Treatment of Acidic Coal Mine Drainage with Vertical Flow Ponds and Drainable Limestone Beds

Robert Hedin
Hedin Environmental
Pittsburgh, Pennsylvania
Common Passive Treatment Technologies Used in the Eastern US Coal Fields

- **Ponds**
  - oxidize Fe, settle solids, mixing

- **Constructed Wetlands**
  - polishing, Mn and solids removal

- **Anoxic limestone beds**
  - alkalinity generation

- **Oxic limestone beds**
  - alkalinity generation, metal removal, polishing

- **Vertical flow ponds**
  - alkalinity generation and metal removal
Technology is based on chemistry,
Sizing is based on loadings
Characterize Mine Water

Net alkaline

- DO, Fe$^{3+}$, Al all < 1 mg/L (high Fe$^{2+}$)
  - Anoxic Limestone Bed
    - Net Alkaline

Ponds

- Wetland

Net acid

- DO, Fe$^{3+}$, Al any > 1 mg/L
  - High Fe$^{2+}$

- Vertical Flow Pond
  - Repeat As Needed

- Oxic Limestone Bed (drainable)

- Ponds

Ponds

- Oxic Limestone Bed
  - Mn

- Wetland
  - Mn

Final Discharge
Passive Treatment of Net Acid Coal Mine Drainage

• Neutralize acidity and generate alkalinity
  1. Calcite dissolution
  2. Bacterial processes in organic substrate

• Remove metal contaminants
  1. Al, Fe, Mn, others
  2. Primary removal as oxide and hydroxide solids
  3. Secondary removal as sulfides and carbonates
Characterize Mine Water

- Net alkaline
  - DO, Fe$^{3+}$, Al all < 1 mg/L
  - Anoxic Limestone Bed
    - Net Alkaline
      - Ponds
        - Wetland
          - Mn
            - Oxic Limestone Bed
              - Mn
                - Wetland
                  - Final Discharge

- Net acid
  - DO, Fe$^{3+}$, Al any > 1 mg/L
    - High Fe$^{2+}$
      - Vertical Flow Pond
        - Ponds
          - Oxic Limestone Bed (drainable)
            - Repeat As Needed
              - Ponds
                - Final Discharge
\[ \text{Fe}^{2+} + \text{Mn}^{2+} + \text{H}^+ \rightarrow \text{Fe}^{2+} + \text{Mn}^{2+} + \text{Ca}^{2+} + \text{HCO}_3^- \]
Characterize Mine Water

Net alkaline

- Anoxic Limestone Drain
  - DO, Fe$^{3+}$, Al all < 1 mg/L (high Fe$^{2+}$)
    - Net Alkaline
    - Net acid
      - Ponds

Net acid

- DO, Fe$^{3+}$, Al any > 1 mg/L
  - High Fe$^{2+}$
    - Red Box: Vertical Flow Pond
      - Ponds
        - Oxic Limestone Bed (drainable)
          - Repeat As Needed
          - Final Discharge

- Ponds
  - Wetland
    - Mn
  - Oxic Limestone Bed
    - Mn
      - Wetland
        - Ponds
          - Final Discharge
Vertical Flow Pond (VFP, SAPS, RAPS, APS)

- Water Level Control Structure
- Influent Pipe
- Standing Water (0.6m)
- Alkaline Organic Substrate (0.3m)
- Limestone Layer (1m)
- Discharge to Pond or Wetland
- Underdrain Plumbing
Delta Maust Passive System (Somerset County, PA)

- Bond forfeiture project
- Design: pond, VFP#1, wetland, VFP#2, wetland
- VFP#1 construction
  - 24 inch depth of spent mushroom compost mixed 2:1 with limestone fines
  - 18 inches AASHTO#3 limestone aggregate
  - PVC pipe underdrain
  - 25,000 ft$^2$ (2,325 m$^2$)
- Installed in 1997
### Delta Maust Passive Treatment System, 1997 - 2012

<table>
<thead>
<tr>
<th></th>
<th>Flow</th>
<th>pH</th>
<th>Alk</th>
<th>Acid</th>
<th>Fe</th>
<th>Al</th>
<th>Mn</th>
<th>SO₄</th>
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<tbody>
<tr>
<td>Influent</td>
<td>20</td>
<td>3.2</td>
<td>0</td>
<td>141</td>
<td>30.2</td>
<td>2.3</td>
<td>13.9</td>
<td>553</td>
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<tr>
<td>VFP#1 out</td>
<td>7.1</td>
<td>152</td>
<td>-130</td>
<td>1.1</td>
<td>0.3</td>
<td>10.3</td>
<td>474</td>
<td></td>
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**Diagram:**
- **Pond 1 influent**
- **VFP#1 eff**

**Graph:**
- Acidity, mg/L
- Flow: Dec-95 to Dec-13

**Data Points:**
- Influent: Flow 20, pH 3.2, Alk 0, Acid 141, Fe 30.2, Al 2.3, Mn 13.9, SO₄ 553
- VFP#1 out: Flow 7.1, pH 152, Alk -130, Acid 1.1, Fe 0.3, Mn 10.3, SO₄ 474
Anna S Mine Passive Treatment Complex (Tioga County, PA)

• Abandoned Mine Land project
• Two independent systems
2 ft standing water
1 ft compost amended with limestone
3 ft limestone aggregate
PVC pipe underdrain
## Anna S passive systems, 2004 - 2016

<table>
<thead>
<tr>
<th>Point (n)</th>
<th>Flow</th>
<th>pH</th>
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<th>Fe</th>
<th>Al</th>
<th>Mn</th>
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<tbody>
<tr>
<td></td>
<td>gpm</td>
<td>s.u.</td>
<td>mg/L CaCO₃</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
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<td><strong>Hunters Drift System</strong></td>
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<tr>
<td>HD in (47)</td>
<td>225</td>
<td>2.8</td>
<td>0</td>
<td>347</td>
<td>35.4</td>
<td>32.7</td>
<td>6.4</td>
<td>551</td>
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<td>VFPs out (25)</td>
<td>6.9</td>
<td>185</td>
<td>-129</td>
<td>19.8</td>
<td>0.6</td>
<td>6.6</td>
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<tr>
<td>HD final (61)</td>
<td>na</td>
<td>7.5</td>
<td>142</td>
<td>-112</td>
<td>0.4</td>
<td>0.3</td>
<td>2.0</td>
<td>493</td>
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<td><strong>Anna System</strong></td>
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<td>S1 in (34)</td>
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<td>138</td>
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<td>S2 in (29)</td>
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<td>Final (45)</td>
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<td>-99</td>
<td>0.8</td>
<td>0.3</td>
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Characterize Mine Water

Net alkaline

DO, Fe$^{3+}$, Al all < 1 mg/L (high Fe$^{2+}$)

Anoxic Limestone Drain

Net Alkaline

Ponds

Wetland

Mn

Oxic Limestone Bed

Mn

Oxic Limestone Bed (drainable)

Repeat As Needed

Final Discharge
Treatment of AMD Containing Al and Fe$^{3+}$ with Oxic Limestone Beds

Research project funded by Pennsylvania Department of Environmental Protection
Two types of solids: attached scale and suspended in interstitial water

Scale on aggregate

Suspended solids in pore water
Key Findings of Flushing Study

• Two types of solids: attached scale and suspended in interstitial water

• Draining bed empty once/week removes suspended solids and maintains permeability
Agri Drain Smart Drainage System
(solar powered computer controlled gate valve)
71% of the Al retained in the DLB during routine operations released during draining
Key Findings of Flushing Study

• Two types of solids: attached scale and suspended in interstitial water
• Draining bed empty once/week removes suspended solids and maintains permeability
• Al and Fe scale can be easily cleaned; treatment restored
Key Findings of Flushing Study

- Two types of solids: attached scale and suspended in interstitial water
- Draining bed empty once/week removes suspended solids and maintains permeability
- Al and Fe scale can be easily cleaned; treatment restored
- Prolonged retention time improves alkalinity generation
- Mn removal feasible
- Sustainable treatment is possible
Mitchell West Box, 2008 – 2016
(regular draining; no cleaning)

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<tr>
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<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
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<tr>
<td>Influent (36)</td>
<td>na</td>
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<td>0</td>
<td>209</td>
<td>7.2</td>
<td>22.1</td>
<td>12.5</td>
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<td>Effluent (39)</td>
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<td>-55</td>
<td>0.5</td>
<td>3.7</td>
<td>3.1</td>
<td>510</td>
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Tangascootac #1 Passive system (Clinton County, PA)

- Abandoned Mine Land project
- Side-by-side treatment with VFP and DLB
- Flow control and distribution
- Vertical Flow Pond
  - 735 tons LS aggregate and 223 CY organic substrate
- Drainable Limestone Bed
  - 1,000 tons LS aggregate
  - AgriDrain SDS
### Scootac system, Dec 2010 – Apr 2014

<table>
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<th>Alk</th>
<th>Acid</th>
<th>Al</th>
<th>Mn</th>
<th>Fe</th>
<th>SO₄</th>
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<td><strong>Raw</strong></td>
<td>86</td>
<td>4.0</td>
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<td>89</td>
<td>11.1</td>
<td>25.9</td>
<td>0.2</td>
<td>927</td>
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<tr>
<td><strong>Vertical Flow Pond</strong></td>
<td>40</td>
<td>7.0</td>
<td>157</td>
<td>-127</td>
<td>0.1</td>
<td>20.3</td>
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<td>927</td>
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<tr>
<td><strong>Drainable LS Bed</strong></td>
<td>45</td>
<td>7.3</td>
<td>192</td>
<td>-169</td>
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<td>1.7</td>
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<td><strong>Polishing Pond</strong></td>
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<td>8.8</td>
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<td>917</td>
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## VFP vs DLB

<table>
<thead>
<tr>
<th></th>
<th>Vertical Flow Pond</th>
<th>Drainable Limestone Bed</th>
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</thead>
<tbody>
<tr>
<td><strong>Footprint</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Cost, capital</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Cost, O&amp;M</strong></td>
<td>Lower</td>
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<tr>
<td><strong>Major maintenance interval</strong></td>
<td>7-15 years</td>
<td>3-7 years</td>
</tr>
<tr>
<td><strong>DOC/BOD production</strong></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Al removal</strong></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Fe Removal</strong></td>
<td>Partial</td>
<td>Yes (oxic)</td>
</tr>
<tr>
<td><strong>Mn removal</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Metals other than Fe, Al, Mn</strong></td>
<td>Oxides and sulfides</td>
<td>Oxides and sorption</td>
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Questions?