Biochar: Is It The Fix All We Have Been Waiting For?

Zachary M. Easton

Biological Systems Engineering, Virginia Tech
Outline

• Goals and Background

• Biochar application: Denitrifying Bioreactors

• Real world application
  - N₂O emissions and microbial abundance

• Cleaning up: Mitigating sulfate reduction
Habitat from denitrifying microorganisms:

1. Organic carbon source
2. Anaerobic conditions
3. NO$_3^-$ as electron acceptor

- Average 50% nitrate removal and up to 90% possible
- Accommodate fluctuating flow rates and influent concentrations
- Sustained removal up to 15 years
Goals

- How can we optimize denitrifying bioreactor performance to maximize their benefits and minimize the downside?
- Prevent harmful intermediaries
- Minimize greenhouse GHG emissions
- Maximize denitrification

Research objectives:
- Reduce GHG emission (N₂O)
- Mitigate additional pollutants
- Minimize additional pollutants

Biological Systems Engineering
Biochar has been proven successful in reducing the mobility of N and P in agricultural soils. Results in stable material with high AEC and CEC were observed in response to biochar.

Reduced \( N_2O \) emission from soil has also been noted, indicating an increase in the abundance and activity of denitrifying microorganisms.
• Determine if biochar addition can enhance N and P removal while simultaneously reducing N\textsubscript{2}O production without substantially altering biofilter hydraulic properties
• Different biochar feedstocks and ratios tested
• N\textsubscript{2}O extracted from column head space and analyzed by GCMS
• NO\textsubscript{3} -, NH\textsubscript{4} +, PO\textsubscript{4} \textsuperscript{3-} measured in aqueous samples
• Denitrifying enzyme activity (N\textsubscript{2}O → N\textsubscript{2} → NO → NO\textsubscript{2}) mediated by four reductase enzymes: narG, nirK, nirS, nosZ

Study 1
Results
Nitrous Oxide
Results - Microbial Data

Buffeted Biochar
Acidified Biochar

Buffered Woodchips
Unbuffered Woodchips

Davies et al. 2016
JEQ in review
More than an order of magnitude less nosZ expression in the woodchip only (low pH) treatment.

Indeed nosZ reductase was significantly inhibited in other enzymes in the denitrification process.

\[ \text{N}_2\text{O reductase (nosZ) is more sensitive to low pH than} \]

\[ \text{N}_2\text{O emissions} \]

\[ \text{pH levels below 5.5 have been shown to increase} \]

\[ \text{Biochar buffers the pH above 6.5} \]

*Combined physiological/biological effect*

**Enzyme Activity**

Why the big \( \text{N}_2\text{O} \) difference?
Paired biofilters woodchip and woodchip+biochar

Series of events of varying concentrations (5-20 mg N L⁻¹), residence times (2-80 hr), and temps $NO_3^-, NH_4^+$ measured in aqueous samples

Study 2. Field Application
Previous experiments revealed that the rapid rate of NO₃⁻ removal creates conditions that favor sulfate reduction (e.g., biocatalysts lower redox potential) but does SO₄²⁻ reduction instead. NO₃⁻ reducers and drive the redox down to that of sulfate reduction, while SO₄²⁻ reducers will outcompete Fe(III) can buffer this redox potential change because Fe(III) reduction Fe(III) bacterial Fe(III) reduction takes place at a higher redox potential than does SO₄²⁻ reduction.

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Downsides

- Previous experiments revealed that the rapid rate of NO₃⁻ removal creates conditions that favor sulfate reduction (e.g., biocatalysts lower redox potential) but does SO₄²⁻ reduction instead. NO₃⁻ reducers and drive the redox down to that of sulfate reduction, while SO₄²⁻ reducers will outcompete Fe(III) can buffer this redox potential change because Fe(III) bacterial Fe(III) reduction takes place at a higher redox potential than does SO₄²⁻ reduction.
<table>
<thead>
<tr>
<th>Treatment</th>
<th>WC</th>
<th>Sand</th>
<th>Biochar</th>
<th>Biochar + Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>T50 (hr)</td>
<td>16.10</td>
<td>5.45</td>
<td>3.05</td>
<td>4.25</td>
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Table:

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<thead>
<tr>
<th>Treatment</th>
<th>NO\textsubscript{2} (ng)</th>
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<tbody>
<tr>
<td>WC</td>
<td>638 a</td>
</tr>
<tr>
<td>Sand</td>
<td>218 b</td>
</tr>
<tr>
<td>Biochar</td>
<td>61 c</td>
</tr>
<tr>
<td>Fe</td>
<td>43 c</td>
</tr>
</tbody>
</table>

Legend:
- WC
- Sand
- Biochar
- Fe

Graph:
- Concentration vs. Time
- Loss with Confidence Intervals
- Time (hrs)
- Nitrous Oxide (ppm)

Source: Easton et al. 2015. Ecol Eng
Current Work
Conclusions

- Opportunities exist to enhance N removal and treat other contaminants
- Future work will explore application to other contaminants, pharmaceuticals, pesticides, pathogens
- Opportunities exist to enhance N removal and treat other contaminants
- Biochar enhances N removal rates and reduced N$_2$O emissions
- Buffers pH
- Increased microbial abundance
- Unfortunately it also causes sulfate reduction
- Substrate engineering can mitigate consequences
- Future work will explore application to other contaminants, pharmaceuticals, pesticides, pathogens