Lessons Learned in ARD/AMD Source Control with Bactericicides in Eastern Coal Mine Settings

By Jim Gusek, P.E. Lakewood, Colorado
Acid Rock Drainage

IN PERPETUITY

Unless we can find practical source control remedies
2017 Design and Construction Issues at Hazardous Waste Sites

OUTLINE

- ARD Suppression Background
  - ARD Tetrahedron
  - History
  - How Bactericides Work

- Three Case Histories

- A Pathway to Walk-Away?
  - Employ New Technologies
  - Decimate, Out-Compete; Sustain [DOS]
Acid Rock Drainage Tetrahedron

Fuel
Air
Heat

Water

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

Pyrite

ARD

Bacteria
DO NOTHING = PERPETUAL TREATMENT
DO SOMETHING (anything) = PATHWAY TO WALK-AWAY
Acid Rock Drainage Tetrahedron

Water

Oxidizer
(Air, Fe^{3+})

Pyrite

Good Bacteria

“PROBIOTIC” PATHWAY TO WALK-AWAY
Bacteria are important (1950)
- Common surfactants are effective bactericides (1980s-1990s)
- Kleinmann & Erickson USBM RI 8847 (1983)
- Probiotic Bacteria Substitution w/Organics (1990 to 2008)
- Revegetation is a key requirement for sustainability

Zaburunov (1987)
Kleinmann & Erickson 1983

- *Thiobacillus ferrooxidans*
  - dramatically increases rate of pyrite oxidation
- developed a laboratory procedure to determine application rates
- Case studies: two sites
  - 60% to 95% decrease in acid production
  - 90% to 95% decrease in iron
- Temporary effect: re-apply three times per year
Known Bactericides

- Sodium lauryl sulfate (SLS)
- Sodium laureth sulfate (SLES)
- Slow release commercial products: ProMac™ (no longer available)
- Alkyl benzene sulfonate (laundry detergent is cheaper than SLS)
- Sodium Thiocyanate (NaSCN)
- Bi-Polar Lipids (patented)

Some of these concepts are 35 years old
Organic Amendments

- Composted sewage sludge (Pichtel & Dick, 1990)
- Composted paper mill sludge (ditto)
- Pyruvic acid (ditto)
- Water-soluble extract from composted sewage sludge (ditto)
- Spent brewery grain (Lindsay et al., 2010)
- Waste milk & dairy products (Jin et al., 2008)
How Bactericides Work (Anionic Surfactants)

Baker-Austin & Dopson (2007)
How Bactericides Work (Organic Acids)

Cell contents “leaking”

Outer membrane disruption

Tuttle, et al. 1977
Bactericide Case Histories

1. Route 43, Jefferson County, OH
2. North Fork Coal Mine, Wise County, VA
3. Fisher Coal Mine, Indiana County, PA
Definition of “Long Term” Success

A. Site exhibits ARD and it received an engineered dose of bactericide or other material intended to disrupt ARD microbial kinetics

B. No evidence of ARD observed in air photo imagery and/or

C. The site has been completely dropped from regulatory sampling programs (nothing to monitor)
# 1 - Route 43, Jefferson County, OH

- **Route 43 ProMac Seep**
- **ProMac Site Rt 43**
- **Control Area**
- **Treated Area**
- **2015**
- **2.4 ha**
# 1 - Route 43, Jefferson County, OH

Acidity

<table>
<thead>
<tr>
<th>Time, Months</th>
<th>Control Plot</th>
<th>Treated Plot</th>
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</table>

Acidity, ppm

Sobek, et al., 1990
# 1 - Route 43, Jefferson County, OH

Sulfate

Sulfate, ppm

Time, Months

Sobek, et al., 1990
# 1 - Route 43, Jefferson County, OH
Three Years After Bactericide Application

<table>
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<tr>
<th>Parameter</th>
<th>Control</th>
<th>Bactericide-Treated</th>
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<tbody>
<tr>
<td>pH (S.U.)</td>
<td>2.6</td>
<td>5.9</td>
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<tr>
<td>Acidity (mg/L)</td>
<td>844</td>
<td>19</td>
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<tr>
<td>Aluminum (mg/L)</td>
<td>38.7</td>
<td>0.5</td>
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<tr>
<td>Iron</td>
<td>104</td>
<td>&lt;0.2</td>
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<tr>
<td>Manganese</td>
<td>6.1</td>
<td>0.3</td>
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<tr>
<td>Sulfate</td>
<td>2,040</td>
<td>100</td>
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<tr>
<td>Specific Conductance</td>
<td>2,910 μs</td>
<td>590</td>
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<tr>
<td>Vegetation health</td>
<td>“destroyed by</td>
<td>“high quality</td>
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<td></td>
<td>seep”</td>
<td>vegetation”</td>
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<tr>
<td>TBFO populations in refuse</td>
<td>1.76 x 10^7</td>
<td>5.61 x 10^5</td>
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<tr>
<td>sample</td>
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<td>Heterotroph populations in</td>
<td>6.43 x 10^5</td>
<td>3.47 x 10^7</td>
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<td>refuse sample</td>
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<tr>
<td>Ratio of TBFO to Heterotroph</td>
<td>1014:1</td>
<td>0.22:1</td>
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<tr>
<td>population</td>
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Maierhofer, 1988

BAD Bugs decimated

GOOD Bugs happy

BAD:GOOD Bugs
#2 – North Fork Coal Mine, VA

- pH <3.4 s.u.
- acidity – 1,000 mg/L
- manganese - 125 mg/L
- iron – 20 mg/L,
- aluminum – 60 mg/L

25% of Site Received Bactericide
1997 Cost: $US104K – 2.8% of total project cost ($US3.7 million)
Not Being Monitored – No Records Available

Site won 1st Place Award in Virginia's “Take Pride in America” Program in 1989
# 3 Fisher Site Location & Conditions

Ref: Gusek & Plocus, 2016
#3 Fisher Coal Mine – 108 km NW of Pittsburgh, Pennsylvania USA

“Not the worst ARD ever, but out of compliance.”

Ref: MTVI, 1994

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Raw Seep Value</th>
<th>Pre-Injection “Bog” Effluent</th>
<th>Regulatory Limits (Monthly avg.)</th>
<th>Regulatory Limits (Instant. Max.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (mg/L)</td>
<td>8 to 42</td>
<td>17.7</td>
<td>3.0</td>
<td>7.0</td>
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<tr>
<td>Manganese (mg/L)</td>
<td>6 to 12</td>
<td>12.4</td>
<td>2.0</td>
<td>5.0</td>
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<tr>
<td>pH (s.u.)</td>
<td>5 to 6</td>
<td>5.5</td>
<td>6.0 to 9.0</td>
<td>n/a</td>
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<tr>
<td>Acidity (mg/L)</td>
<td>&gt;alkalinity</td>
<td>Est. ~54</td>
<td>&lt;alkalinity</td>
<td>n/a</td>
</tr>
</tbody>
</table>
1995 Injection Event

- Seep pH was 5.5; iron 17 mg/L and higher
- Passive treatment alone could not meet discharge limits
- Geophysics targeted three 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
- **Cost of reagents:** $US8,400
- Seepage continues to be net alkaline 21 years later; bond release is under review (State is OK with it).
Sulfate Trends

Ref: Gusek & Plocus, 2016
Why Does It Still Work – 21 Years Later?

Alkaline injection neutralized residual acidity in groundwater

High dose of bactericide (SLS) destroyed acidophiles

Well-established vegetation promoted development of diverse microbial community
What is Walk-Away?

The site requires:

1. Little or no maintenance
2. Infrequent inspection
3. Little or no long term monitoring
4. A final land use that benefits society

How Can We Get There?
Employ New Technologies

- Drip irrigation technology for ARD suppressant solution delivery
- Use temporarily stable foams to deliver bactericidal reagents (solid, liquid, or gaseous)
- Buffering of reagent solution could lower bactericide concentration & costs
- Advances in revegetation technology (biochar amendments) to accelerate site cover maturity
DECIMATE; OUT-COMPETE; SUSTAIN [DOS]

1. Primary application of SLS to decimate acid-loving bug populations

2. Application of waste milk or other organic (with inoculant) to make heterotrophic good bugs happy & out-compete acid-loving bugs

3. Establishing a vibrant and sustainable vegetative cover to keep good bugs happy for decades or longer
Acid Rock Drainage Tetrahedron

DO SOMETHING (anything) = PATHWAY TO WALK-AWAY
Thank You

Nihil simul inventum est et perfectum

- Latin Proverb

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Thank You

Nothing is invented and perfected at the same time.

-Latin Proverb

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