A REVIEW OF PASSIVE TREATMENT TECHNOLOGY

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Background of presentation

This presentation grew from talks given by Jeff Skousen in Canada in 2015 and earlier papers by Skousen and Zipper.

It has been updated and extended by the current list of authors.


The paper includes sizing and design parameters, success/failure information and about 200 references.

The perspective is mainly eastern US where about 500 passive systems have been constructed.

In today’s version I’ll summarize the publication but emphasize certain topics and features, including a method not covered in the review.
Types of Passive Systems

Treatment is accomplished by **biological and organic** effects, largely on redox state of Fe, S and Mn, and **chemically** by limestone to neutralize acidity.

Largely **biological** treatment:
- Aerobic wetlands (AeW)
- Anaerobic wetlands (AnW)
- Vertical flow wetlands (VFP, VFW)
- Sulfate-reducing bioreactors (SRB)
- Fibrous metal removal units
  - (Continued)
Types of Passive Systems (cont.)

Mainly Chemical:

- Anoxic limestone drains (ALD)
- Flushed limestone beds (FLB)
- Limestone Leach beds (LLB)
- Low-pH Fe removal systems
- Open limestone channels (OLC)
- Limestone sand
- Manganese removal beds (MRB)
- Steel slag beds
- Diversion wells
AMD Chemistry

Mine Drainage can be acid (AMD) or alkaline; both are treatable passively. If limestone is present in overburden or spoil, drainage may be alkaline but Fe-rich.

To select a treatment method, data on chemistry (pH, acidity, Fe, Al, Mn, redox state) and flow are needed.

Systems are usually sized to treat the 75th to 90th percentile of the flow and load.
Feed with External Water (Low Al, Fe, & Mn) to Add Alkalinity

Determine Flow
Analyze Water Chemistry
Calculate Loads

Evaluate Acidic Water Options

If Low Al & Fe, High DO

If Net Alkaline

If Net Acidic

If Low DO, Fe²⁺ & Al (ideal: all < 1 mg/L)

Anoxic Limestone Drain

Limestone Pond or Slag Leach Bed

Evaluate Acidic Water Options

If Low Al & Fe, High DO

Settling Pond

Aerobic Wetland

Anaerobic Wetland

Vertical Flow Wetland

Bioreactor

Chitin

Flushed Limestone Pond

Open Limestone Channel

Aeration, Settling Pond, &/or Aerobic Wetland

Does Water Quality Meet Treatment Goals?

If No

Re-evaluate Design; Retrofit to Improve Performance

If Yes

Discharge Water
Acidity is the amount of alkaline material to neutralize the water, usually to pH 8.3. In mine drainage, Fe, Al, Mn and other cations can furnish acidity.

\[
\text{Fe}^{2+} + 0.25 \text{O}_2 + 2.5\text{H}_2\text{O} = \text{Fe(OH)}_3 + 2\text{H}^+ 
\]

Acidity by Standard Methods or the EPA method is a NET Acidity, in contrast to some state regulations that specify Acidity minus Alkalinity (WRONG!).

Calculated Acidity:

\[
\text{Acidity (mg/L CaCO}_3\text{)=50(2C}_{\text{Fe}}/56 + 2C_{\text{Mn}}/55 + 3C_{\text{Al}}/27 + 10^{3-\text{pH}}}-\text{Alkalinity}
\]

- Concentrations (C) should be dissolved amounts for this equation.
Vertical Flow Wetlands/Ponds

SCHEMATIC DIAGRAM OF VERTICAL FLOW SYSTEM
Processes in a VFW

**Water layer**
Possible Fe oxidation and precipitation, settling on compost (bad)

**Compost layer**
Consumption of dissolved O2
Reduction of Fe$^{3+}$ to Fe$^{2+}$, $SO_4^{2-}$ to $S^{2-}$, some FeS formation
Generation of some alkalinity

**Limestone layer**
Neutralization of acidity, increased pH
Possible precipitation of Al

**Oxidation-Settling pond**
Oxidation of Fe, precipitation as Fe(OH)₃
Settling of Fe and Al precipitates.
Al problems

- Al(OH)₃ will precipitate in the limestone layer at pH>5;
- Coating and plugging limestone.
- Problem does not seem to be serious up to about 10-20 mg/L?

**Solutions:**
- Periodic Flushing (covered later)
- Add 10-25% fine limestone to compost – Al hangs up in the compost; limestone bed operates OK. Systems with limestone-amended compost seem to be more effective in treatment.
Flushing Systems

- For discharges with moderate to high AI, regular automatic flushing of limestone beds can allow good treatment for many years.
- Flushers consist of a large valve opened weekly or so by a small computer energized by a solar panel.
- On opening the valve, water flows out rapidly, carrying out the interstitial precipitate and some of limestone coatings.
- Automatic weekly flushing is much better than monthly manual flushing.
- Used with limestone beds and some VFW’s
Flushable Limestone Pond
Agridrain Flusher

- Solar Panel
- 12-Volt Linear Actuator
- Valve
- Water Level Sensor
- Control Box
- Rain Collector
FIBROUS METAL REMOVAL UNITS
Fibrous Metal Removal Units

- A patented method using coconut fiber (coir) to grow and trap Fe, Al and Mn
- The units are boxes up to 8 ft long with upflow thru the fiber mass – very small area.
- The metal compounds grow selectively on the fibers.
- The metal concentration, pH and redox determine the metal removed; metals removed down to tenths of mg/L.
- The boxes are flushed/cleaned periodically to regenerate them.
- Developed and sold by Ecoislands of Altoona, PA.
- www.ecoislandsllc.com
Reliability of Passive Treatment

- Many passive systems, especially VFW’s, have not completely treated their discharge.
- In a study by PA DEP in 2009-10, about 150 passive systems were sampled twice.
- About 40% of the systems released net acid water, and were termed “failures”
- In 2013 I selected 18 “failures” for further evaluation, plus 6 “successes” with large flow and substantial metals.

Object – What were the reasons for “failure”? 

## Summary of Problems

<table>
<thead>
<tr>
<th>System</th>
<th>Design</th>
<th>Constr.</th>
<th>Maint.</th>
<th>Sampling</th>
<th>Perform. (%*)</th>
<th>Stream</th>
<th>Type</th>
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<tbody>
<tr>
<td><strong>AMD &amp; Art</strong></td>
<td>Poor</td>
<td></td>
<td>Lacking</td>
<td></td>
<td>Unclear (?)</td>
<td></td>
<td>AW,VFP</td>
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<td>Avery</td>
<td>Problems Inadeq.</td>
<td></td>
<td>Misleading</td>
<td>Good (99)</td>
<td>Recover.</td>
<td>VFP,HFLB</td>
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<tr>
<td>DeSale 1</td>
<td>Good</td>
<td></td>
<td>Misleading</td>
<td>Good (91)</td>
<td>Recover.</td>
<td>LS,VFP</td>
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<tr>
<td>Finleyville</td>
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<td>Misleading</td>
<td></td>
<td></td>
<td>VFP, LS</td>
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<tr>
<td>Harb-Walk. 2</td>
<td>Fair</td>
<td></td>
<td>Lacking?</td>
<td>Poor (??)</td>
<td>VFP, LS</td>
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<tr>
<td>Kalp</td>
<td>Good</td>
<td>Misleading</td>
<td></td>
<td>Good (100?)</td>
<td>LS,VFP</td>
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<td></td>
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<tr>
<td>Klondike 1</td>
<td>Problems Good</td>
<td></td>
<td>Fair (73)</td>
<td></td>
<td>VFP</td>
<td></td>
<td></td>
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<td>Metro</td>
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<td>Lacking</td>
<td></td>
<td>Poor (18)</td>
<td>VFP</td>
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<td>Lacking</td>
<td></td>
<td>Poor (37)</td>
<td>VFP</td>
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<tr>
<td>Yellow Cr.</td>
<td>Poor</td>
<td>Inadeq.</td>
<td>Misleading</td>
<td>Fair (100)</td>
<td>Bio</td>
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<td>Long Run LR0D2</td>
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<td>Good</td>
<td></td>
<td>Unclar (92?)</td>
<td>LS</td>
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<tr>
<td>Six Mile SX0D6</td>
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<td>Fair (92)</td>
<td>Recover.</td>
<td>VFP</td>
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<tr>
<td>MR Frog</td>
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<td>Unclear</td>
<td>Unclar</td>
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<td>Recov.</td>
<td>LS. AW?</td>
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<tr>
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<td>Fair (100?)</td>
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<td>Cessna Run</td>
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<td>Robbins</td>
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<td>LS</td>
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<td>Bear Rock Run</td>
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<td>Misleading</td>
<td>Good (100)</td>
<td>Recover</td>
<td>LS</td>
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<tr>
<td>McKinley</td>
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<td>Misleading</td>
<td>Good (89)</td>
<td>VFP</td>
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</table>

*% acidity removal 2008-13

**BIO, bioreactor; VFP, vertical flow pond; AW, anoxic wetland; LS, limestone bed;**

**HFLB, horizontal flow limestone bed**
Performance of “failed” systems
% of influent acidity removed (2005-13)

- **Low Risk Systems**
  - McKinley
  - Bear Rock
  - Robbins
  - Guion Run

- **Medium Risk systems**
  - Clinton Rd
  - MR Fog
  - SX0D6
  - U002

- **High Risk systems**
  - Yellow Cr.
  - Webster
  - Metro
  - Klondike 1
  - Kalp
  - Finleyville
  - DeSales I
  - Avery
### Successful Systems – High Risk

<table>
<thead>
<tr>
<th>System</th>
<th>Built</th>
<th>Flow</th>
<th>pH in</th>
<th>Acidity in</th>
<th>Fe in</th>
<th>Al in</th>
<th>Acidity out</th>
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<tr>
<td>Anna S</td>
<td>2004</td>
<td>219</td>
<td>3.2</td>
<td>125</td>
<td>6.2</td>
<td>11</td>
<td>-103</td>
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<tr>
<td>Hunters Dr</td>
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<td>245</td>
<td>2.8</td>
<td>343</td>
<td>35</td>
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<td>-113</td>
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<td>555</td>
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<td>Maust</td>
<td>1998</td>
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<td>3.2</td>
<td>143</td>
<td>33</td>
<td>2</td>
<td>-39</td>
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<tr>
<td>Longs R D10</td>
<td>2005</td>
<td>20</td>
<td>3.2</td>
<td>442</td>
<td>145</td>
<td>10</td>
<td>-61</td>
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</table>
Cost Passive vs. Active

Cost of acidity removal, $/ton

- Metro Webster
- HW2
- Typical large Active System, $1200/T
- Median Passive systems, $702/T
- HW1
- Robbins
- Bear Rock

Median, Passive systems, $702/T
Design and sizing

Aerobic wetland 10 g Fe m\(^{-2}\) d\(^{-1}\)
1 g Mn m\(^{-2}\) d\(^{-1}\)

Anaerobic wetland 3 g acidity m\(^{-2}\) d\(^{-1}\)
10 g Fe m\(^{-2}\) d\(^{-1}\)

Vert Flow Wetland 35 g acidity m\(^{-2}\) d\(^{-1}\)
Maintenance

Passive systems, especially large ones, need monitoring, maintenance and renovation.

Replacement of compost at Klondike-1 (high Fe) after 9 years

VFW’s – compost replacement, limestone cleaning after 6-10 yrs.
Conclusions


2. Passive treatment is an effective method to restore AMD to acceptable water, but does require correct design and construction, and some maintenance.