Passive Treatment in Mine Remediation

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What Is Passive Treatment?

Passive treatment ≠
What Is Passive Treatment?

If it’s not a Black Box, what is it?

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.
Typical Wetland Ecosystem

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

(oxidizing conditions)
Oxidation and Reduction Processes in Competition
Natural Wetland
Balances All Possible Processes

Versus

Constructed Wetland
One Process is Emphasized in Each Cell
Passive Treatment Metal Removal Mechanisms

- **Major**
  - Hydroxide and oxide precipitation
  - Sulphide and carbonate precipitation via Sulphate Reducing Bacteria (SRB)
  - Carbonate dissolution/neutralization
  - Filtering/settling of metal precipitates
  - Metal uptake into plant tissues
  - Adsorption onto organic & oxide materials

- **Minor**
Anaerobic BCR’s

Also known as Vertical Flow Bioreactors and Sulphate Reducing Bioreactors

Aluminum and heavy metal removal, pH adjustment, alkalinity & hardness additions
Biochemical Reactor: Schematic Cross Section

- **INFLOW**
- **WATER SURFACE**
- **ORGANIC MATTER & LIMESTONE MIX (SUBSTRATE)**
- **DRAINAGE SYSTEM**
- **DISCHARGE**
BCR Cell Construction
SO$_4^{2-}$ + 2 CH$_2$O $\Rightarrow$ HS$^-$ + 2HCO$_3^-$ + H$^+$

*(Sulphate reduction and neutralization by bacteria)*

Zn$^{+2}$ + HS$^-$ $\Rightarrow$ ZnS (s) + H$^+$

*(Sulphide precipitation)*

Fe$^{+3}$ + 3 H$_2$O $\Rightarrow$ Fe(OH)$_3$ (s) + 3 H$^+$

*(Hydroxide precipitation on the surface)*

H$^+$ + CaCO$_3$ $\Rightarrow$ Ca$^{+2}$ + HCO$_3^-$

*(Limestone dissolution)*
**Al**$^{3+}$ + 3H$_2$O => Al(OH)$_3$ (Gibbsite) + 3H$^+$
(problematic due to sludge buildup)

Conditions within BCRs are favorable for aluminum hydroxysulphate precipitation:

\[ 3\text{Al}^{3+} + \text{K}^+ + 6\text{H}_2\text{O} + 2\text{SO}_4^{2-} \Rightarrow \text{KAI}_3(\text{OH})_6(\text{SO}_4)_2 + 6\text{H}^+ \]
*Alunite*

\[ 6\text{Ca}^{2+} + 2\text{Al}^{3+} + 38\text{H}_2\text{O} + 3\text{SO}_4^{2-} \Rightarrow \text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12}:26\text{H}_2\text{O} + 12\text{H}^+ \]
*Ettringite*
Seyler, et al., 2003

<1% of Total Bugs!!!
“Typical” Sulphate Reducing Bacteria Sources

Cellulolytic Bacteria Source
System Design Parameters

- NO COOKBOOK (YET)
  - MIW Geochemistry controls cell sequencing & cell type
  - Dimensions governed by Metal & Acidity Loading
    i.e. concentration X flow rate
Passive Treatment: Staged Design Phases

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

Buckeye Landfill, OH
POP Test Bottles

Brewer Gold Mine, SC
POP Test Bottles
Passive Treatment: Bench Scale Tests

Weekly sampling schedule is typical
Bench BCR Biopsy
Pilot Scale Cells

- BCR - Wyoming
- BCR - Missouri
- Aerobic - Missouri
- Aerobic - Brazil
Selected Case Studies
Applications of Biochemical Reactors and Aerobic Systems in the Passive Treatment of Mining Influenced Water
Large Scale, Demonstration, and Pilot Scale Systems

- West Fork, Missouri, USA (Large)
- Judy 14, Pennsylvania USA (Demo)
- Fran Mine, Pennsylvania USA (Pilot)
- Golinsky Mine, California USA (Pilot)
West Fork, Missouri

Full Scale Passive Treatment of Dissolved Lead at 4.5 m³/min

Settling Pond

BCR Cells

Anaerobic Cells

Aerobic Rock Filter Cell

Polishing Pond

West Fork of Black River

Constructed in 1996 for $700,000

5 acres, 1,200 gpm
West Fork System Layout

1,500 gpm (Max)
1,200 gpm (nominal)

Underground Mine
Pump
Mine Shaft
Settling Pond
North Anaerobic Cell
South Anaerobic Cell
Aeration Pond
Outfall
West Fork of Black River
Rock Filter
West Fork System
Key Components / Dimensions

- Settling Pond 3,000m²
- 2 Anaerobic (BCR) Cells 2,000m² each,
  2m deep, 40mm HDPE liner - substrate:
    - 67% sawdust, 19% limestone (low Mn),
    - 12% manure, 2% hay
- Aerobic Rock Filter – 6,000m²
- HDPE-lined Aeration Pond – 8,000m²
- Total cost (1996) with engineering: $US 700,000
### West Fork System Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent Water</th>
<th>SRBR Effluent Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td>pH – 7.8 s.u.</td>
<td>pH - 7.8 s.u. (no change)</td>
</tr>
<tr>
<td><strong>Pb</strong></td>
<td>Pb – <strong>0.6 mg/L</strong> as aqueous lead</td>
<td>Pb - <strong>0.027 to 0.05 mg/L</strong> (meets NPDES standard)</td>
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<tr>
<td></td>
<td>carbonate complex</td>
<td></td>
</tr>
<tr>
<td><strong>Zn</strong></td>
<td>Zn – 0.08 mg/L</td>
<td>Zn – &lt;0.05 mg/L</td>
</tr>
<tr>
<td><strong>Sulphate</strong></td>
<td>Sulphate ~180 mg/L</td>
<td>Sulphate – &lt;140 mg/L</td>
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</tbody>
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**4.5m³/min, 24 hours/day, 7 days/week; Constructed in 1996**
Demo Scale BCR
Judy 14 Pennsylvania Coal Mine

Constructed with Pennsylvania Growing Greener Funds by the Blacklick Creek Watershed Association
Judy 14 Project Background

- Seepage from Abandoned *Judy 14* underground coal mine (mined in 1950’s)
- SAPS units were not working
- *Elevated aluminum caused plugging problems*
- Experience from a pilot system @ 9.5 L/min on a similar water was good
Judy 14 Bioreactor
Key Components / Dimensions

- Valved diversion pipe
- One SRBR Cell 0.75m deep, 1,300 m² bottom area, 300mm compacted clay liner, substrate:
  - 50% wood chips, 30% limestone;
  - 10% manure, 10% hay
- Aerobic Rock Filter – designed, but built undersized
- Total cost with engineering: $US158,000
Influent Water
pH – 3.0
Fe – 45 mg/L
Al – 33 mg/L
Mn – 2.6 mg/L
Zn – 0.86 mg/L
Cu – 0.10 mg/L
Ni – 0.32 mg/L

BCR Effluent Water
pH – 6.6
Fe – 0.5 mg/L
Al – 0.07 mg/L
Mn – 2.3 mg/L
Zn – 0.06 mg/L
Cu – BDL @.0009
Ni – 0.002 mg/L

Flow: 38 Liters/min
Constructed in late 2002
The “worst acid drainage in Pennsylvania” – work sponsored by Allegheny Mtn Chapter of Trout Unlimited
Fran Mine Project Background

- Abandoned surface coal mine seepage
- Mined in 1970’s, pit was backfilled
- Injection of fly ash grout helped control MIW but it was not enough
- Total flow of 160L/m @ full scale impacts 8 km of trout fishery
- Bench scale BCR tests successful – no plugging problems from aluminum precipitates
- Pilot system design and construction funded by private donations & government grants
Fran Mine Bioreactor
Key Components / Dimensions

- Valved diversion pipe (problematic)
- One BCR Cell 1m deep (buried), 404m$^2$ bottom area; 40mm PVC liner, substrate:
  - 50% wood chips, 30% limestone;
  - 10% manure, 10% hay
- Aerobic Rock Filter – designed, but not built; mini version added later.
- Total construction cost: $US42,400; engineering cost $US20,000
### Fran Mine Pilot BCR Results

#### Influent Water
- pH – 2.4
- Fe – 298 mg/L
- Al – 257 mg/L
- Mn – 25 mg/L
- Cu – 0.56 mg/L
- Zn – 2.0 mg/L
- **Acidity** – 2,734 mg/L
- **Sulphate** – 3,215 mg/L

#### Effluent Water
- pH – 6.4
- Fe – 64 mg/L \((Fe^{+2} = 46)\)
- Al – <0.02 mg/L
- Mn – 26.4 mg/L
- Cu – BDL @0.0009 mg/L
- Zn – 0.127 mg/L
- **Alkalinity** – 1,038 mg/L
- **Sulphate** – 752 mg/L

**Flow:** 3.8 to 7.6 L/m  
**Construction:** Constructed in late 2002  
**Design:** Design Complete; full scale on hold as of 2008
Golinsky Mine, California

Remote Location
Project Phases

- Bench Test (*Jan ‘04 to May ‘04*)
- Pilot Scale Test (*July ‘04 to Sept ‘06*)
  
  decommissioning data suggested about 20 yrs of longevity remained
- Full Scale Pipeline (*Fall, ‘04*)
- Full Scale Design SRBR - module #1 (2008)
- Module 1 Construction - 2009
Golinsky Mine Pilot BCR
Key Components / Dimensions

- Valved diversion (off 150mm pipeline)
- One BCR Cell 0.75m deep, 95m$^2$ bottom area, 18mm HDPE Permalon™ liner, substrate:
  - 40% co-gen fuel, 29% limestone, 1% ash,
  - 10% rice hulls, 10% manure, 10% hay
- Aerobic Rock Filter – not designed, but natural channel functioning as one.
- Total cost with engineering: ~$US 350,000
Golinsky Mine, CA (USFS)

Pilot BCR

45,420 cubic meters treated over 27 months

Influent

- 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

Total cost with engineering: ~$350,000
Why Don’t Passive Systems Always Work As Designed?

- No design “Just build a swamp here, fill that pond over there with manure and call it good.”
- Poor design **Undersized for load**, applying wrong geochemical approach, phased design lacking, complex geochemistry, startup and operational procedures.
- Not enough maintenance (low maintenance does not mean “NO” maintenance).
- Last minute changes to construction specs can affect system performance - experience helps.
### Advantages of Passive BCR Treatment

- No aluminum plugging
- Uses waste organic materials
- Easy to test conceptual designs
- Simple to operate
- Resilient to loading variations
- Consumes sulphate or selenate
- Bury to minimize vandalism

- Can easily handle net acidic water or net alkaline water
- Generates more net alkalinity in effluent
- Might be able to place in underground mines
- Opportunities for community involvement in organic procurement
In Water Treatment, If You’re Not Part of the Solution, You’re Part of the Precipitate.

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