

Also 2 cells with a CCBE with till and mixture of tailings-bentonite.

Each CCBE had 3 layers placed on top of reactive tailings.

The top layer was made from 0.3 m sand and the bottom is 0.4 m made from the same concrete sand.

The fine material layer, placed between the two sand layers, was made of low sulphide tailings with a different thickness for each cell: 0.3 m for cell #3, 0.6 m for cell #1 and 0.9 m for cell #5.

A control cell was also built to evaluate the performance of the CCBE in limiting the generation of AMD; sulphidic tailings contain about 5% pyrite and are considered acid generating, with a Net Neutralization Potential (NNP) of -88 kg $CaCO_3$/tm (Bernier 1997).

The covers built for the experimental cells were instrumented and monitored between August 1995 and November 1998.

The main parameters monitored included volumetric water content θ, matric suction ψ, and chemical composition of the leachate.

A time domain reflectometry (TDR) technique was used to measure the volumetric water content.

The matric suction was measured in each of the three layers of the different covers, using Watermark sensors and Jet Fill Tensiometers (model 2725).

Each of the sensors was located close to a TDR probe allowing a comparison between the θ-ψ relationships obtained in the laboratory and *in situ*.

The cell design also allowed for the collection of the percolated water in underground reservoirs.

During and after sampling, the chemical water characteristics were analyzed for pH, conductivity and sulfate and metal contents.

All the results have been included in the preliminary reports submitted to MEND and were also presented in a concise format within the final report (Project 2.22.2c).

Includes Figures that show typical volumetric water content measurements (θ vs depth) for covered cells at different times; as expected, the value of θ was low in the two sand layers (usually between 0.05 to 0.15) and high in the fine layer (usually above 0.33).

For cells #1, #3 and #5 (cells with low sulphur tailings as moisture retaining layer), the degree of saturation, corresponding to the measured volumetric water content, was usually above 85% to 90%.

Some water quality monitoring results are also shown in the reports.

Results demonstrate that the pH of the percolated water from the covered cells #1, #3 and #5 remained above 6 for the entire experiment.

The pH from the control cell leachates confirmed that the sulphidic tailings were acid generating, with drops in pH from approximately 6 for the first year to values of about 2 by the end of the experiment.

The conductivity measurements were consistent with the measured pH values; high values were obtained for the percolated water from the control cell (from ≈ 10 to 50 mS/cm) while much lower values were measured in the water from the covered cells (between 2 to 3 mS/cm).

Sulphates are produced by the oxidation of sulphide minerals; cover performance can also be evaluated from the sulphate concentration of the percolated water.

There is an approximate difference of two orders of magnitude in the sulphate concentrations between the control cell and covered cells; oxidation is reduced by approximately two orders of magnitude - even if the precipitation of secondary minerals (like gypsum and jarosite) in the control cell is ignored (nevertheless, these minerals were observed).

The relative performance of the covers can be evaluated by comparing metals concentration in the water from the control cell and the water from the covered cells. For cells #1, 3 and 5, results indicate an approximate reduction in zinc concentration of 3 to 4 orders of magnitude.

Similar results were observed for copper and iron.

The covers were efficiently designed and constructed; the individual efficiency varied according to the specific configuration and material characteristics.

LARGE SCALE APPLICATIONS

The LTA site

The Lorraine site

The Goldstrike site

DISCUSSION

The laboratory work, numerical modeling, and field applications have provided much needed information on the analysis, design and construction of CCBE, for wet and semi-arid climate.

Some issues still of concern, including freeze-thaw effects and bio-intrusions; under investigation.

CONCLUSION

Presented the results of a detailed study on the behavior of CCBE acting as oxygen and/or water barriers to reduce the generation of AMD.

A key feature of the cover systems was that one of the layers was made of mine residues , i.e. low sulphide tailings (Manitou and LTA) and Carlin silt (at Goldstrike).

The laboratory and field studies demonstrate the good performance of the covers in which the silty materials acted as a moisture retaining layer.

For the duration of the test periods, both the field and laboratory results indicate that there was little or no oxidation generated from the reactive tailings protected by the covers.

Work is still underway to monitor the long term performance of these covers.

New applications are also being studied.