SECTION B.17

PREDICTION OF PIT LAKE DRAINAGE CHEMISTRY

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A Method to Predict Evolving Post-Closure Pit Lake Chemistry

by:

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### The Ying and the Yang of Pit Lake Chemistry (mg/L)

<table>
<thead>
<tr>
<th></th>
<th>Berkeley Pit</th>
<th>Cortez Pit</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>2.8</td>
<td>8.1</td>
</tr>
<tr>
<td>As</td>
<td>0.05</td>
<td>0.038</td>
</tr>
<tr>
<td>Fe</td>
<td>386</td>
<td>0.134</td>
</tr>
<tr>
<td>Mn</td>
<td>95</td>
<td>0.002</td>
</tr>
<tr>
<td>Zn</td>
<td>280</td>
<td>0.002</td>
</tr>
<tr>
<td>Cl</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>SO₄</td>
<td>5740</td>
<td>90</td>
</tr>
</tbody>
</table>
Flow Chart Describing Progress and Integration of Pit Lake Chemical Prediction

**Objective**
- Ultimate Pit Surface Geologic Block Model
- Ultimate Pit Surface Oxidation Potential
- Weathering Rind Thickness
- Post Closure Groundwater Discharge to Pit
- Geochemical Constraints

**Tool**
- Chemical Release Functions
- Regional Groundwater Model Elemental Discharge
- Solute Mass Discharge Pit Lake Volume
- PHREEQC
- CE-QUAL-W2

*Requires Field Specific Data*
Leaching Tests

Methods
- Meteoric Water Mobility Tests
- Column Tests
- Humidity Cell Tests
- Field Oxidation and Leaching Tests

Issues
- Acid Generating/Neutralizing Potential
- Reactive Surface Area (particle size)
Comparison of Precipitation, Field Oxidation, Leachate, and Humidity Cell Leachate

- Precipitation
- 2-4 mm
- 4-16 mm
- 16-64 mm
- <2 mm
- 2-4 mm
- 4-16 mm
- 16-64 mm

Field

Humidity Cell
Average SSR3 Arsenic Concentrations

- Humidity Cell
- Field Oxidation

Arsenic (mg/L) vs. Average Particle Size (mm)
Arsenic in Field Oxidation and Humidity Cell Leachates
Sulfate in Field Oxidation and Humidity Cell Leachates
Pyrite Oxidation Model

Based on the Davis-Ritchie Approach

Other Features
- Variable Air-Filled Porosity
- Variable Particle Size

Modifications
- Wall Rock Geometry
- Fractures versus Porous Media
- Water Content Oxidation Rate Limitation
Bulk vs. Fracture Based Pyrite Oxidation

Planar Approach

Layered Approach
Photogrammetric Analysis of Macro-Fracture Density in the SOAP-GQ Pit Wall Rock
Observed Rate Limitation in Pyride Oxidation

- Field (4-16 mm) Data
- Field (4-16 mm) Model
- Field (16-64 mm) Data
- Field (16-64 mm) Model
- Humidity Cell (4-16 mm) Data
- Humidity Cell (4-16 mm) Model
- Humidity Cell (16-64 mm) Data
- Humidity Cell (16-64 mm) Model

cumulative SO4 (moles)

0 10 15 20 25 30

time (weeks)
Bulk Chemistry

Total mass of solutes contributed by:

Wall Rock Leaching
Groundwater Inflow
Surface Runoff
Precipitation
Groundwater Outflow
Schematic of Hydrologic Cycle for a Refilling Pit

- Wall Rock Runoff
- Direct Precipitation
- Evaporation

- Groundwater Flow
- Sludge
- UPS Oxidized Rind
Dissolved Chemistry

1. Mix various solutions
2. Evapoconcentration
3. Solid and Gas Phase Equilibrium
4. Sorption to AFH
5. Charge Balancing
6. Analog Test
Equilibrium Phases

Gases

Carbon Dioxide
Oxygen

Solids

Amorphous Ferric Hydroxide
Calcite
Gibbsite
Barite
$\text{PCO}_2$ as a Function of pH in Carbonate Aquifers

(source: Plummer et al. 1976; Langmuir 1971)
Pipeline/South Pipeline Evapoconcentration Experiment: Predicted (—) and Experimental (■) Data
Hydrodynamic Model

Does the pit lake mix and turn over?

Does the pit lake become anoxic?
Temperature Profiles for the Dual Pit Lakes with Waste Rock Rock Scenario
Dissolved Oxygen Profiles for the Dual Pit Lakes with Waste Rock Scenario
Comparison of Predicted Pit Lake Water Quality to an Analog Pit Lake

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Cortez Pit Lake (20 years after refilling)</th>
<th>Predicted South Pipeline Pit Lake (20 years after refilling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.07</td>
<td>8.19</td>
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<tr>
<td>alkalinity</td>
<td>282</td>
<td>265</td>
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<tr>
<td>arsenic</td>
<td>0.038</td>
<td>0.020</td>
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<tr>
<td>calcium</td>
<td>45</td>
<td>66</td>
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<tr>
<td>chloride</td>
<td>24</td>
<td>85</td>
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<tr>
<td>fluoride</td>
<td>2.4</td>
<td>2.9</td>
</tr>
<tr>
<td>iron</td>
<td>&lt;0.01</td>
<td>0.0004</td>
</tr>
<tr>
<td>sodium</td>
<td>69</td>
<td>123</td>
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<tr>
<td>sulfate</td>
<td>90</td>
<td>219</td>
</tr>
<tr>
<td>TDS</td>
<td>432</td>
<td>810</td>
</tr>
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Conclusions

This methodology for predicting pit lake water quality is proposed for fulfillment of the technical requirements for an Environmental Impact Statement, or as part of permitted facility closure.

- Improved definition of constraints on pyrite oxidation in arid environments
- More accurate representation of leaching characteristics of wall rock
<table>
<thead>
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<th>Issue</th>
<th>Remedy</th>
</tr>
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<tbody>
<tr>
<td>Determination of background water quality</td>
<td>monitoring well samples, appropriate detection limits</td>
</tr>
<tr>
<td>Wall rock leachate quality</td>
<td>laboratory/field testing, leaching of representative samples</td>
</tr>
<tr>
<td>Oxidation modeling</td>
<td>results of the leaching tests, characterization of rock fractures and porosity</td>
</tr>
<tr>
<td>Bulk chemistry</td>
<td>water balance, groundwater flow model</td>
</tr>
<tr>
<td>Dissolved chemistry</td>
<td>identification of equilibrium phases, evapoconcentration tests, analog tests</td>
</tr>
<tr>
<td>Hydrodynamic modeling</td>
<td>comparison to existing lakes</td>
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<tr>
<td>Other influences</td>
<td>microbial activity</td>
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