Passive Treatment of Metal-Bearing Runoff/Seepage 101: An Overview of the Technologies

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Terms

Acid Mine Drainage (aka Mining Influenced Water – [MIW])

Acid Rock Drainage
Acid Rock Drainage Tetrahedron

Water

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

Pyrite

Bacteria
Mine Water Treatment Options

- Active treatment
- Passive treatment
- Combination active/passive (hybrids)
What Is Passive Treatment?

Passive treatment ≠
If It’s Not a BLACK BOX, What Is Passive Treatment?

It’s the:

Sequential
Ecological
Extraction

Of metals in a man-made but naturalistic bio-system
Definition of Passive Treatment

Any water treatment process that:

- Utilizes common geochemical reactions typically assisted by microbes or plants,

- Does not require the addition of chemical reagents, power and/or short term exchange of process media, and

- Functions without human intervention for long periods.
P.T. Metal Removal Mechanisms

**Major**
- Sulfide and carbonate precipitation via sulfate reducing bacteria, et al.
- Filtering of suspended materials and precipitates
- Carbonate dissolution/replacement
- Metal uptake into live roots, stems and leaves

**Minor**
- Adsorption and exchange with plant, soil and other biological materials
**Passive Treatment Chemistry 101**

**Reducing/A Anaerobic Conditions**

\[ \text{SO}_4^{2-} + 2 \text{CH}_2\text{O} \rightarrow \text{HS}^- + 2\text{HCO}_3^- + \text{H}^+ \]

*(Sulfate reduction and neutralization by bacteria)*

\[ \text{Zn}^{+2} + \text{HS}^- \rightarrow \text{ZnS} \text{ (s)} + \text{H}^+ \]

*(Sulfide precipitation)*

**Oxidizing Conditions**

\[ \text{Fe}^{+3} + 3 \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 \text{ (s)} + 3 \text{H}^+ \]

*(Hydroxide precipitation)*

**All Conditions**

\[ \text{H}^+ + \text{CaCO}_3 \rightarrow \text{Ca}^{+2} + \text{HCO}_3^- \]

*(Limestone dissolution)*

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*Golder Associates*
Al<sup>3+</sup> + 3H<sub>2</sub>O => Al(OH)<sub>3</sub> (Gibbsite) + 3H<sup>+</sup>  
(problematic due to sludge buildup)

Conditions within BCRs are favorable for aluminum hydroxysulfate precipitation:

3Al<sup>3+</sup> + K<sup>+</sup> + 6H<sub>2</sub>O + 2SO<sub>4</sub><sup>2-</sup> => KAl<sub>3</sub>(OH)<sub>6</sub>(SO<sub>4</sub>)<sub>2</sub> (Alunite) + 6H<sup>+</sup>

6Ca<sup>2+</sup> + 2Al<sup>3+</sup> + 38H<sub>2</sub>O + 3SO<sub>4</sub><sup>2-</sup> => Ca<sub>6</sub>Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>(OH)<sub>12</sub>:26H<sub>2</sub>O (Ettringite) + 12H<sup>+</sup>

Typical Wetland Ecosystem

Sulfate Reducing Bacteria (SRB’s) live here (reducing conditions)

(oxidizing conditions)
Sulfate Reducing Bacteria (SRB’s) live here (reducing conditions)

Thiobacillus - F. O. live here (oxidizing conditions)
Natural Wetland Balances
All Possible Processes

Versus

Passive Treatment System
One Process is Emphasized in Each Cell
Iron precipitation at abandoned metal mine in Colorado near drinking water reservoir
Another Aerobic Process – for Mn Removal

Algae Strand
leptothrix discophora

Algae Holdfast of MnO₂

River Rock
Volunteer Manganese Mitigation

Manganese (70 mg/L) Oxidation Assisted by Algae in Arizona

12 Biotic mechanisms identified for Mn removal (Robbins, 1999)

“Manganocrete” (MnO2)
Biochemical Reactor (BCR) Schematic Cross Section

- INFLOW
- WATER SURFACE
- ORGANIC MATTER & LIMESTONE MIX (SUBSTRATE)
- DRAINAGE SYSTEM
- DISCHARGE
Sulfate Reducing Bacteria Sources

Cellulolytic Bacteria Source
Seyler, et al., 2003

<1% of Total Bugs!!!
Passive Treatment System Components

**Biological Components**
- Anaerobic Biochemical Reactors (BCRs)
- Aerobic Cells or Rock Filters
- Successive Alkalinity Producing Systems (SAPS)

**Limestone Components**
- Limestone Sand
- Anoxic Limestone Drains (ALD’s)
- Alkaline Ponds
- Open Limestone Channels

**Settling Ponds & Flow Equalization Ponds**
Passive Treatment Decision Tree 1994

FOCUSED ON COAL MIW (Fe, Mn, Al, Acidity)

Analyze Raw Water Chemistry
Determine Flow Rate

Net Alkaline Water

Net Acidic Water

DO, Fe, Al
Acceptable

DO, Fe, Al
Unacceptable

Anoxic Limestone Drain

pH > 4

pH < 4

Settling Pond

Aerobic Wetland
Size based on:
20 gmd Fe
0.5 gmd Mn

Influent Acidity < 300

Influent Acidity > 300

Settling Pond

Compost Wetland
Size based on:
5 gmd Acid
0.5 gmd Mn
Ref: Gusek, 2008
The Periodic Table of Elements with MIW Issues

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# Periodic Table of Passive Treatment

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## LEGEND

- **Red**: Passive untreated
- **Blue**: Anaerobic
- **Green**: Beneficial
- **Uncertain**: Untreatable?
- **Orange**: Oxidizing

**Actinide Series**

- U (92)

**Anaerobic and oxidizing**
Passive Treatment Chemistry 101

Reducing/A Anaerobic Conditions

\[
SO_4^{-2} + 2 \text{CH}_2\text{O} \rightarrow HS^- + 2\text{HCO}_3^- + \text{H}^+ \\
\text{(Sulfate reduction and neutralization by bacteria)}
\]

\[
\text{Zn}^{+2} + HS^- \rightarrow \text{ZnS} \text{ (s)} + \text{H}^+ \\
\text{(Sulfide precipitation)}
\]

Oxidizing Conditions

\[
\text{Fe}^{+3} + 3 \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 \text{ (s)} + 3 \text{H}^+ \\
\text{(Hydroxide precipitation)}
\]

All Conditions

\[
\text{H}^+ + \text{CaCO}_3 \rightarrow \text{Ca}^{+2} + \text{HCO}_3^- \\
\text{(Limestone dissolution)}
\]
Anaerobic Biochemical Reactors (BCRs)

AKA
Vertical Flow Reactors or
Sulfate Reducing Bioreactors (SRBRs)

Aluminum and heavy metal removal, selenium removal, de-nitrification, pH adjustment, alkalinity & hardness addition
Aerobic Cells

AKA Rock Filters

Fe, As, Biochemical Oxygen Demand (BOD), and Mn removal
Aerobic Cell Special Case:
Iron Terraces – Cure or Curse?

Drain Pipe, Elizabeth Mine, VT
Successive Alkalinity Producing Systems (SAPS)

Alkalinity addition to oxygenated Fe$^{+3}$ - bearing acidic MIW
(no aluminum allowed)
The limestone will be distributed downstream by periodic flooding.

The sand must be replenished approximately 1 or 2 times per year, depending on flooding frequency.

Limestone sand addition is most effective for streams that have low pH, but also relatively low dissolved metal concentrations.

Iron and/or aluminum hydroxides precipitate in the stream, but probably over a shorter stretch than without treatment.
Anoxic Limestone Drain (ALD)

Alkalinity addition to oxygen-free Fe$^{+2}$-bearing, mildly net-acidic MIW
(no aluminum allowed)
Open Limestone Channels

Open Limestone channels are made of cobble-sized limestone.

They are best used in steep terrain with oxygenated MIW.

The limestone gets coated by iron or aluminum hydroxides, but some limestone dissolution still occurs.
Limestone up-flow ponds are constructed on the upwelling of an MIW seep or underground water discharge point. Limestone is placed in the bottom of the pond and the water flows upward through the limestone, adding alkalinity.

Steel slag has also been used to add alkalinity (Faulkner and Skousen 1995).
Settling/Surge Ponds

Collection of suspended solids & clarifying, flow equalization
Cell Design Parameters

- MIW Geochemistry (cell sequencing & cell type)
- Metal Loading = (concentration X flow rate)
- Surface Area is a function of loading
- Cell Depth can be a function of loading

NO COOKBOOK (YET)
Passive Treatment Staged Design Phases

- Lab (proof of principle) tests
- Bench tests
- Pilot tests
- Limited full scale (modules)
- Full scale implementation
Lab - Proof of Principle Tests

Buckeye Landfill, OH
POP Test Bottles

Brewer Gold Mine, SC
POP Test Bottles
Bench Scale Tests

Weekly sampling schedule is typical
Pilot Scale Cells

BCR - Wyoming

BCR - Missouri

Aerobic - Missouri

Aerobic - Brazil
Total cost with engineering: ~$350K

Influent MIW
- pH: 3.0
- Fe: 104 mg/L
- Al: 24.5 mg/L
- Mn: 1.3 mg/L
- Zn: 54.9 mg/L
- Cu: 9.0 mg/L
- Ni: 0.031 mg/L
- Cd: 0.71 mg/L
- SO4: 797 mg/L

Effluent
- pH: 7.2
- Fe: 0.8 mg/L
- Al: 0.06 mg/L
- Mn: 2.5 mg/L
- Zn: 0.1 mg/L
- Cu: <0.003 mg/L
- Ni: 0.007 mg/L
- Cd: 0.006 mg/L
- SO4: 488 mg/L
Golinsky Site Access Challenges
“The Worst Surface Mine AMD/MIW in PA”
Local Residents
Fran Mine BCR Cell (Buried)
(Allegheny Mtn. Chapter Trout Unlimited)

Influent
pH - 2.4
Al – 249 mg/L
Fe – 274 mg/L
Acidity – 2.4 g/L

Effluent
pH - 6.54
Al – 0.6 mg/L
Fe – 73 mg/L
Alkalinity – 0.9g/L

Total construction cost: $42,400; engineering cost $20,000
West Fork Lead Mine, Missouri
Constructed in 1996 for Asarco
Full Scale Passive Treatment of Dissolved Lead at 1,200 gpm

1998 Engineering Excellence Award Winner in Waste Water Treatment - Colorado Section of American Consulting Engineers Council (ACEC); National ACEC Honor Award

West Fork Lead Mine, Missouri
Full Scale Passive Treatment System Example

Full Scale Passive Treatment of Dissolved Lead at 1,200 gpm

Settling Pond

5 acres, 1,200 gpm

Two BCR/SRBR Cells

Aerobic Rock Filter Cell

Polishing Pond

West Fork of Black River

Constructed in 1996 for $700,000
Key Treatment Issues

- Land surface available?
- System longevity/maintenance
- Disposal of residuals (hazardous waste?)
- Performance criteria/odors
- Cost (design, capital, operating, NPV)
- Why don’t they always work as designed?
P.T. Advancements 1985 to 2009

- Established design protocol
  - Lab, bench, pilot studies
  - Physical and geochemical design parameters
  - Better understanding of microbiology

- Wide range of operating conditions
  - pH 2.5 to 8.5
  - Metals (Fe, Cu, Pb, Zn, Cd, Cr, Mn, Hg, Mo, Al, Se, As, U, Co, Tl)
  - Non-metals (CN, SO$_4$, NO$_3$, NH$_3$, BOD$_5$, P)
  - Temperatures (0 to 30 deg C)
  - Flows up to 1,200 gpm
Advantages of Passive Treatment

- Low NPV cost (50% of active treatment)
- No moving parts
- Simple to operate
- Resilient to quantity variations
- Wildlife habitat?
- Long term (but not walk-away) solution
- Mimics Mother Nature
- Blends into landscape
- Politically correct
- Non-hazardous residuals (depends on MIW)
- Regulatory acceptance
- Resource recovery in future
Summary

- Any mine water can be treated... for a price; passive is **HALF** the cost of active treatment for identical chemistry.

- Passive treatment systems can handle a wide variety of flows, water, chemistry and site conditions (low to high: pH, metal concentration, flow and temperature).

- P.T. system longevity is on the order of decades.

- Design process is established; passive treatment is a proven methodology for treating MIW.
In Water Treatment, If You’re Not Part of the Solution, You’re Part of the Precipitate.

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