A Review of Potential Improvements to Mine Rock Stockpile Construction Methods

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1: Okane Consultants, 2: Earth Systems, 3: INAP

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December 4-5, 2019
"... **Essence** of the proposed project is to determine, through **strategic MRS construction** methodologies, whether there is a **mine-life-cycle cost benefit** to reducing risk associated with MRS **geochemical stability**, by changing MRS **construction methods**, for a minimal incremental cost, **during life-of-mine** ..."
Session Discussion Themes

- Project Timeline
- Project Scope (within 9 tasks)
- Opportunities
• Project Timeline

• Project Scope (within 9 tasks)
  1. Framework for Communicating Risk
  2. ML-ARD…
    Why Focus on Mine Rock Stockpiles?
  3. Conceptualization / Evaluation of:
    - Conventional MRS Performance
    - Alternative MRS Construction Approaches
  4. Communicating Opportunity using Risk-Based Approach Supported by…
    - Literature Review and Case Studies
    - Semi-Quantitative Assessment thermal / gas / water, and acidity generation modelling

• Opportunities
Project Timeline(s)

- **May 2018 Discussion**
  - Four (4) phases discussed

- **December 2018 Proposal**
  - Phase 1: Review and Summary of Methodologies/Technologies

- **April 2019 draft Report**

- **November 2019 final Report**
  - Minor edits/changes
  - Final version to be available very soon at:

  www.inap.com.au

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Project used the **Failure Modes and Effects Analysis (FMEA)** as a tool to inform on, and communicate, Incremental Benefit...

**...Alternative to Alternative**
“… What conditions could lead to the **geochemical failure** of the applied MRS construction method, whereby “failure” refers to **inadequate** spatial extent of **suboxia** conditions and/or **increased treatment** requirements? ...”
FMEA
Evaluating Timeframe:

**Immediate-Term:**
- Permitting, planning, design, construction and the operation years (assumed 10 years of rock placement)

**Short-Term:**
- Closure Period >10 years

**Long-Term:**
- Post-Closure Period >100 years
We developed several (~20) ‘high-level’ Potential Failure Modes
## FMEA

### Evaluating Timeframe:

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Effects and Pathways</th>
<th>Likelihood</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>Risk Ranking</th>
</tr>
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<tbody>
<tr>
<td>FM #1</td>
<td>EP #1-1</td>
<td>High</td>
<td>Minor</td>
<td>Major</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
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</table>

### Consequence Severity

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Low (L)</th>
<th>Minor (M)</th>
<th>Moderate (M)</th>
<th>Major (M)</th>
<th>Critical (C)</th>
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<tbody>
<tr>
<td>Expected (E)</td>
<td>Moderate</td>
<td>Moderately High</td>
<td>High</td>
<td>Critical</td>
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Framework for Communicating Risk

FMEA
Evaluating Timeframe:

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<td>S-T</td>
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<tr>
<td>L-T</td>
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Example, for: Immediate-Term to Short-Term

Application of an Alternative MRS Methodology

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ML/ARD: … Focus on Mine Rock Stockpiles?

• Over the wide range of climate conditions possible…
• Mine Rock Stockpiles (MRSs) typically contribute 75%, or more, of the acidity load at mine site, and
ML/ARD: …Focus on Mine Rock Stockpiles?

- Over the wide range of climate conditions possible...
- Mine Rock Stockpiles (MRSs) typically contribute 75%, or more, of the acidity load at mine site, and...
- The mining industry typically manage this risk…
Six “Improved” Construction Methods Identified for Assessment

- Four (4) “geotechnically-focused” methods
- Two (2) “geochemically-focused” methods (geochemical engineering)

Geotechnically-Focused Methods:

1. Decrease lift height
2. Engineered layers on top of lifts to limit vertical gas transport capacity
3. ‘True’ Encapsulation (vertical and lateral)
4. Base-up, thin lift, compacted

Geochemically-focused methods:

1. Oxygen consuming materials
2. Sulfide passivation

Manage Vertical and/or Lateral Gas Transport Capacity

Additional (evolving) methods also identified in report
Case Study...
Vertical Gas Management

- Köppen-Geiger Climate Classification
  - Bwh – Hot Desert

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Case Study...
Vertical Gas Management

• Open Pit - Highly reactive pyritic / carbonaceous shale

Evolution of Waste Rock Management and Cover System Design at A Large Open Cut Mine in the Eastern Pilbara Western Australia

Mike O’Kane, Dave Christensen, Gillian Allen and Kristie Bonstrom – O’Kane Consultants Pty Ltd.

First Evidence of ARD

Pyritic Shale Integration into Waste Rock Management

Mt. Whaleback

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Case Study... Vertical Gas Management

- Open Pit - Highly reactive pyritic / carbonaceous shale

Pond A Trial Data

Gaseous Oxygen or Carbon Dioxide Concentration

- Oxygen ($O_2$)
- Carbon Dioxide ($CO_2$)

Temperature

In Situ Temperature (°C)

BHP Billiton Iron Ore
Page 25 January 28, 2010 – O’Kane Consultants Pty Ltd.
Case Study... Vertical Gas Management

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Gaseous Oxygen or Carbon Dioxide Concentration

In Situ Temperature °C

Temp. ??

Convective Cell

Convective Cell & Self Heating

Airflow Limited??

O₂

CO₂

Temp.

Organic Carbon and Pyrite Oxidation

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Case Study...
Vertical Gas Management

- Open Pit - Highly reactive pyritic / carbonaceous shale
Finer- and Coarser-Textured Mine Rock

- Conceptualization... Finer-Textured Mine Rock vs. Coarser-Textured Mine Rock
Case Study... Vertical Gas Management

- Open Pit - Highly reactive pyritic / carbonaceous shale

![Graph showing percentage of original sulfide oxidized over years with Sonic Drill Core Sampling markers for > 1km and > 30m drilling.]

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Case Study... ‘True’ Encapsulation

- Köppen-Geiger Climate Classification
  - Aw/As – Tropical Savannah

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Case Study... ‘True’ Encapsulation

- **Mine Rock...**
  - S% ave. ~ 3%
  - ~40% PAF (PAG)

- **We should observe...**
  - “Typical ML-ARD” .... but we don’t
Case Study... ‘True’ Encapsulation

• Why Not..?
  ➢ For a ~100m high x 1km wide x 2km long MRS...
  ➢ After > 10 years ... only one seep with water quality issues of any significance (SO$_4$ only)
Case Study... ‘True’ Encapsulation

• **Why Not...?**
  - Oxygen availability during rock placement
  - Acidity generation is **not** “defined” by “all sulfides” oxidizing
Why Not...?

- Oxygen availability during rock placement
- Acidity generation is not “defined” by “all sulfides” oxidizing
- ~0.3m clay layer for truck tire damage
- Limits Vertical Advective Gas Transport Capacity
Case Study... ‘True’ Encapsulation

- **Why Not..?**
  - Oxygen availability during rock placement
  - Acidity generation is not “defined” by “all sulfides” oxidizing
  - ~0.3m clay layer for truck tire damage
  - Limits Vertical Advective Gas Transport Capacity
  - Base up, thin lift
  - Limits Lateral Advective Gas Transport
Case Study... ‘True’ Encapsulation

- A system was created with **Low Vertical Air Flow Capacity** and
- **Low Lateral Air Flow Capacity**

- Rather than a system with **High Air Flow Capacity**

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Case Study... ‘True’ Encapsulation

- Conceptual / Numerical... Low vs. High Gas Transport Capacity

< $10^{-6}$ m$^3$/m$^2$/s
Let’s Evaluate a Valley Fill MRS...
Let’s Evaluate a Valley Fill MRS...

“Moderately Reactive Mine Rock Material”
Let’s Evaluate a Valley Fill MRS...

“Moderately Reactive Mine Rock Material”

Two Approaches

1. “Conventional”… Ridgeline End-Dumping ‘high tip-head’
Let’s Evaluate a Valley Fill MRS…

“Conventional”... Ridgeline End-Dumping ‘high tip-head’

• Advective and Diffusive Air Flow - Coupling of Water, Heat, Gas
Let's Evaluate a Valley Fill MRS...

"Moderately Reactive Mine Rock Material"

Two Approaches

1. "Conventional"... Ridgeline End-Dumping 'high tip-head'
2. "Alternative"... Bottom Up End-Dumping 'short tip-head'
Let's Evaluate a Valley Fill MRS

“Moderately Reactive Mine Rock Material”

1. “Conventional”

2. “Alternative”

Ambient Temperature < Internal Temperature
Let's Evaluate a Valley Fill MRS

CUMULATIVE ACIDITY GENERATION

Cumulative Acidity Generation for Cross-Section of 1m Unit Thickness (Kg/m)

Simulation Year

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Let's Evaluate a Valley Fill MRS

CUMULATIVE ACIDITY GENERATION

CUMULATIVE ACIDITY GENERATION FOR CROSS-SECTION OF 1M UNIT THICKNESS (Kg/m)

SIMULATION YEAR

0 5 10 15 20 25

0 200 400 600 800 1000 1200 1400

~4 TIMES REDUCTION

YEAIR 10

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• Opportunities
- Unexpectedly high amounts of PAF would increase acidity generation (high likelihood).
- Environmental effects are assumed to be minor because we will treat the water.
- Requirement of water treatment incurs higher consequence cost:
  - Long-term: Catastrophic consequence cost due to treatment in perpetuity and construction of additional treatment plants (> $100 M).
- High confidence – there are many sites in this situation.
- Very high risk rating – a key driver for this project.

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### Communicating Risk and Opportunity

<table>
<thead>
<tr>
<th>Failure Mode ID</th>
<th>Likelihood</th>
<th>Timeframe</th>
<th>Environment Effects</th>
<th>Consequence Cost</th>
<th>Regulatory Approval</th>
<th>Level of Confidence</th>
<th>Highest Risk Rating</th>
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</thead>
<tbody>
<tr>
<td>12</td>
<td>H</td>
<td>Immediate-Term</td>
<td>M</td>
<td>M</td>
<td>Mi</td>
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<tr>
<td>12</td>
<td>H</td>
<td>Short-Term</td>
<td>M</td>
<td>Mo</td>
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<tr>
<td>12</td>
<td>VH</td>
<td>Long-Term</td>
<td>M</td>
<td>C</td>
<td>VH</td>
<td>Mi</td>
<td>H</td>
</tr>
</tbody>
</table>
Even if there is more PAF material than expected, the construction methods result in ~80% of the MRS remaining suboxic (no re-supply of oxygen).

The likelihood of the failure mode causing ‘the question’ is decreased.

I-T: Potential need for water treatment because suboxia does not occur immediately.

Short- and Long-Term: Suboxia established; the risk of the failure mode can be mitigated.

Low confidence in risk ranking – Generational Change; we require more full-scale data from purposeful MRS construction.

Moderate risk rating – decreased from a ‘very high’ risk rating.

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**Engineered layers are a key facet to controlling airflow capacity; site-specific designs are required**

- There is a risk of increased costs if the material on site cannot meet performance expectations
- Costs include making the material on site, shipping material to site, or treating water
- Can the other improved MRS construction methods mitigate these risks?
Communicating Risk and Opportunity

- **Adding ‘true’ encapsulation (lateral gas transport),** oxygen consuming layers, and sulfide passivation
  - Strategic placement of NAF material around PAF material
  - Placement of alkalinity released materials of top of MRS
- If there was insufficient material for the engineered layers, it is unlikely that water treatment needs would increase
- The risks are further mitigated by the presence of additional construction methods

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• Opportunities

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Opportunities

• Incorporating Mine-Life-Cycle costing into Life of Mine Planning
• Evaluating existing MRSs
• Field-Scale Evaluations
  ➢ Setting Expectations... Spatial and Temporal Influences!
Thank You!

Our Rainbow of Hope for Children and, Habitat for Humanity Initiative

Ask us for more information on

UNIVERSITY OF SASKATCHEWAN
Mine Overlay Site Testing Facility
GLOBAL INSTITUTE FOR WATER SECURITY
MOSTFACILITY.USASK.CA
Let’s Evaluate a Valley Fill MRS...
“Alternative”... Bottom Up End-Dumping ‘short tip-head’

Spoil Pile Oxidation – Convective Air Flow - Coupling of Water, Heat, Gas

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