Development and application of mine site reclamation methods to control acid generation in Canada

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Introduction
Two main types of wastes: waste rock and tailings

Specific impoundments created using natural topography and dykes

Tailings – pumped to tailings impoundment

Aubertin et al., 2002
Introduction

• Main potential environmental impacts:
  – Physical stability problem (not discussed here)
  – Chemical stability problem: acid mine drainage (AMD)

• What is AMD?
  – Water flowing through mine wastes – affected by natural bio-geochemical phenomena
  – Two main reactions:
    • oxidation by sulphide minerals (ex. pyrite, pyrrhotite, arsenopyrite)
    • neutralization by carbonates (calcite, dolomite) and some silicate minerals

Aubertin et al., 2002
Introduction

• How can we control the AMD problem?
• By reducing the availability of one (or more) of the three ingredients (sulphide, water, and oxygen), or by controlling tailings temperature

• Different methods have been developed:
  – Oxygen barriers
  – Water infiltration barriers
  – Desulphurization
  – Thermal barriers
Oxygen barriers
- Water covers
- Elevated water table (EWT) with monolayer cover
- Covers with Capillary Barrier Effects (CCBE)
Oxygen barriers – water covers

• Use of water covers

  Objective: to limit O$_2$ migration - water is an excellent barrier (diffusion coefficient is $10^4$ less in water than in air)

  Challenge: long term stability of the dykes, old tailings

Applied with success at many sites (ex. Louvicourt, Solbec, etc.)
Oxygen barriers – water covers

Subaqueous disposal = good performance to control AMD

Awoh, 2009

Don Rouyn, Rouyn, Qc, Can

Louvicourt, Val-d’Or, Qc, Can

MEND MANUAL
VOLUME 1 – SUMMARY
MEND 5.4.2a
Oxygen barriers – water covers

Flooding after tailings oxidation (ex. Quirke; Solbec)

- Interactions between the contaminated pore water and the water cover.
- Progressive improvement of water quality.
- A diffusion barrier can reduce the influence of prior water contamination

Solbec (Québec)
Oxygen barriers – EWT and monolayer cover

- Use of a monolayer cover combined with an elevated water table (EWT)

Reduce water loss by ET

- Objective: Maintain AMD tailings saturated at all times (low $O_2$ concentration)

Bussière, 2007
Oxygen barriers – EWT and monolayer cover

Flux of O$_2$ that reach the Manitou tailings < 2 moles/m$^2$/yr

Manitou, Val-d’Or, Qc, Can

Ethier et al., 2013
Oxygen barriers – Cover with Capillary Barrier Effects (CCBE)

O$_2$

Oxygen barriers

Cover with Capillary Barrier Effects (CCBE)


Aubertin et al., 1995

Mbonimpa et al., 2002

$F_0^D (z,t) = -D_e \frac{\partial C(z,t)}{\partial z}$

Effective diffusion coefficient, $D_e$ (m$^2$/s)

Saturation degree, $S_r$ (-)

Experimental data

Collin (1987) model; for $n=0.40$

Proposed model ($p_a = p_w = p = 3.3$) for $n=0.40$
Oxygen barriers – CCBE at Lorraine site

- CCBE built on the tailings
- Instrumentation installed in the cover layers
- 3 dolomitic drains (Dol-1, Dol-2 and Dol-3)
- 1 limestone drain (Cal-1) – No AMD at this drain

Bussière et al., 2009
Oxygen barriers – CCBE at Lorraine site

Before

After

Instrumentation

NSERC Industrial Chair on Environment and Mine Waste Management
Oxygen barriers – CCBE at Lorraine site

– Steady-state oxygen flux were calculated using Fick’s first law and \( D_e \) estimated from volumetric water content measurements

The CCBE is effective as oxygen barrier
Water infiltration barriers
- Low saturated hydraulic conductivity covers
- Store-and-release cover (not discussed)
Covers made of low $k_{sat}$ materials

- Low $k_{sat}$ materials (double liner is usually recommend): natural and/or geosynthetics

- Challenge: stop water infiltration in the long term (not easy in humid climates)

Applied at abandoned sites in Quebec: Poirier, Aldermac, Barvue, Normétal
Covers made of low \( k_{sat} \) materials

Maurice et al., 2002

Poirier site, Joutel, Qc, Canada

- Geomembrane (HDPE) on a geotextile directly on tailings
- Protected by a 1m till layer (sand and gravel)

- No long term monitoring data available
- Drop of water table, but still contaminated effluent
Desulphurization
Desulphurization

• Concentrate:
  – To paste backfill plant
  – To a specific portion of the tailings impoundment

• Desulphurized tailings:
  – Can be used as construction material

Concept: reduce the mass of problematic tailings at the mill and to re-use the non problematic portion

Bois et al., 2004
Desulphurization

• Main uncertainties:
  – New way of managing tailings
  – Desulphurization cost (0.15 to 0.75$/t)
  – The level of desulphurization needed

Bois et al., 2004
Desulphurization

Manitou site
- Use of the desulphurized Goldex tailings as cover material
- Combined with an EWT

Agnico-Eagle Mines Ltd
Desulphurization

- Option: Desulphurized Westwood tailings to produce cover material
- Combined with an EWT
- Evaluated at intermediate scale in the field

Rey et al., 2016
Thermal barriers
Thermal barriers

NRCan web site
Thermal barriers

- Integrate tailings within the permafrost by adding a cover of inert material
- Low temperature in the reactive tailings will:
  - slow down both chemical and biological oxidation reactions
  - reduce the generation and migration of pollutants (Holubec, 1993)
- Target tailings temperature
  - tailings can still oxidize at temperature below 0°C (-2°C; Meldrum et al., 2001; -4°C; Elberling, 2001)

Soil temperature profile in continuous permafrost zone (modified from Andersland and Ladanyi, 2004)
Thermal barriers

$T^\circ$ and $\theta$ at the tailings interface

![Graphs showing temperature and unfrozen volumetric water content over time]

**Coulombe, 2012**
Conclusion

• Reclamation = control the AMD formation
• Different options – site specific (no panacea)
• Each technique has his own challenges
  – Water cover – dyke stability and prior contamination
  – CCBE, EWT and thermal covers – Climate change
  – Geomembrane covers – durability, physical stability
  – Desulphurization – production of a non-problematic desulphurized tailings
• R&D is essential to improve existing reclamation approach
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