An Innovative Method for Mitigating Impacts from Acid-Producing Rock

Jim Gusek and Paul Eger
Golder Associates
Brian Masloff & John Fodor
Cellular Concrete Solutions
Acid Rock Drainage
Acid Rock Drainage Tetrahedron

Fuel

Air

Heat

Water

Fuel

Oxidizer
(Air, Fe$^{+3}$)

Pyrite

ARD

Bacteria
The **BIG** question?

Can we really stop the reaction?
ARD is a global **bacterial infection**.

Large number of “geo-antibiotics”
Successful in laboratory
Problem has been application
What’s needed is a mining-analogue to an I-V drip of tetracycline and/or oral antibiotics.

And then there’s the question: Do we need to Vaccinate or Medicate?

What is currently available in the ARD prevention “pHarmacy”?
Known bactericides

- Sodium lauryl sulfate (EPA-endorsed)
- Alkyl-benzene sulfonate (laundry soap)
- Waste milk (bacteria out-complete *acido-thiobacillus*)
- Sodium Thiocyanate (NaSCN)
- Bi-Polar Lipids

Note: We need to consider the *physics* of delivering and distributing a weak bactericide solution into a porous, *unsaturated* medium (it’s been done, but it wasn’t easy)
Cheap alkalinity (acidity)

- Limestone (quarried) – crusher fines?
- Dolomite
- Lime kiln dust or cement kiln dust
- Steel slag
- Sodium bicarbonate

Note: We need to consider the physics of delivering and distributing a solid into a porous unsaturated medium
Cheap organics (oxygen)

- Sawdust (the finer, the better)
- Paper (newsprint, office waste [shredded])
- De-inking residue
- Biosolids
- MicroCg™, Lactoil™, others?

Note: We need to consider the physics of delivering and distributing a solid into a porous, unsaturated medium
Passivation coatings (oxygen)

- Keeco Mix (micro-silica)
- Potassium permanganate (Glen Miller, UNR)
- Oil and latex based paint
- Potassium humate (commercial agricultural amendment)
- Others?

Note: We need to consider the physics of delivering and distributing a coating into an unsaturated porous medium.
One Particular Problem

Treating existing waste rock dumps

- Deliver bactericides without complete flooding of waste rock mass
- Focus the delivery of alkalinity in the “hot zones”
- Deliver organics in hot zones and without complete flooding
Has it been done before?

- **Fisher Coal Mine, PA – 1995 Vapco Engineering**
  - Geophysics targets 3 ARD–generating zones
  - Multiple injection boreholes on a tight spacing
  - Injection of 20% NaOH solution simultaneously into 12 shallow (3 m deep) boreholes with packers
  - Injection of 2% sodium lauryl sulfate bactericide
  - Seepage continues to be net alkaline 16 years later, bond release is reportedly imminent
Has it been done before?

- Sesquatchie Coal Mine, TN – 2008 Western Research Institute
  - Geophysics used to target ARD
  - Two doses - drip application of waste milk and biosolids (as inoculant)
  - Seepage reportedly net alkaline after four years.
  - Patent issued January, 2012
  - Check out ITRC website

http://www.itrcweb.org/miningwaste-guidance/cs31_sequatchie.htm

Fig. 6 Substrate dosage experiment: biofilm growing on pyrite after 213 days in a microcosm filled with ground water impacted with acid mine drainage, pyrite, 3 wt% effluent solids (ES) and 5x the required stoichiometric concentration of C (as returned milk) that bacteria would consume while reducing all the SO$_4^{2-}$ in the microcosm. This image was taken at x450 magnification with a scanning electron microscope.

Ref: Jin et al., 2007

Fig. 7 Conceptual model of the community structure of biofilm growing on pyrite in microcosms. Layers A and B of the biofilm are composed of anaerobic and facultatively anaerobic bacteria that consume oxygen (O$_2$) diffusing through the biofilm from overlying water. Layer C is an anaerobic-dominant layer containing sulfate reducing bacteria and other facultative anaerobes; therefore, oxygen diffusion to the pyrite and generation of acid mine drainage is prevented.
Perhaps a better way:

Use engineered **FOAM** as a delivery medium for bactericide “cocktail”

- Use waste milk (biocide) in the liquid phase
- Use sodium lauryl sulfate (bactericide) as part of the surfactant mix
- Add powdered limestone for alkalinity
- Add paper, sawdust, or **biosolids** as the organic (hoof & horn protein surfactant too)
Perhaps a better way:

Use engineered FOAM as a delivery medium for bactericide “cocktail”

This process is very similar to pressurized grouting, only the grout mass is mostly gaseous, engineered to be temporary, and designed to deposit a coating of active ingredients.
Foam Characteristics
(Think shaving cream – a LOT of it)

Two-phase “colloid”, the gas phase is separated by a liquid phase

Foam can contain a third phase – **suspended solids**

- “Dry” foam (e.g., shaving cream)
- “Wet” foam (e.g., hand soap)
Adding pHoam™ containing powdered limestone to gravel in the lab
Recent Experiments in the Laboratory

Limestone-Coated Gravel
Recent Experiments in the Laboratory

Garden hose tremmie pipe
What’s the difference between foam and pHoam™??

pHoam™ is a mixture of traditional foam plus one or more “active ingredients” that induce a desirable biological, geochemical, or process-related reaction or Foam + active ingredients that suppress an undesirable reaction.
### Some Potential Application Concepts

<table>
<thead>
<tr>
<th>Vaccination (Prevention)</th>
<th>Medication (Mitigation)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Waste rock dumps at active mines</strong> (&quot;sterilize&quot; ARD rock by the truckload before it is placed in the dump)</td>
<td><strong>Small-scale “dog hole” abandoned underground mines</strong> that produce ARD</td>
</tr>
<tr>
<td><strong>Active coarse coal refuse piles</strong> (sterilize refuse by adding a “wet” pHoam™ in the feed hopper of a conveyor belt)</td>
<td><strong>Waste rock dumps or coarse coal refuse facilities at abandoned mines</strong> (even if they are capped)</td>
</tr>
<tr>
<td><strong>Active tailings storage facilities</strong> (sterilize the cycloned coarse tails in the embankment – the material most likely to form ARD before capping and revegetation)</td>
<td><strong>Abandoned underground mine stopes</strong> (use geophysics for targeting and inject pHoam™ through bore holes) – use mine fire/foam equipment?</td>
</tr>
<tr>
<td><strong>Active underground mine stope</strong> backfill materials</td>
<td><strong>Backfilled pits</strong> (coal or metal) that are poorly capped</td>
</tr>
</tbody>
</table>
Waste Rock Dump = Big Humidity Cell
Application Concept: Mine Dumps

Borehole spacing varies with acid-generating rock geometry and internal pile structure.

Typical designed pHoam & active ingredient injection borehole casing.

Acid generating mine rock identified by temperature, acid-base accounting test data, or geophysical data.

Injection borehole casings can be inclined or horizontal.

"Bulb" of "dry" pHoam and active ingredients injected into permeable acidic rock deposited in waste dump.

Neutral pH Drainage (no metals).

Bench.

Mine Waste Dump.

Native ground or bedrock.

Neutral pH seep.

Waste Rock Dump.
pHoam injection kinetics - theory

Theoretical pHoam front velocity, ft/min vs. circular bulb radius, ft

Assumed injection conditions: 29% voids, pHoam injected at 3.7 cy/min (100 cfm)
Figure 1. Gravity segregation and resulting interbedded structure in waste rock dumps.

After G.W. Wilson, 2008
Implementation Concepts

pHoam injection system layout is simple
Teaming Partners

- Golder Associates Inc.
  - Water Treatment and Geochemistry Groups
  - Colorado School of Mines Chemistry Dept.
  - Golder Construction Division
- Cellular Concrete Solutions LLC (CCS)
- Site owner/operator or interested entities like watershed groups
Development Steps

- Initial patent filing (16 August 2011)
- Initial demo – injecting into a gravel-filled pipe (done)
- Lab Testing (4Q 2011 to 2Q 2012)
  - Entity provides pyrite waste rock dump samples (done)
  - CCS treats samples with foam & amendments (done)
  - Golder/CCS conducts humidity cell tests in-house (ongoing)
  - CCS evaluates foam flow through porous medium (gravel) [planned]
- Demonstration Site (injecting into a real dump) 3Q 2012
- Monitor demo site Q4 2012 and beyond
What about CO$T$????

- Need to do comparison with perpetual ARD treatment (either active or passive technologies) or other remedies
- We have a cost model but it has **not** been validated/calibrated, **so we need demonstration sites**
- Example: to perpetually treat ARD from a 73 hectare waste rock dump in Western USA would cost about $US 30 million. If one assumes that only 25% of the total dump volume would accept or require pHoam™, the treatment cost is on the order of $US 15 million.
- Longevity of the treatment is a big issue. The non-pHoam™ treatment at the Fisher Coal Mine in 1995 with NaOH and bactericide is still effective after 16 years.
What about CO$T$????

- Our cost model is appears to be most sensitive to the cost of solid active ingredients and the surfactant.
- Even a minor credit for disposal of a local waste (e.g., biosolids) could result in a break-even condition.
- Without the credit, cost of treatment might be less than $1.00 per ton of rock to a fraction of that, depending on whether the rock is “vaccinated” or “medicated”.
Ideal pHoam™ Demonstration Site

- Has research funding available
- Contains mine waste that is fully characterized, mapped, and is acid-generating
- Is relatively small in scale (1 to 2 acres) (<1Ha)
- Is relatively accessible by conventional construction equipment
- Is amenable to “dissection” after pHoam application
- Has documented ARD impact
- Is on publicly-owned land (USFS, USBLM, USEPA Superfund)
- Is not a part of or contingent upon ongoing litigation
WHY IS pHOAM™ SO SPECIAL?

- Uses very little water
- Flexible design (wet/dry/stiff/flow-able)
- Flexible longevity (hours to days)
- Flexible active ingredients for suppressing ARD – whatever is inexpensive locally
- Easy to manufacture with traditional equipment
- Pumpable or flow-able
- Biodegradable surfactants can double as bactericides
- Permeates unsaturated zones of mine waste to deliver anti-ARD “cocktail” that could last for decades, maybe longer
Thank You

Nihil simul inventum est et perfectum

Latin Proverb

jgusek@golder.com
or
ddunham@cellularconcretesolutions.com
Nothing is invented and perfected at the same time

Latin Proverb
Early avoidance of ARD problems is a best practice technique that is integrated into mine planning, design and waste mgt strategies.
AR D Mitigation Framework

| EXPLORATION | characterization |
| ASSESSMENT | prediction |
| DESIGN | |
| CONSTRUCTION | surface water; control works; groundwater control |

**Planning for avoidance**

**Co-disposal, in-pit disposal... bactericides, alkaline materials, organics**

**Passivation**

---

REF: GARD Guide 2010

Also see:

Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania; Brady et al., 1998
**Best Practice Methods - Avoidance**

- Avoidance
  - Special handling methods
  - Incorporate into mine plan
  - Segregation
  - Tailings desulphurization
  - Compaction and conditioning
  - Encapsulation and layering
  - Blending
  - Co-disposal
  - Permafrost and Freezing

**What about abandoned mines?**

**REF: GARD Guide 2010**
Best Practice Methods (Decommissioning)

- **Dry Cover Methods**
  - Soil
  - Alkaline
  - Organics
  - Synthetics
  - Gas barriers
  - Vegetation
  - Landform design

- **Water Cover Methods**
  - Subaqueous disposal
  - Partial water cover
  - Wetland covers
  - Attenuation
  - Stream flow regulation
  - Water recycle and reuse

**REF:** GARD Guide 2010
Best Practice Methods - Passivation

- Additions and Amendment Methods
  - Passivation
  - Alkaline materials
  - Organics
  - Bactericides (Brady, Ch. 15)

- Water Management Methods
  - Hydrogeological & Hydrodynamic Controls
  - Dewatering
  - Diversion
  - Flooding
  - Seals

How do you implement these methods at abandoned mines?
Prevention and Mitigation of ARD

Approach
- Eliminate one or more legs of the tetrahedron
- Minimize oxygen supply
- Minimize water infiltration and leaching
- Minimize, remove, or isolate sulfide minerals
- Control bacteria and biogeochemical processes
Pyrite oxidation is exothermic

If a pHoam™ encounters a “hot zone” with elevated pyrite, the bubbles should collapse and preferentially deposit the “active ingredients”

This feature could potentially give pHoam™ a “heat-seeking missile” capability that could automatically deliver more ARD-suppressing active ingredients to a mine waste site in the zones where it is needed the most.
Figure 1. Gravity segregation and resulting interbedded structure in waste rock dumps.

After G.W. Wilson, 2008