Feasibility of Utilizing Acid Mine Drainage Sludge in an Innovative Iron-based Wastewater Treatment Process

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Municipal Wastewater Treatment

- Aeration: > 50% electricity utilization
- Activated sludge related treatment units: 12 – 17%
- Nutrients discharge to surface waters
- CO₂ emission

Microbial metabolism

<table>
<thead>
<tr>
<th></th>
<th>Aerobic</th>
<th>Denitrifiers</th>
<th>Sulfur Reducing Bacteria</th>
<th>Methanogenic Microbes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. degradation rate [l]</td>
<td>8.8 – 13.2</td>
<td>4</td>
<td>??</td>
<td>0.5</td>
</tr>
<tr>
<td>Y (kg VSS/kg COD)</td>
<td>0.42 – 0.49</td>
<td>0.25</td>
<td>??</td>
<td>0.057</td>
</tr>
</tbody>
</table>

Organic C as e donor, Rittmann and McCarty (2001)
Innovative Fe(III)-dosed Wastewater Treatment Technology

Main biogeochemical reactions

- **Chemoheterotrophs**
  - Iron reducing bacteria (IRB)
    \[ \text{Fe}^{3+} + \text{organics} \rightarrow \text{Fe}^{2+} + \text{HCO}_3^- + \text{CO}_2 + \text{H}^+ \]
  - Sulfate reducing bacteria (SRB)
    \[ \text{SO}_4^{2-} + \text{organics} \rightarrow \text{HS}^- + \text{CO}_2 \]

- **Possible chemoautotroph**
  - Feammox (Yang et al., 2012)
    \[ 3\text{Fe(OH)}_3 + 5\text{H}^+ + \text{NH}_4^+ \rightarrow 3\text{Fe}^{2+} + 9\text{H}_2\text{O} + 0.5\text{N}_2 \]

- **Chemical precipitation**
  \[ \text{Fe}^{3+} + \text{HS}^- \rightarrow \text{FeS(s)} + \text{H}^+ \]

*Deng and Liu, 2017; Ahmed and Lin, 2017; Deng et al., 2018*
Fe(III)-dosed wastewater treatment

Distribution of major chemical elements in the AMD sludge based on a field survey on 118 AMD sludge cells in Maryland, Pennsylvania, Ohio, and West Virginia. Concentrations are based on the dry weight basis.

Acid Mine Drainage Sludge

Distribution of major chemical elements in the AMD sludge based on a field survey on 118 AMD sludge cells in Maryland, Pennsylvania, Ohio, and West Virginia. Concentrations are based on the dry weight basis.
Environmental diagenetic and AMD treatment factors

- Temperature
- pH
- Aging
- Alkaline treatment
- Fine sludge properties: 
  - Soluble phase
  - Crystallinity
  - Reactivity

Fe sludge characteristics

- pH treatment performance

Effects of pH Neutralizer on Sludge Composition

- Hydrated lime (Ca(OH)₂) neutralization
- Ferric hydroxide and gypsum
- Magnesium oxide (MgO) neutralization
- Ferric sulfate and undissolved magnesium oxide
- Lime (CaO) neutralization
- Iron and higher calcium content
- Limestone (CaCO₃) neutralization
- Iron and lower calcium content
- Ammonia neutralization
- Iron and aluminum

Microbial cell reduction and A pollutants removal
**pH Dependent Ferric Mineral Formation**

- pH < 2.0: Jarosite
- 2.5 < pH < 3.5: Schwertmannite
- pH > 5.0: Nearly amorphous compounds
- pH > 5.0: Ferrihydrite

**Mineral Phases of AMD Sludge**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Major mineral phases</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-step passive remediation</td>
<td>Schwertmannite, Fe₈O₈(OH)₆(SO₄)·ₙH₂O, Hydrozincite, Zn₅(CO₃)₂(OH)₆</td>
<td>Macias et al. 2012</td>
</tr>
<tr>
<td>Passive pond-based abiotic treatment</td>
<td>Goethite, Fe(OH)₃</td>
<td>Kirby et al. 1999</td>
</tr>
<tr>
<td>Passive lime bed treatment</td>
<td>Lepidocrocite, γ-FeO(OH)</td>
<td>Aube et al. 1999</td>
</tr>
<tr>
<td>Passive vertical flow reactor</td>
<td>Schwertmannite, Fe₈O₈(OH)₆(SO₄)·ₙH₂O, Goethite, Fe(OH)₃</td>
<td>Florence et al. 2016</td>
</tr>
<tr>
<td>NaOH and NH₄OH neutralization</td>
<td>Magnetite, Fe₃O₄, Hematite, Fe₂O₃, Hausmannite, Mn₃O₅</td>
<td>Kefeni et al. 2015</td>
</tr>
<tr>
<td>Limestone bed treatment</td>
<td>Goethite, Fe(OH)₃, Calcite, CaCO₃</td>
<td>Cui et al. 2012</td>
</tr>
</tbody>
</table>
**Crystallinity & Microbial Fe-reduction Rate**

- **Increasing pH** leads to higher crystallinity and slower microbial Fe-reduction rate.
- **Increasing temperature** also increases crystallinity and reduces microbial Fe-reduction rate.

**FePO₄·4H₂O > Fe(OH)₂ > γ-Fe(OH)₂ > α-Fe(OH)₂ > Fe₂O₃**

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**pH Effects**

- **Less microbial reduction rate**:
  - Crystalline ferric mineral
  - Amorphous ferric mineral

- **Increasing pH**:
  - Baltpurvins et al., 1996
  - Weber et al., 2006

- **Increasing pH**:
  - Less microbial reduction rate
  - Insoluble ferric mineral
  - Soluble ferric mineral
Fe/Al Products from AMD - Treatment steps

- AMD
- Selective extraction of Fe and Al
- Floc separation
- Products
  - Coated sorbents
  - FeCl₃, Al₂(SO₄)₃
- Final treatment for discharge

Conclusions & Current Status of Technology

- AMD can be a source of ferric iron for the innovative Fe-dosed wastewater treatment technology
- Tremendous opportunities exist for using Fe-containing wastes for beneficial uses that improve food-energy-water nexus efficiencies
- Environmental, diagenetic, and AMD treatment are important factors for Fe sludge characteristics
- Technical feasibility of the treatment concept proven
- Pilot testing to start this summer
Acknowledgement

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Fe sludge properties:
- Size
- Phase
- Composition
- Crystallinity
- Solubility
- Reactivity

Microbial Fe(III) reduction rate & pollutants removal

Aging

Temperature

pH

Alkaline treatment